THE INFLUENCE OF CONCEPTS OF INFORMATION THEORY ON THE BIRTH OF ELECTRONIC MUSIC COMPOSITION: Lejaren A. Hiller and Karlheinz Stockhausen, 1953 - 1960

by

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ABSTRACT

Despite significant contributions concerning the application of information theory in music analysis, its utilization in the field of electronic music composition has not been investigated in greater detail. Seen as supporting a remarkable compositional shift from model to rule based design in the 1950s, this theory is presented as a major formative force regarding the development of computer and electronic music.

The early days of information theory from Hartley's discoveries in the 1920s to Shannon/Weaver's famous paper in 1948 are traced. The validity of its application in the field of music composition in the 1950s is then explored. This leads to a double study encompassing the examination of the early electronic works of Lejaren A. Hiller and Karlheinz Stockhausen in the 1950s.

A thorough investigation of ILLIAC SUITE will reveal how basic concepts of information theory affected a conceptual shift in compositional design as formalized in Hiller's automated computer program routines. However, while these early computer music experiments possess considerable limitations regarding the creation of larger formal sections, compositional improvements in this regard are further discussed regarding Hiller's COMPUTER CANTATA. Focusing on the generative properties of Markoff chain processes which simultaneously govern the formation of music and phonetic speech, information theory emerges as an even stronger factor determining the overall shape and structure of the entire work.

Concepts of information theory in this piece represent a valid means to govern the creation of both syntactic and semantic structures. A common link between these and

Stockhausen's experiments in the realm of phonetic speech and electronic music can be established in a study of GESANG DER JÜNGLINGE.

Tracing the influence of information theory in Stockhausen's early electronic works provides an entirely new perspective in terms of musicological research. Based on newly discovered sources from 1989, evidence will be provided that Stockhausen's pioneering electronic works would probably have been incomprehensible without taking into account the considerable influence of Werner Meyer-Eppler, Stockhausen's teacher in acoustics, phonetics, and information theory.

It will be demonstrated how Meyer-Eppler's introduction of the term 'aleatory' in speech analysis and synthesis with Stockhausen's ensuing use of the aleatory principle from as early as his STUDIE II in 1953/54 challenges common assumptions that the decay of serialism in Europe commenced as late as 1956. This has remarkable consequences in the understanding of the underlying principles governing Stockhausen's GESANG DER JÜNGLINGE. Here, the integration of aleatory technique into the principle of serial composition will be distinguished as the seed for the creation of the concept of statistical form, which in itself is a major step in the development of 20th century music.

Finally, Stockhausen's interpretation of statistical form as an aleatory process in its relationship to the use of information theory concepts in this work will be evaluated. The deterioration of serialism in Europe was thus quietly but profoundly affected by Stockhausen himself. The results provide far-reaching consequences. Not only did concepts of information theory initiate a compositional shift from model-based to process-oriented design in the works of both Hiller and Stockhausen, they also had a considerable historical impact. Simultaneously they gave birth to computer music in America and initiated the decay of serialism in Europe in the

1950s. This implies a new perception of the 1950s as a pivotal period in terms of music history, suggesting that certain commonly held notions regarding the development of electronic music composition will have to be reassessed.

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INTRODUCTION - THE INFLUENCE OF INFORMATION THEORY ON ELECTRONIC MUSIC COMPOSITION IN THE 1950'S: APPLICATIONS OF LEJAREN A. HILLER AND KARLHEINZ STOCKHAUSEN

1. Introduction

During the 20th century, the development of a new scientific discipline called Cybernetics[2] evolved in the wake of studies in communication and control. Scientific research conducted by Norbert Wiener and Claude Shannon finally led to the development of a theory of communication, which allowed the mathematical analysis of all segments involved in the technical communication chain of large telephone networks. The basic set of equations which relates to the quantity of information within the concept of communication theory is called information theory. Some authors proposed that these equations could be applied to any form of human communication. Accordingly, information theory has been applied in the field of music, the most elaborate of these applications being the domain of electronic music composition.

2. Purpose and Objectives

The purpose of this dissertation is to examine the formative role of information theory in the birth of computer music and electronic music composition. While Hiller's pioneering work has been acknowledged in the past,

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[2]Cybernetics: Study of system control and communications in living organisms and electrically operated devices such as calculating machines. From the greek "Steersman". The Pocket Oxford Dictionary of Current English, Oxford, 1969, p. 205.

a study of the source of the conceptual shift towards regarding music as a system of communication that could hence be formalized through computer programming, has not been conducted to date.

Furthermore, to my knowledge, the influence of concepts of information theory in Stockhausen's early electronic works which determined the course of electronic music composition in Europe in the 1950s has been completely neglected until now by musicological research. This is surprising at first glance, as common sources have mentioned Stockhausen's thorough studies in acoustics, phonetics, and information theory with Werner Meyer-Eppler from 1954 to 1956. However, some important research material supporting my thesis became available as late as 1989, when Meyer-Eppler's entire estate was catalogued for the first time by Elena Ungeheuer. Taking these new sources into account, one of the objectives of this dissertation is to validate an understanding of Stockhausen's development of new compositional processes from the angle of concepts of information theory which he learned from Meyer-Eppler.

I propose that the new compositional designs introduced by Hiller and Stockhausen were both based on a similar theoretical principle, making a great case for comparative musicological analysis. The main objective of this dissertation will be to provide facts and arguments in support of this proposition, demonstrating that the concepts of information theory were the source of a crucial paradigm shift in compositional method, simultaneously giving birth to computer music in America and initiating the decay of serialism in Europe in the 1950s.

3. Synopsis of Content

In order to establish the influence of information theory, it will be necessary to study its underlying mathematical foundations, the history of its development, and its original applications within communication theory. In Chapter I, as a basis for evaluating the implications of this theory in music, the relevant basic concepts of information, redundancy and entropy, as well as concepts related to stochastic processes, Markov chains, and transitional probabilities will be discussed. Realizing how this field of application represents only a fraction of the entire concept of information theory, we will limit the scope of this discussion of mathematical concepts to those which were actually used by both Hiller and Stockhausen.

Having gained some basic understanding of the principles underlying the historical and mathematical foundations of information theory, we will proceed to evaluate its relationship with music in greater detail in Chapter II. Taking the crisis of musical form in the 20th century as our general point of departure, we will study the reasons for the emergence of information theory as an attractive catalyst combining probabilistic concepts and the creation of musical form. Referring to the proposition that music could be understood as a system of communication, we will describe an information theory model of music as a stochastic source of information. Keeping in perspective various applications of this theory in music, encompassing the analytic, analytic/synthetic, and synthetic compositional approaches, a point of reference to existing research can be established from where our objective, the study of electronic music composition, can be conducted with confidence. As the crucial paradigm shift from model-based to rule-based compositional design can be attributed mainly to procedural advancements in the field of automated electronic music composition, Hiller's approach will be taken as a starting point to discuss the influence of information theory in this regard: musical structure is created via the process of the compositional principle itself.

Chapter III provides an excellent example of how information theory was applied in the design of automated computer routines. As the birth of computer music involved great attention to detail, Hiller's and Isaacson's pioneering concept of computer music composition will be closely followed, with an in-depth account of both the ILLIAC SUITE and its accompanying chronicle, Hiller's EXPERIMENTAL MUSIC.

A critical analysis of the limitations of Hiller's use of Markov chain processes in compositional design will form the bridge to Chapter IV, wherein certain aspects which could not be discussed in connection with the ILLIAC SUITE will be examined in the light of the compositional procedures which led to Hiller's COMPUTER CANTATA. With the latter serving as an example of how Hiller gained a more definite control on the automated compositional processes involved in the genesis of musical form by means of new computer software, information theory will be regarded as the driving compositional force behind the COMPUTER CANTATA, particularly regarding its application in the form of Markoff chain processes, simultaneously underlying the genesis of the written score, that of electronic sound textures, and the assembly of speech. Confirming that concepts of information theory are a valid means of governing the creation of both syntactic and semantic textures, we will highlight the common link established between these elements with regard to Stockhausen's treatment of phonetic speech in GESANG DER JÜNGLINGE.

In Chapter V we will focus on the formative influence of information theory on Stockhausen's GESANG DER JÜNGLINGE, a pivotal achievement in the history of electronic music composition. Contrasting the influence of Meyer-Eppler on Stockhausen with the latter's own compositional approach, we will present GESANG DER JÜNGLINGE as a work reflecting all aspects of the problematic issues related to the integration of indeterminate procedures into serialist technique. As this work, Stockhausen's most elaborate composition in this respect, profoundly affected the development of composition theory in the mid-1950s, I would like to demonstrate that it could simply not have been conceived without reference to concepts of information theory.

In fact, one of the purposes of Chapter V is to challenge the common belief that chance procedures were introduced to the Darmstadt School as late as 1956, with John Cage's famous lecture, and that this signalled the beginning of the decay of serialism. Wondering whether a more organized, conceptual framework had been developed for some concepts of a probabilistic nature beyond the game of dice, I found that this particular need had actually been met, as early as 1953-54, through the concept of aleatory technique, which gained increasing momentum in Stockhausen's early electronic works. A brief discussion of STUDIE II will be inserted at this point, attempting to properly date Stockhausen's first experimentation with indeterminate form genesis, and casting a new light on how the phenomenon of indeterminacy cropped up first within the domain of electro-acoustic music composition.

Finally, a synopsis of the main principles of serial composition technique will serve as a background for an evaluation of the impact of information theory on GESANG DER JÜNGLINGE. Here, the principle of aleatory technique, with its fundamental effect on the overall structural design of this work, will be distinguished as the seed for the creation of the concept of statistical form, a major step in the development of 20th century musical form. Stockhausen's interpretation of statistical form will be evaluated in its relationship to concepts of information theory, shedding new light on how the deterioration of serialism in Europe was quietly but profoundly affected by one of its most prominent proponents, Stockhausen himself.

The final purpose of this dissertation is to establish conclusively that the concepts of information theory not only initiated a paradigm shift from model-based to process-oriented compositional design in the works of both Hiller and Stockhausen, but they also had a considerable historical impact on the development of electronic music composition in Europe and the United States.

CHAPTER I - INFORMATION THEORY

> No human investigation can be called truly scientific if it does not pass through mathematical methods of expression.
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> -Leonardo da Vinci
> *On Painting, I, 1*

1. Prelude

Any true understanding of a scientific issue must include some knowledge of its historical growth. Consequently, and in order to demonstrate the true impact information theory had on other disciplines besides the sciences, the keynotes concerning its evolution will be provided at the beginning of this chapter.

a) A Definition of Information Theory

Information theory is a mathematical theory of the transfer of information, signals, and information content, which includes concepts of entropy[3] and redundancy.[4] One

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[3]Introduced a century ago by Clausius, the concept of entropy, central to IT, has at least a more or less formal equivalence in thermodynamics (Brillouin, 1956). In brief, it refers to the degree of randomness of a system, and the tendency of physical systems to become less and less organized, as expressed in the second law of thermodynamics. The following source discusses the concept of entropy in greater detail: M. J. Harrison: "Entropy Concepts in Physics", in Entropy and Information in Science and Philosophy, Libor Kubat and Jiri Zeman eds., Academia, Prague, 1975, p. 41.

result of information theory was to make sign transmission more efficient within the communication media. Its foundation was laid by Hartley (1928), whose premises were taken up later by Wiener (1948), Shannon/Weaver (1949) and others. Its classical presentation was originally technical and dealt mainly with certain assumptions to be made about signs being transmitted through a "noisy" communication channel. Soon, its original restrictions as a scientific theory were extended because its fundamental concepts were found to possess a great intuitive attractiveness for other disciplines. Several applications of information theory were initially performed in the fields of perception psychology (Garner[5] and Hake[6]), psychology (Bar-Hillel and Carnap,[7] 1952), music and semantics (Meyer-Eppler,[8] 1959; A. Moles,[9]

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[4]The concept of redundancy addresses issues of reduction of the information content of messages through certain technical or psychological measures improving the predictability of messages to be received.

[5]W. R. Garner: "The Amount of Information in Absolute Judgments", Psychological Revue, 58, 1951, pp. 446-59.

[6]H. W. Hake: "A note on the Concept of 'Channel Capacity' in Psychology", in H. Quastler: Information Theory in Psychology, The Free Press of Glencoe, New York, 1956.

[7]Bar-Hillel and Carnap: "Semantic Information", in Willis Jackson ed., Communication Theory, Academic Press, New York, 1952.

[8]Werner Meyer-Eppler: Grundlagen und Anwendungen der Informationstheorie, Springer, Berlin, 1959.

[9]Abraham Moles: Théorie de l'information et perception esthétique, Paris, Flammarion, 1959, trans. Joel E. Cohen as Information Theory and Aesthetic Perception, Urbana, University of Illinois Press, 1965.

1954; Quastler[10] and Strizenec,[11] 1956), and art (Pierce,[12] 1961). In some cases, the application of information theory seemed justified by properly applying an appropriate calculus to a certain field of investigation. In other cases, the application of this theory seemed over-extended: the reader's imagination was simply drawn towards vague universalities referring to Shannon's famous equation for the statistical content of information. Where the study of music and the arts is concerned, it is especially important to cast a discerning look at the validity of any given application of information theory.

b) Developing Concepts of Communication: Language

> Man is essentially a communicating animal; communicating is one of his essential activities. Whereas the lower living creatures cope with the environment on a moment-by-moment basis, the higher animals possess the faculties of learning...and their actions are influenced by their past experiences. Man has developed such faculties to the most pronounced degree in coming to terms with a hostile world; he possesses the unique powers of speech and writing. Human experience is not a moment by moment affair, but has continuity; man has contact with his ancestors

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[10]Quastler, H.: Information Theory in Psychology, The Free Press of Glencoe, New York, 1956.

[11]Strizenec, M.: "Information and Mental Processes", in Entropy and Information in Science and Philosophy, Libor Kubat and Jiri Zeman eds., Academia, Prague, 1975, pp. 149.

[12]J. R. Pierce: Symbols, Signals and Noise, Harper & Row, New York, 1961, 250-267.

and descendants, and a sense of history and continuity."[13]

Language conditions our perception of the world as much as it is commonly related to our social activities. Therefore, every form of communication essentially involves language, a collection of symbols which may take the form of spoken phonemes, letters (encoded phonemes), Morse code signals, or a chain of binary digital signals in a computer system.[14] One of the most important steps in human development was the invention of phonetic writing: speech and writing were linked by symbols, representing specific sounds, finally developing into a system involving a limited set of alphabetically distinct letters. Also related to communication is the theory of cryptograms and ciphers. Many historical examples exist: one that is especially important for us is a cipher called "Francis Bacon's Biliteral

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[13]Colin Cherry: On Human Communication, M.I.T. Press, Cambridge, Mass., 1957, 2nd Ed. 1966, p. 32.

[14]Colin Cherry writes: "Egyptian inscriptions and papyri have presented the greatest difficulties of decipherment to scholars, partly because they so commonly used mixtures of phonetic signs and pictograms, together with many signs and embellishments. The *Rosetta Stone*, for example, contained hieroglyphic, demotic, and Greek transcriptions, with many *redundant* signs . . . The gradual evolution of true phonetic writing, during the Coptic period, and the establishment of regular syntax built redundancy into language in a really useful way. "Redundancy" means additional signs or rules which guard against misinterpretation - an essential property of language . . . " Colin Cherry: On Human Communication, p. 33.

Code."[15] According to Bacon, any written information can be conveyed by means of a two-state code.

One modern adaption of this theorem was the Morse code,[16] employing only dots and dashes. This type of coding, called binary[17] coding, became increasingly important for the further development of electrical means of communication: coded telegraphy, punched-card filing systems and, finally, computers. The attractiveness of the binary code to modern communication is mostly due to the ease of constructing technical devices supporting efficient binary coding. It was of vital importance for the development of information theory that the effectiveness of information transmission was found to be dependent on certain statistical aspects of the language incorporated into its coding design. In order to increase the efficiency of signal transmission, Morse designed his alphabet according to its

[15]Ibid, p. 35: " . . . Bacon (1561-1626) suggested the possibility of printing seemingly innocent lines of verse or prose, using only slightly different fonts (called *A* and *B*). The order of the *A*'s and *B*'s was used for ciphering a secret message: each letter of the alphabet was coded into five units, fonts *A* and fonts *B* being used as such units."

[16]Morse completed his famous code book in 1837, representing an efficient means of coding the transmission of signals. "While working with Alfred Vail, the old coding was given up, and what we now know as the Morse code had been devised by 1838." Quoted from J. R. Pierce: Symbols, Signals, and Noise: The Nature and Process of Communication, Harper, New York, 1961, p. 24.

[17]Because it was represented by a repertoire of only two, or "binary" elements.

statistical frequency in the English language: fewer total symbols[18] are used to code a message of a certain length.[19]

However, a quantitative means of measuring the amount of information contained in a message was still missing. An important step towards a clear formulation of these findings was taken by Zipf[20] as a result of his experimentation with statistical aspects of speech and writing. Today, statistical analysis represents a major component of linguistic studies. An exact measure of information on a statistical basis could only be generated after communication was recognized as a statistical concept. This was finally developed by Wiener,[21] Kolmogoroff,[22] and finally by Shannon and Weaver in A Mathematical Theory of

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[18]In fact, Morse's attempt was highly successful. Pierce writes: "Modern theory tells us that we could only gain about 15 per cent in speed....The lesson provided by Morse's code is that it **matters** profoundly **how** one translates a message into electrical signals. This matter is at the very heart of communication theory". In: J.R. Pierce, Symbols, Signals and Noise: The Nature and Process of Communication, p. 25.

[19]See Table 1 in the appendix.

[20]G. K. Zipf: Human Behaviour and the Principle of Least Effort, Addison-Wesley, Cambridge, Mass., 1949.

[21]N. Wiener: Cybernetics, The Technology Press of M.I.T. and Wiley & Sons, New York, 1948, 2nd Ed. Cambridge, Mass., 1961.

[22]A. Kolmogoroff: "Interpolation und Extrapolation von stationären zufällige Folgen," Bulletin academic sciences U.S.S.R serial mathematics, 5, 1942, pp. 3-14.

Communication,[23] published in 1948.[24] This paper is considered to mark the birth of information theory.

2. History of Information Theory

Information theory came about as a theoretical fallout of mastering information technology on the engineering level of communication, rather than from statistical mechanics. Soon, the pressure of economics led to a search for methods of increasing its efficiency. Problems of signal compression emerged, finally leading to the concept of "quantity of information", embedded in a theory which was able to set forth the problem and its possible solutions in mathematical terms.

A. G. Bell's invention of the telephone in 1875 encountered technical difficulties beyond the capacities of binary-type signal transmission in telegraphy: currents of continuous varying amplitudes and frequencies being transmitted at rates several times faster than those encountered in manual telegraphy had to be technically

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[23]C. E. Shannon: "A Mathematical Theory of Communication", Bell System Technical Journal, vol. 27, pp. 379-423, July 1948.

[24]An interesting relationship exists between Wiener's and Shannon/Weaver's development of their respective theories. Warren Weaver remarks that " . . . Dr. Shannon has himself emphasized that communication theory owes a great debt to Professor Norbert Wiener for much of its early philosophy. Professor Wiener, on the other hand, points out that Shannon's early work on switching and mathematical logic antedated his own interest in the field; and generously adds that Shannon certainly deserves credit for the independent development of such fundamental aspects of the theory as the introduction of entropic ideas." Warren Weaver, "Recent Contributions to the Mathematical Theory of Communication", A Review of General Semantics, Vol. 10, No. 4, p. 261.

mastered. Several mathematicians helped to establish an adequate mathematical treatment of the phenomena involved in telephony, most prominently Henri Poincare[25] and G. A. Campbell, of the American Telephone and Telegraph Company. These scientists used mathematical extensions of the work of Joseph Fourier, who had conducted studies on the nature of heat flow[26] and applied his findings to the study of vibration.

> The "Fourier analysis"[27] of signals into components of various frequencies makes it possible to study the transmission properties of a linear[28] circuit for all signals in terms of the attenuation and delay it imposes on sine waves of various frequencies as they pass through it.[29]

Fourier analysis proved to be a powerful tool for the analysis of signal transmission problems. But at first, it presented engineers and mathematicians with a puzzle of

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[25]Henri Poincare: Science and Hypothesis, (in English), The Walter Scott Publishing Co., London and New York, 1905.

[26]Fourier's mathematical attempt focused on some of the problems of heat flow through a very particular mathematical function called a *sine wave*.

[27]We can write Fourier's theorem algebraically as follows:

$$S(t)=\sum_{1}^{n} A_i \sin(2\pi i f t+\Phi i)$$

S (t) denotes the instantaneous amplitude at any time; t, A_i is the maximum amplitude of the i-th member of the series of harmonics, or partials, where i=1, 2, 3, ... n; n being the highest partial present; f is the frequency of the lowest partial; with the last part, of denoting the phase angle of the i-th partial.

[28]In a linear electrical circuit or transmission system, signals act as if they were present independently of one other; they do not interact.

[29]op. cit: Pierce, Symbols, Signals..., p. 34.

results which were hard to incorporate into current beliefs. This situation persisted until Harry Nyquist, a mathematician with remarkable talent, tackled the problems of signal transmission after he came to AT&T in 1917.[30] Nyquist stated that if symbols are sent at a constant rate, the speed of transmission W is related to m, the number of different symbols or current values available:[31]

$$W = K \log m$$

One should note that Nyquist stated for the first time in mathematical terms **why** Edison's quadruplex telegraph doubled the speed of transmission: for example, eight values for electrical current would increase the speed by a factor of four, etc. Nyquist also revealed that a remarkable portion of a signal was occupied by a steady sinusoidal component of constant amplitude, which was useless on the receiver's side as it was perfectly predictable and therefore **redundant**. His second important paper, "Certain Topics in Telegraph Transmission Theory,"[32] developed even higher standards of quantitative measurement. Both papers embrace much important material that is now embodied in information theory.

Serious problems had to be faced in 1925-27 when Baird and the B.B.C. attempted to transmit television pictures over ordinary sound-broadcasting wires. At first, they were

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[30]H. Nyquist: "Certain Factors Affecting Telegraph Speed", Bell System Technical Journal, 3, 1924, pp. 324.

[31]K is a mathematical constant and equals the Boltzmann constant $K = 1.3804 \cdot 10^{-23} JK^{-1}$

[32]H. Nyquist: "Certain Topics in Telegraph Transmission Theory", quoted in Pierce Symbols, Signals..., p. 39.

seriously discouraged because they couldn't match the enormous channel capacity required for detailed imaging within the available narrow signal bandwidth of existing transmission cables. Extensive studies in channel capacity and noise problems were performed in order to find technical and theoretical solutions. However, the transmission problem remained.

Wireless transmission finally brought long sought solutions to the problems of information capacity. Shortly before 1925, analysis was applied to problems of carrier wave "modulation."[33] While the advantages of reducing the spectral bandwidth were soon acknowledged (sufficient quality plus increased amount of information), the representation of the problem of modulation lacked mathematical support. Carson[34] changed this situation in 1922, demonstrating that the use of frequency modulation (FM) did not necessarily compress a signal into a narrower bandwidth. In 1924, through research unrelated to that of Nyquist, Küpfmüller[35] discovered that in order to transmit telegraph signals at a certain given rate of information, a definite bandwidth is required.

This law was more generally expressed by Hartley[36] in 1928. He presented an interesting concept in which the

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[33]i.e., superimposing a signal upon a radio carrier wave.

[34]J. R. Carson: "Notes on the Theory of Modulation", Proc. I.R.E., 10, 1922, p. 57.

[35]K. Küpfmüller: "Über Einschwingvorgänge in Wellenfiltern", Elektronische Nachrichten Technik, 1, 1924, p. 141.

[36]R. V. L. Hartley: "Transmission of information", Bell System Technical Journal, 7, 1928, p. 535.

sender of a message is seen as being equipped with a set of symbols or signs from which he mentally selects symbol after symbol, thus generating a sequence of symbols. Hartley was able to demonstrate that in order to transmit a given "quantity of information", in a bandwidth ***F*** and over a period of time ***T***, the outcome is proportional to the product $2FT \cdot \log S$.[37] What is important here is the notion of ***S*** as a discrete determinant. In other words, speech messages could be transmitted at a reasonable level of quality by representing their numerical values not as a continuous curve, but as a sequence of discrete[38] signs. Hartley observed that these types of signals cannot contain an infinite amount of information because the sender cannot control the wave form with complete accuracy. It is important to note that Hartley's definition of information was not concerned with semantics but rather with strictly statistical information represented by a successive selection of signs from a fixed repertoire. He rejected the term "meaning" as being merely subjective because he said that it is the **sign** which is transmitted, not its meaning. In other words: ***N*** signs chosen from a set or "repertoire" of ***S*** signs contain S^N combinatory possibilities. Its quantitative information ***H*** can be defined mathematically as:

$$H = N \log S$$

[37] *S* represents the number of distinguishable power levels of the signal.

[38] The term "discrete" relates to systems which are able to change their states only in discrete, discernable steps, creating a "disjunct" output of fluctuating values as in quantum theory.

This equation is considered to be one of the most important seeds of modern communication theory.

Gabor[39] inferred certain results of uncertainty within the Fourier analysis model and associated the uncertainty of signal time and bandwidth with Heisenberg's uncertainty principle in wave mechanics.[40] His research revealed that our aural perception of sound is simultaneously one of time **and** frequency and that future signal representations should incorporate both parameters rather than describe them either purely by frequency or according to time alone. For example, a single sound element, being considered finite both in frequency and in time, is regarded as the smallest "unit of structural information" or "logon".[41] Even if Gabor didn't include the concept of noise in his Theory of Communication (a document of primary importance in communication theory), his contributions were highly significant for the development of information theory. The concept of

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[39]D. Gabor: "Theory of Communication", Journal of the Institute of Electrical Engineers. (London), 93, Part 3, 1946, p. 429.

[40]If, in early theories of modulation, a basic signal is considered as a continuous sine wave, its "Fourier analysis" is basically timeless because of the assumption that these waves last forever. In other words, a signal can be described by its frequency only. The attempt to describe the same signal as a function of time falls into the reverse extreme because it seems that the values of the signal at two consecutive instants were independent. But in reality, signals are of course of finite duration and also occupy a certain bandwidth. The longer the time window *T*, the narrower the frequency bandwidth; that indicates its discrete frequency.

[41]Cherry writes: "It is important to appreciate that the *structural* aspect of communication theory has nothing to do with probability theory. The logon is a unit which relates to a specified *channel*, but not to any one particular signal transmitted. In Colin Cherry, On Human Communication, 3nd Edition, M.I.T. Press, Cambridge, Mass., 1978, p. 45.

uncertainty, which was investigated initially by Gabor, was later generalized by MacKay[42] in 1948, contributing significantly to the genesis of a modern "theory of information".

Because of the pressing need to improve the rate of information in technical telecommunication systems by removing those components which do not contribute markedly to speech intelligibility (Paget[43] and Fletcher[44]), it became clear that besides the bandwidth x time theorem, something more drastic had to be done to compress speech signals without loss of information. Research towards the compression of speech finally led to Dudley's[45] invention of the *VOCODER* in 1936, a device for **analyzing** and **re-synthesizing** speech.[46] In order to reproduce intelligible speech, this device (or talking machine) could be controlled by merely transmitting and receiving rudimentary signals

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[42]D. M. Mackay: "Operational Aspects of Some Fundamental Concepts of Human Communication", Synthese, 9, issue 3, 1948, Nos. 3-5, pp. 182-198.

[43]Paget, Sir Richard: Human Speech, Kegan Paul, Trench, Trubner & Co, London, 1930.

[44]Harvey Fletcher: Speech and Hearing, D. van Nostrand Co., New York, 1929.

[45]H. Dudley: "The Carrier Nature of Speech", Bell System Technical Journal, 19, Oct. 1940, p. 495.
_____. "Remarking Speech", Journal of the Acoustical Society of America, 2, 1939, p. 165.
_____., R. R. Riesz, and S. S. A. Watkins. "A synthetic Speaker", Journal, Franklin Institute., 227, 1939, p. 739.

[46]This technical device was of crucial importance to Meyer-Eppler's research on the application of information theory in music from 1949 onward.

which are syntactically more elementary than speech signals. On the transmitter's side, these fluctuations were analyzed and sent over a narrow bandwidth channel while a parallel signal was sent to indicate the type of the fundamental *larynx pitch* (voiced sounds like *mm* or *oo*) or, if absent, colored noise or hissing. These signals would then modulate a "hiss" generator on the receiver's side in order to reproduce the desired phonemes. Finally, the required control signals for re-synthesis were conveniently produced by coupling them with an electronic, automated analysis of the speaker's actual voice.

Dudley's design was paralleled by similar developments, carried out by Halsey and Swaffield.[47] For the first time it was possible to bypass the restrictions formerly imposed on a communication channel by the bandwidth theorem: the Vocoder allowed an increase in the information rate of speech through "frequency compression",[48] beyond what was possible by means of fixed channel parameters as described by Gabor.[49]

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[47]R. J. Halsey, and J. Swaffield: "Analysis-Synthesis Telephony, with Special Reference to the Vocoder", Journal Institute Electrical Engineers (London), 95, Part 3, 1948, p. 391.

[48]For example, from the transmitter's side, speech is scanned repeatedly by electrical "pickups" which run themselves at a different, but constant speed. Because of interferences, or the *Doppler effect*, the bandwidth of the signals is considerably reduced, and can be transmitted and later expanded to its original bandwidth on the side of the receiver. This represented a substantial reduction of information to be sent over a communication channel.

[49]D. Gabor: "New Possibilities in Speech transmission", Journal Institute Electrical Engineers (London), 94, Part 3, 1947, p. 369; and 95, Part 3, 1948, pp. 39 and 412.

War-induced developments in the field of *radar* raised unprecedented difficulties in clearly discriminating the signals representing the position of a single airplane from those generated by meaningless erratic current or noise. At first, it looked desirable to attenuate the frequencies which were most prominent in noise, while allowing the frequency components present in the original signal to pass. To predict the future course of the airplane, the current received at any given moment could then be passed on through other circuits to *predict* what the values of the signals might be in the near future. However, the design of a technical solution to this problem involved the prediction of not just one, but an entire *set* of possible solutions (possible random flight courses), as a response to one "question", and this was further aggravated by prevailing noise. This problem was finally solved independently by Kolmogoroff[50] and Wiener,[51] and substantial elements of their solutions eventually found their way into the work of Claude Shannon. His famous paper was published, in collaboration with Warren Weaver,[52] the same year as

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[50]A. Kolmogoroff: "Interpolation und Extrapolation von stationären zufälligen Folgen", Bulletin academic sciences U.S.S.R. series mathematics, 5, 1942, pp. 3-14.

[51]Pierce, in Symbols, Signals...: "...during the war he produced a yellow-bound document, affectionately called 'the yellow peril' (because of the headaches it caused), in which he solved the difficult problem".

[52]"A Mathematical Theory of Communication" was published by both Claude Shannon and Warren Weaver, formerly known as the 'Shannon/Weaver Theory'. Footnote of Weaver in: Warren Weaver: "Recent Contributions to the Mathematical Theory of Communication", A Review of General Semantics, Vol. 10, No. 4, pp. 261-281. However, it was Shannon's mathematical definition of information theory which made his contribution so famous.

Wiener's Cybernetics,[53] in which issues of information and control were investigated, and is regarded as the foundation of information theory.

Both of the mathematical solutions presented were capable of finally dealing not only with a single signal, but with *any* signal selected from a set of possible signals received. Shannon's approach made it possible not only to treat a signal-plus-noise so as to get the best estimate of the signal but also, on the transmission end, to encode a signal so as to best convey messages of a given type over a particular sort of noisy channel. Shannon was able to synthesize the main ideas of his predecessors into a coherent mathematical system which was to be named information theory. Its main areas of application encompass the following subjects:

- A clear definition of the amount of information of any given message.
- A clear definition of the maximal capacity of a channel with and without noise.
- A study of the flow of information in discrete messages through channels with and without noise.
- The formulation of important coding theorems: for a given source and fixed channel one can always devise an encoding procedure leading to the maximal rate of transmission of information.
- A study of the flow of information through continuous signals in the presence of noise: an extension of the case of discrete signals.

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[53]N. Wiener: Cybernetics, The Technology Press of M.I.T. and Wiley & Sons, New York, 1948. 2nd Ed., M.I.T. Press, Cambridge, Mass., 1961.

Today what we call "Shannon's formula" is a basic equation which states the maximum possible *capacity* of a communication channel to communicate information. Shannon finally accomplished what generations of scientists and engineers aspired to produce: an elegant, clear mathematical definition of the information content of **any** possible message[54]:

$$H_n = W\log\left(1+\frac{P}{N}\right) bits/sec$$

In a sense, it is a pity that the mathematical concepts stemming from Hartley's work have been called "information" at all, because H_n is only a measure of a small facet of the entire concept of information. Shannon's and Wiener's definition of information is only concerned with the statistical rarity of a source of message-signs. Literally thousands of articles have investigated the influence of information theory on other disciplines, including music. How could such a limited concept have such a tremendous impact on such a wide range of applications in the 1950's?

Up to this point, we have followed the evolution of information theory in order to illustrate how this theory played a formative role in the development of modern information technology. However, in attempting to discuss its influence on music, we require a brief discussion of some of its basic concepts related to the phenomenon of communication. If music could be understood as a system of communication, the mathematical concepts of information theory could be applied to music as well. However, I have

[54] H_n means the amount of information, **W** equals the bandwidth, in the presence of uniform, random (Gaussian) noise; **P** and **N** are the mean signal and noise power, with amplitude modulation.

found that the composers selected for this study resorted to composition procedures which reflected only a very basic use of this theory, especially when compared with the unabridged system of information theory as it was presented by Shannon. As we are limited by the scope of this dissertation, the following description of the mathematical foundations of information theory will be restricted to the presentation of its most essential concepts, as deemed necessary to follow the application of this theory in the compositional procedures of Lejaren Hiller and Karlheinz Stockhausen.

3. A Mathematical Basis of Information

a) Claude Shannon's Model

During the historical development of communication systems, it appeared to be of increasing interest to formalize technical problems in mathematical terms. One of the most important contributions establishing a definition of information in technical and mathematical terms was Shannon's and Weaver's[55] A Mathematical Theory of Communication.[56] This famous paper on information theory

[55]Having acknowledged both authors, the name of Warren Weaver will be omitted from here on whenever relevant material regarding the above publication is mentioned in this dissertation. This is done purely for practical reasons, not to underestimate Weaver's significant contribution to the development of information theory.

[56]Claude E. Shannon: "A Mathematical Theory of Communication", Bell System Technical Journal, vol.27, July 1948, pp. 379-423.

launches with a schematic diagram of a communicating system resembling Hartley's original idea.[57]

Shannon's model of communication describes the transfer of information between an emitting source and a receiver. However, his understanding of information theory does **not** concern itself with the communicative processes involving a receiver possessing human qualities, but deals exclusively with its direct application to the technical equipment itself. Technical communication systems have only a limited amount of *information capacity* and can therefore be defined strictly in mathematical terms. Every application of this theory outside of this sphere has to be regarded as an extrapolation beyond its legitimate domain of operation, and its method has to be carefully matched with certain criteria of validity before it can be legitimately put into practice.

b) A Definition of Information Theory

First, I would like to define what the term "information" represents in information theory, and how the information content of a message can be measured in mathematical terms. Information content can be interpreted from different perspectives:

i) semantic information content relates to the **absolute** gain of information from a message received;

ii) pragmatic or structural information content relates simply to the **relative** gain of information for a **particular** receiver;

[57]See Fig. 1. in the appendix.

iii) <u>idealized</u> information content relates to the gain of information assembled by a **particular** receiver following specific selection rules;

iv) <u>selective</u> or <u>syntactic</u> information contents have nothing to do with the significance of a message, or its meaning for a specific receiver, or even its aesthetic value, but instead refer to the organization of the information contained in the signal itself.

Of these four forms, only the <u>selective</u> or <u>syntactic</u> information contents are relevant to Shannon's definition of information theory. The reason for this is that the transmission of messages involves a more or less arbitrary process of selecting certain symbols out of a limited "pool" of elements or "alphabet[58]". That Shannon's measure of "information"[59] content $\mathbf{H}_n$[60] does not specify any distinct meaning is simply a result of its mathematical appearance: it applies to a group or set of messages, not to a single message which could have a specific "meaning". Therefore the <u>syntactic approach</u> is preferred for the application of information theory.

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[58]This notion of "alphabet" is the result of a historical episode: the application of information theory took place first in the area of telecommunications and speech.

[59]"In fact, in this new theory [information theory] the word information relates not so much to what you *do* say, as to what you *could* say. That is, information [-content] is a measure of your freedom of choice when you select a message". W. Weaver in: "The Mathematics of Information", <u>Automatic Control</u>, ("A <u>Scientific American</u> book"), Simon and Schuster, New York, 1955, p. 100.

[60]See Shannon's formula, p. 23.

c) Measurement of Information Content

In 1928, Hartley demonstrated that the information content of a message, consisting of a series of symbols chosen from a limited set, could be defined as the *logarithmus dualis* of the number of possible sequences of symbols selected from that set:

$$H = n \log s.$$

In this case, ***n*** represents the number of selected symbols, and ***s*** the total number of symbols contained in the set, while the unit of measurement of information is conveniently termed a Hartley (H). However, this formula is valid only if each symbol of the set is invested with the same probability of being selected. A good example is that of tossing a coin, where repeated tossing will never change the 50% probability of exhibiting head or tail on the next toss: the events are in fact unrelated. Expressed as a quantitative measure, the number of symbols selected being one, and the number of symbols in the set being two, the above equation reads as $H = n \log s = \log 2 = 1$. The results could be described in terms of binary digits or bits: our basic example contained one bit of information to be gained every time the coin is tossed. Similarly, the throw of a die would contain *log* 6, or 2.585 bits.[61]

However, we have already seen, in the example of the Morse code, that this is not the case with English text: the letter E, for instance, is far more likely to be picked in the printer's office than the letter W. A source which emits

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[61]Value taken from the table of values for *f(x)* = ld *x*, found in Rul Gunzenhäuser: Maß und Information als ästhetische Kategorien: Einführung in die Theorie G.D. Birkhoffs und die Informationsästhetik, Baden-Baden, 1975, pp. 182-189.

discrete symbols through a process involving unequal probabilities, in which the likelihood of being selected depends also on certain probabilities related to the preceding choices, is called a stochastic source. The process of emission of messages can therefore be characterized as a stochastic process.

Retaining the logarithm to the base 2 from Hartley, Shannon was now in a position to determine the information content of both equiprobable and stochastic sources such as English text. He could demonstrate that, where the possible correlations between these symbols range from total autonomy to total dependency, the information content of a message is equal to the sum of the probability of each symbol times the logarithm of that probability[62]:

$$H=-[p_1 \log p_1+p_2 \log p_2+...+p_n \log p_n]$$

However, this is equivalent to the famous Shannon formula:

$$H=-\sum p_i \log p_i$$

The frequency with which certain symbols $\mathbf{S_i}$ are transmitted is dependent on assigned probabilities $\mathbf{p_i}$. This means that a certain (statistical) uncertainty exists prior to the reception of a symbol, which will be completely eliminated after reception: information is eliminated uncertainty. In other words, the amount of information contained in a symbol is directly related to the probability of its likely emission. However, the information contained in a single symbol cannot be characterized by the symbol itself: it has to be correlated with the totality of the symbols contained

[62]Claude Shannon and Warren Weaver: The Mathematical Theory of Communication, p. 27.

in a source. Therefore the information content per symbol has to be averaged as $\mathbf{p_i}$ over all symbols $\mathbf{S_i}$. A simple description of a (limited) source of information **(I)** can be formulated as:

$$I:\begin{pmatrix} S_1 \ldots S_i \ldots S_n \\ p_{(1)} \ldots p_{(i)} \ldots p_{(n)} \end{pmatrix}$$

This setup exemplifies a source **"I"**, which supplies a randomized sequence of completely independent symbols $\mathbf{S_i}$ in correspondence with their probabilities $\mathbf{p_{(i)}}$. Let us briefly investigate the following examples to illustrate the above formula: an <u>ergodic source</u>[63] is imagined, which emits the first three letters of the English alphabet. The following message is received:

A B B A C A C A A

This message contains a total of 9 letters, five A's, two B's and one C, thus representing the following approximate probabilities: A is 55%, B is 22%, and C is 11%. Applying Shannon's formula, we obtain the following result:

H = -[pA logpA + pB logpB + pC logcC]
H = -[.55 x -.4714 + .22 x -2.1714 + .11 x -3.1714]
H = -[-.2618 + -.4825 + -.3523]
H = 1.096 bits

According to Shannon, the information content of the above message equals 1.09 bits. If all the letters had been

[63] A source is called ergodic if it emits symbols which have unequal probabilities.

received with the same frequency (three A's; B's; C's), the information content would have been:

$$H = -[.33 \times -1.5864 + .33 \times -1.5864 + .33 \times -1.5864]$$
$$H = -[-.5287 + -.5287 + -.5287]$$
$$H = 1.58 \text{ bits}$$

This value is considerably higher and represents the maximum amount of information which can be transmitted by a limited set of three letters. It is interesting to note that Shannon, in the course of similar experiments, does not refer to the meaning of messages of this kind, but resorts rather to the quantitative term <u>entropy</u>. The reason for this can be found in earlier work by Weaver:

> Dr. Shannon's work roots back...to Boltzmann's observation, in some of his work on statistical physics (1894), that entropy is related to "missing information", inasmuch as it is related to the number of alternatives which remain possible to a physical system after all the macroscopically observable information concerning it has been recorded[64].

The term entropy, well known in the field of statistical mechanics, refers to the unpredictability related to the velocity and position of molecules. Transferred by analogy to the field of communication theory, the term entropy was then used to indicate the unpredictability of the information content of a message. The more discrete symbols a set contains, the more unpredictable becomes the selection process involved in the assembly of messages, leading to higher information content

[64]Warren Weaver, quoted from a footnote in Warren Weaver: "Recent Contributions to the Mathematical Theory of Communication", <u>A Review of General Semantics</u>, Vol. 10, No. 4, p. 261.

or entropy. In mathematical terms, the entropy of a system can be written as follows:

while **k** represents the Boltzmann-constant, and **ln = $_e$log**,

$$E = -k \sum_i p_{(i)} \ln p$$

and p_i indicates the probability of finding a discrete value A_i out of a given physical dimension **A**.[65] The expression **H = ld n** for the equiprobability of symbols is therefore a special case of Shannon's equation[66]. According to Shannon's formula, **ld n** is the maximum value of information that entropy can reach. In other words, maximum entropy is attained when the individual probabilities of all symbols reach equality: the unpredictability related to the selection of a certain symbol reaches a maximum, leading to maximum information content, as we have seen in the second example above[67]. Thus, in communication theory, unpredictability, information content, and entropy are treated as equivalent terms.

While it provides, in terms of communication theory, the mathematical means of computing the absolute information content of a message, information theory also makes it

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[65]W. Macke: Thermodynamik und Statistik, Akademische Verlagsgesellschaft, Leipzig, 1963, p. 233

[66]In this case: $p_{(i)} = 1/n$ $(i = 1...n)$

[67]Following the general equation that Max H = log n, an example containing 4 symbols would have contained 2 bits, one containing 8 symbols, 3 bits, one containing 16 symbols, 4 bits, and so on. These values were obtained from Gunzenhäuser, op. cit, p. 206.

possible to determine the percentage of information gained during the communication process: represented as the ratio between the currently received entropy of a message and its maximum possible value according to Hartley's formula, this is called relative entropy:

$$RelH=\frac{H}{MaxH}$$

In the case of our above examples we would get:

$$RelH=\frac{1.09bits}{1.58bits}=.689$$

In other words, the above value represents the amount of freedom, on the side of the source, to select the original 9-symbol message from the original set of three discrete symbols, in this case: 68.9%. That means that at least six symbols could have been selected arbitrarily. On the other hand, the remaining percentage of 31.1%, or approximately three symbols, was the direct result of structural restraints located within the source itself. This value of 31.1% is called the redundancy[68] of a message, in our case represented by the frequent symbol A. In communication theory, it is important to note that the amount of redundancy in a message is not limited by the structural characteristics of the source itself, but can also affect messages during the communication process, or be governed according to stylistic restraint.

However, in most cases involving sequential selection processes, the choice of a certain symbol is somehow dependent on the choice of one or more of the preceding symbols. For example, linguistic research shows that each

[68](lat. redundantia, circuitous, lengthy).

character of an alphabet has a different "transition probability" of attracting another, following letter. As the probabilities of each symbol in this case are not equal, and their accompanying transitional probabilities are influenced by preceding selection processes, this represents a stochastic process which can be mathematically expressed as a Markoff chain process.[69] For example, if we know that within the English alphabet,[70] a Q would almost certainly be followed by a U, but a U would seldom be followed by a Q, a matrix of transitional probabilities can be drafted reflecting this relationship in mathematical terms. This, in fact, is of critical relevance for determining the properties of technical communication systems by means of information theory.

If we consider transitional probabilities which depend on only one preceding choice, we are talking about a first-order Markoff chain: the probability of a symbol S_j is conditioned by only one preceding symbol S_i. In this case, the conditional probabilities $p_i(j)$ describe the probability for S_j, if they were preceded by S_i. A Markov chain where two preceding choices are considered is called a second-order Markoff chain, and where n symbols are considered, an n-th order Markoff chain. Regarding the assembly of messages

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[69]The application of information theory presupposes that Markoff chains are ergodic. A Markov chain is called ergodic if picking a number of sufficiently long sequences out of a chain does not change all the generated statistical results. In practical applications, messages have to be picked up for a sufficiently long time or in significant amounts to validate the ergodic nature of the source. It is very difficult to validate a source in terms of true ergodicity. Therefore ergodicity is often a hypothetical prerequisite for applications of information theory.

[70]The English alphabet consists of twenty-six letters and the space between letters.

from symbols, symbol sequences containing two letters are called digrams, those containing three letters are called trigrams etc. On the side of the receiver of a message, the interpretation process of gaining information could be described as follows:

> The information gained when a Markov chain moves one letter ahead, that is the average information content per letter, cannot be measured by the H_1-formula alone. Considering second-order dependencies, the information gained from the second letter of the "digram" equals the total information content of the digram **(i,j)** minus the information content of the first letter **(i)**. Hence the average information gain is:[71]

$$H_2 = H_i(j) = H_{(i,j)} - H_i$$

In other words, the information gained on the receiver's end will be considerably lower than the simple sum of the information content of every individual symbol received. This makes sense, as we know that in printed English text the letter Q will almost certainly be followed by a letter U. Thus the sequence QU must have a lower information content[72].

> ...if [in] a finite scheme...**A**[S_i] is dependent on **B**[S_j], so that the occurrence of A_k changes the probabilities in **B**, then the occurrence of A_k can only reduce the uncertainty associated with **B**. The result is that [in] a sequence of events whose schemes are dependent on preceding events, the additional uncertainty of each new event tends to diminish.[73]

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[71]E. Cohen, p. 140.

[72]In tonal music, this situation would be represented by a V-I cadence: except for possible tonal deceptive resolutions, the step after the dominant is almost certain to be the tonic.

[73]Cohen, op. cit., p. 139.

In extreme cases, if all the probabilities in a finite scheme are zero except one ($\mathbf{p}_{(i)}$ and $\mathbf{p}_{(j)} = 1$), uncertainty is excluded: the related event $\mathbf{E}_i$ will occur ($\mathbf{H}_i = 1$). If all the probabilities in a scheme of n events are equal, uncertainty (or entropy) is maximal. **H** then assumes its maximal value ($\mathbf{H}_i = \mathbf{log\ n}$). This, as we have seen already, is the formula provided by Hartley: an event received will be of greatest surprise for a receiver when it possesses the highest amount of information.

d) Linguistic Studies

The statistical relationships between digrams, first explored in linguistic research, had already been the subject of an investigation by A. A. Markoff, who started with his statistical study[74] of Pushkin's novel *Eugene Onegin*. He revealed that sequences of words can be constructed according to statistical tables of transition probabilities that bear a striking resemblance to an English text, without making "sense" in the resulting message. In fact, the degree of resemblance is only dependent on the value of the n-grams, including "space" as a character.

Shannon utilized this idea of composing written "messages" simulating a stochastic process, that is, as a "series of signs (letters or words), each one being chosen entirely on a probabilistic basis, depending upon the one, two, three or more signs immediately preceding"[75]. Afterwards, he demonstrated how English words and text can

[74]A. A. Markoff: "Essai d'une recherche statistique sur le texte du roman 'Eugene Onegin'...," Bulletin Academic Imperial Sciences St.Petersbourg, 7, 1913.

[75]Colin Cherry, op. cit., p. 39.

be approximated by a mathematical process which could even be carried out by a machine[76]. His example[77], obtained by an equivalent process, reads as follows:

1) Zero-order approximation (symbols independent and equiprobable)
XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSGHYD QPAAMKBZAACIBZLHJQD

2) First-order approximation (symbols independent but with frequencies of English text)
OCRO HLI RGWR NMIELWIS EU LL NBNESEBYA TH EEI ALHENHTTPA OOBTTVA NAH BRL

3) Second-order approximation (digram-structure as in English)
ON IE ANTSOUTINYS ARE T INCTORE ST BE S DEAMY ACHIN D ILONASIVE TUCOOWE AT TEASONARE FUSO TIZIN ANDY TOBE SEACE CTISBE

3) Third-order approximation (trigram structure as in English)
IN NO IST LAT WHEY CRATICT FROURE BIRS GROCID PONDROME OF DEMONSTURES OF THE REPTAGIN IS REGOACTIONA OF CRE

If we examine Shannon's example, we see an increasing resemblance to English text: this is a true application of information theory within the realm of linguistics. In fact, Shannon could demonstrate that while the entropy of randomly selected letters of the English alphabet averages 4.7 bits per letter, that of printed English averages only 2.62

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[76]C. Shannon quoted in J. R. Pierce: Symbols, Signals, and Noise: The Nature and Process of Communication, Harper, New York, 1961, p. 48.

[77]C. E. Shannon: "A Mathematical Theory of Communication", Bell System Technical Journal, vol. 27, July 1948, p. 382.

bits[78]. This is because the difference between the two values (2.08 bits) relates to the relative entropy or redundancy inherent in the structure of printed English.[79] Considering the above obtained values of relative entropy, a significant portion of printed English text appears to be 44% redundant:

$$R=\frac{H}{H\max}=\frac{2.08}{4.7}=.422=44.2\%$$

Shannon could demonstrate that, taking this particular characteristic into account, the speed of a signal transmission involving English text could be greatly improved: through proper coding, the redundant portion of a message could be compressed or completely eliminated at the start, on the side of the transmitter, significantly shortening the communication process without losing information on the receiver's side. One of Shannon's major achievements in the field of communication theory was to demonstrate that these coding procedures could be applied to any type of messages.

e) Establishing Communication

How then is communication established between a transmitter and a receiver of messages? As an example, let us use eight letters from the English alphabet. We assume in this case that a certain (ergodic) source sends symbols

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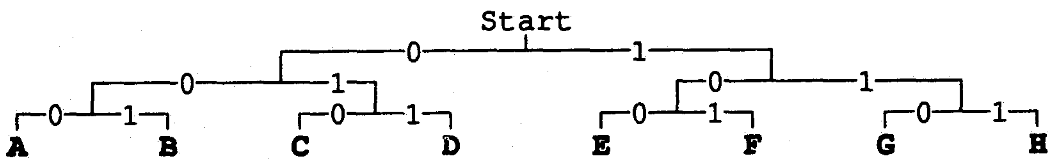
[78]Claude E. Shannon: "Prediction and Entropy of Printed English", Bell System Technical Journal, Vol. 30, 1951, p. 50.

[79]Claude E. Shannon: "Prediction and Entropy of Printed English", Bell System Technical Journal, Vol. 30, 1951, p.50.

[**A**,**B**,**C**,**D**,**E**,**F**,**G**,**H**] with equal probability, the letters being totally independent. The transmission of a message will take place as follows: transmitter and receiver have first of all agreed to code and decode the symbols **A**...**H** according to the following scheme or 'tree':



If the transmitter attempts to send the symbol "**C**", he has to "walk" through three successive choices, in this case: 0-1-0. This operation is called <u>coding</u>. If the receiver obtains the same symbol "**C**", he or she has to walk through the above, previously agreed upon coding scheme as well. In the case of this particular source, every possible choice could be represented by such a representative trigram (here: 0-1-0), consisting merely of two binary choices, "yes" or "no", 1 or 0, or electric impulses "on" or "off". In other words, every symbol transmitted out of the limited set of characters [**A**...**H**] contains the "choice-content" of 3 bits.[80]

Referring back to Shannon's figure for the transmission of information between transmitter and receiver, we assume now that this type of noiseless[81] channel transmission takes place, providing the receiver with a set of symbols. On the side of the receiver, uncertainty is eliminated by exactly following the mutually agreed upon binary selection

[80]("bit" = "**bi**nary digi**t**").

[81]I.e., a channel which would transmit messages without adding to, subtracting from, or distorting the original information content sent by the transmitter.

process (three binary choices per symbol): three bits of information per symbol can thus be gained on the side of the receiver. For sources which emit non-equiprobable symbols we have to consider that, if the probability of occurrence of a certain symbol is high, its "newness" for the receiver, or its relative information content, is low, i.e. it is redundant.

For example, in music, whereas the presentation of constantly new material would create a situation of overwhelming information content without hints of structural coherence on the side of the receiver, the concept of redundancy is of fundamental importance: it allows the receiver to obtain a measurement of musical events that is comprehensible within an established structural system. In other words, the comprehension of a message increases proportional to the amount of redundancy contained within it. Contrary to entropy, redundancy provides a quantitative measurement of order within a sequential structure[82] and is therefore an essential ingredient of structured messages.

f) The Presence of Noise

"From the view of information theory, the most interesting relation between physics and information theory lies in the evaluation of the

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[82]"To the degree that a sequence is redundant, it is in some manner regular, or lawful. Any order of redundancy above the first implies that the events are more or less patterned, that *sequential dependencies* exist among them. But neither the degree nor the order of the redundancy tells us specifically what *kind* of lawfulness, or patterning, is involved." In: Fred Attnaeve: Applications of Information Theory to Psychology, New York, 1956.

unavoidable limitations imposed by the laws of physics on our ability to communicate".[83]

One of the great breakthroughs of information theory was the capability of describing the impact of noise on the transmission of information within the sphere of semantics in quantitative terms, **without** being required to specify the nature of the disturbance.

"Noise" is everything which interferes with an original message in an unintentional way. Noise can occur at any accessible and inaccessible position in the communication chain, as well as in the domain of signs. The presence of noise hampers the observation, diagnosis, or linguistic understanding of a message. The concept of noise in information theory is extremely general. Its influence is of vital significance for the quality of resulting relationships between communicating systems. Any form of noise has the capability to modify, change, or even destroy a bond of communication between systems in correspondence. Let us refer to the formerly specified structure of communication, in the following figure denoting a number of possible locations of "noisy" interferences.[84]

All efforts to diminish disturbances within a communicative system can be summed up under the heading of <u>matching</u>. Regarding the linguistic communication chain, we have to discriminate clearly between signal matching and sign matching, because effective and economical coding of messages is possible only if both areas are coupled comprehensively. We might ask now, what kind of impact does the concept of noise have on the quantitative measurement of information content as promised by information theory?

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[83] Pierce, <u>Symbols, Signals</u>..., p. 198.

[84] See Fig. 2. in the appendix.

Perceived from the side of the receiver, the presence of noise in a communication channel changes the signal from a more probable to a less probable state because the entropy of a message is increased as redundancy is decreased due to the unpredictability of noise. Hence, a higher degree of "unexpectedness" is created on the side of the receiver: he has to face increased difficulty in extracting the proper message from the signal as it must distinguish between desirable and undesirable information.

> Since noise, whether cultural or acoustical, generally creates uncertainty, it would seem that noise is...important in the arousal of meaning and information. One must, however, distinguish between desirable and undesirable uncertainty. Desirable uncertainty is that which arises within and as a result of the structured probability of a style system in which a finite number of antecedents and consequents become mutually related through the habits, beliefs, and attitudes of a group of listeners. Undesirable uncertainty arises when the probabilities are not known, either because the listener's habit responses are not relevant to the style (cultural noise), or because external interferences (acoustical noise) obscure the structure of the situation being considered.[85]

In order to "harden" a transmitted message in a noisy environment, a certain amount of "useful" redundancy has to be re-inserted into the message: redundancy further helps to avoid errors introduced by **noise** into the communicating channel[86] by assisting the receiver in extracting the

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[85]Leonard B. Meyer: Music, the Arts, and Ideas - Patterns and Predictions in Twentieth Century Culture, Chicago and London, 1967, p. 17.

[86]An important theorem in information theory postulates that there is a maximum limit of **transmittable** information for any noisy channel. A limited maximum amount of information can therefore be transmitted through the appropriate coding of messages with various deliberate quantities of small errors.

proper message from the signal. The analysis of musical structures has often been compared to the analysis of the structure of speech because the psycho-acoustical transformation processes involved during their perception are of a similar kind. In music, redundancy is induced through musical form, while in speech it is through linguistic structure generating comprehensibility.

Both fields of speech and music share a common purpose of establishing communication. Having established some basic principles of information theory, and their method of application in the field of communication, we are now in a position to pursue the objective of this dissertation, which is to illustrate how the relationship between information theory and music evolved. Sir Thomas Eddington, in a passage of his "The Nature of the Physical World" remarks:

> Suppose that we were asked to arrange the following in two categories - *distance, mass, electric force, entropy, beauty, melody.* I think there are the strongest grounds for placing entropy alongside beauty and melody, and not with the first three. Entropy is only found when the parts are viewed in association, and it is by viewing or hearing the parts in association that beauty and melody are discerned. All three are figures of arrangement. It is a pregnant thought that one of these three associates should be able to figure as a commonplace quantity of science. The reason why this stranger can pass itself off among the aborigines of the physical world is that it is able to speak their language, viz., the language of arithmetic.[87]

The maximum information capacity that can be conveyed in correlation with time is called <u>channel capacity</u>.

[87]T. Eddington, as quoted in Warren Weaver in "Recent Contributions to the Mathematical Theory of Communication", <u>A Review of General Semantics</u>, Vol. 10, No. 4, pp. 280-281.

CHAPTER II - INFORMATION THEORY AND MUSIC

1. Music and Mathematics

Modern growth in the sciences has been prominently influenced by new theories of symbolism, encouraging generalized mathematical applications of ordinary logic in social sciences, the arts, and music. The nature of musical communication has been one of the issues which has been discussed since ancient times in connection with scientific discoveries. For example, Cassiodorus (ca. 485-ca.575) described the mathematical *quadrivium* as:

> Mathematical science is that science which considers abstract quantity. By abstract quantity we mean that quantity which we treat in a purely speculative way, separating it intellectually from its material and from its other accidents, such as evenness, oddness, and the like. It has these divisions: arithmetic, music, geometry, astronomy. Arithmetic is the discipline of absolute numerable quantity. Music is the discipline which treats of numbers in their relation to those things which are found in sound. . .[88]

If music, then, in both its syntactic and symbolic expressions, can be related to structural characteristics, it should be possible to quantify these attributes in the form of a mathematical expression of some sort. Before the 1950s, this view had not only been shared by some eminent musicians and music theorists[89] of earlier times, but it had also found a more contemporary manifestation in

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[88]Cassiodorus: "Institutiones", II, iii, paragraph 21, as quoted in O. Strunk, Source Readings in Music History, W. W. Norton Inc., New York, 1950, p. 88, footnote 6.

[89]Notably Jean-Philippe Rameau in Treatise on Harmony (1722), Helmholtz in Sensation of Tone (1863), and Hindemith in Craft of Musical Composition, etc.

Schillinger's "System of Musical Composition".[90] Although it is interesting to note that Schillinger's publication appeared during the same year (1948) in which Wiener, and later Shannon, published their ground-breaking work on information and communication theory, this cannot be seen as a case of analogy since Schillinger's approach is based on his research dating from the 1930s, and does not concern itself with communication theory at all. In fact, Schillinger's method does not have a significant scientific or mathematical foundation except for devising a system of numerical proportions as a means to assemble musical textures. However, in our context, at least a few ideas of the Schillinger System should be cited, as they did exhibit a considerable amount of affinity to certain 20th century compositional methods that became so influential in compositional design in the 1950s: i.e. serialism, electronic music composition, and computer music. In fact, the work of Hiller and Stockhausen bears many parallels to Schillinger's perspective, which viewed music as a time-

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[90] Josef Schillinger: The Schillinger System of Musical Composition, N.Y., 1948, and The Mathematical Basis of the Arts, Johnson Reprint, New York, 1966. In our context it is important to note that Schillinger developed his system from 1918 to 1928, while holding various teaching positions in his native Russia. Immigrating to the United States in 1928, he continued his work, which progressed considerably in the wake of his collaboration with Leon Theremin on experiments involving electromagnetic music and electronic design. It is considered certain that he started to test his systems at various American colleges and schools from 1932 onward. In fact, by the early 1940s he was considered one of the best known composition teachers in North America. Schillinger died in 1943, leaving his material sufficiently prepared to be compounded and published in 1948 and 1966, respectively. The Schillinger System of Musical Composition appeared first in consecutive form of lectures, held at the Juilliard School of Music during the summer of 1945.

space entity, capable of graphic projection into space. Schillinger had arrived at these fundamental ideas[91]:

1) Music is defined as a logical system in the Cartesian or Einsteinian manner, i.e. it consists of a system of correlated variables.

2) The aesthetic qualities of music may be analyzed as the geometric relations of its components: rhythm, melody, harmony.

3) Variations may be achieved through the modification of such inherent geometric relations.

4) Music may be composed by taking a system of number values, transforming them into geometrical relations, and thereafter into corresponding components of rhythm, melody and harmony.

5) Just as the understanding of natural and biological forms requires an understanding of the laws of their growth - i.e. the forms of regularity and evolution - the exploration of music involves the discovery of the patterns of regularity and evolution...

6) Musical patterns, viewed in the universe of physical, biological, and aesthetic objects, are only special cases of the general scheme of pattern-making.

7) Schemes of pattern-making have their origin in natural and biological objects - the ratios of curvature of celestial trajectories; the formation of crystals; the division and multiplication of cells in growing things, etc. When they are analyzed quantitatively, such patterns yield various number series.

8) These number series or quantities projected into music excite the same cerebral centers as were stimulated by animate beauty.

9) Thus, every great work of art, every great musical composition, is the realization of a certain mathematical logic. The creations of a non-mathematical musician involve such logic regardless of whether he is conscious of it or not. The aesthetic harmony embodied

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[91]Quoted from: Josef Schillinger: The Schillinger System of Musical Composition, Carl Fischer, New York, 1948, p. xxi.

> in all great musical compositions may be discovered through the application of mathematical techniques of analysis.

Lighting the way to the very beginning of communication science and information theory, Schillinger's ideas contained a remarkable vision of things to come, i.e., the development of statistical and automated compositional design, which emerged during the 1950s and 1960s. In fact, Hiller's general approach in the ILLIAC SUITE does not fall too far short of the objectives of Schillinger's system of composition, though his perspective was based on information theory.

According to Peter Hoffmann[92], artistic and scientific reflections are often expressions of a common history of philosophical ideas. For example, a musician such as Xenakis allowed music to be linked with certain fundamental ideas which shaped 20th century scientific models: theory of relativity, quantum theory and "Chaos" theory.

> There is more in man and in music than in mathematics, but music includes all that is in mathematics. The latter have helped me to formulate my thoughts and intuitions in a better way, and to master the technical data. The mathematical data by themselves cannot express anything, but they [may] be used to express something, provided the artist discerns in their mechanism a teleology, let us say, an atavistic promise . . . Music, being a message conveyed by the material from nature to man or from man to man must be able to speak to the complete human scale of perception and intelligence. A constant stream between the biologic nature of man and the constructions of intelligence must be established, otherwise the abstract extensions

[92]Peter Hoffmann: Amalgam aus Kunst und Wissenschaft: Naturwissenschaftliches Denken im Werk von Iannis Xenakis, Europäische Hochschulschriften: Reihe 36, Musikwissenschaft. Bd. 110, Frankfurt/M, 1994

> of the music today threaten to get lost in the desert of sterility.[93]

Numerous scientific theories exerted a crucial influence in shaping the course of new compositional developments,[94] including several concepts related to probability theory[95] and information theory. In fact, the 1950s have produced musical works that support some composers' professed mission to re-establish music as a scientific discipline, taking into consideration music's particular potential to act as a catalyst between the sciences and human experience.

However, the new scientific methods accompanying the formalization of new approaches to compositional design required not only innovative forms of music representation, but also a re-definition of composition theory. In fact, today we still have to consider the 1950s as the pivotal point in the development of Western music with regard to distinct changes that fundamentally affected all musical work production, prompted a re-definition of musical creativity and compositional strategies, and clearly

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[93]Iannis Xenakis, as quoted by Claude Rostand on Musical Heritage Society recording #1187 containing Xenakis' Nuits and Medea.

[94]An excellent example can be found in: Iannis Xenakis, Formalized Music - Thought and Mathematics in Composition, Bloomington and London, 1971.

[95]An excellent example of the application of probability theory and music can be found in Xenakis' description of PITHOPRAHTA in his article "Wahrscheinlichkeitstheorie und Musik", Gravesaner Blatter, Vol. 2, No. 6, Dec. 1956, pp. 28-34. At that time Xenakis spelled his name as 'Janis Xenakis'.

illustrated the apparent struggle regarding the issue of 20th-century musical form.[96]

2. The Crisis of Musical Form in the Twentieth Century: A New Beginning

While the transition from the 19th to the 20th century seems to have been mainly effected by a crisis of the fundamental concept of tonality accompanied by requisite adjustments in compositional theory, 20th century music has certainly been even more deeply affected by a severe crisis of musical form. In a way, both developments are related, as evidenced by the 12-tone technique, and by serialism during the early 1950s. In fact, this crisis of form affected not only music, but all of the arts, and has lasted ever since[97].

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[96]This includes the proposition of a crucial shift from model-based to rule-based compositional design by means of automated composition, which will be addressed later.

[97]Eric Salzman, at the end of his book 20th Century Music, came to the following conclusion: "The old categories - serial, aleatory, closed form, open form, chance and ultra-rationality - are no longer really relevant. For the younger composers, and many of the older ones, the barriers are down, the categories destroyed, the old battles over and done with. Any kind of statement is possible. All possible material and all possible relationships between the creator, creation, performer and perceiver are possible (including none)... Today, more than ever, the problems,the materials, the premises and the forms, the expressive means and realizations, the psychological, artistic and human meaning of the new music must be unique to each work of art - established anew with each act of creation and realization, and yet universally valid in terms of the scope and universal potential of human experience and knowledge." Quote found in Everett Helm: Composer, performer, Public - A study in communication, Florence, 1970, p. 57.

To complicate matters even further, it was during the 1950s that art production threatened to self-destruct through structural annihilation[98]. However, this was also a situation of tremendous potential for developing completely new concepts of musical form without the shackles of historical reference. In short, music was looked at from a completely different perspective. This perspective was influenced to a surprising degree by models borrowed from the sciences, affecting both the analytical and the compositional means of formalizing musical structures[99]. However, throughout the development of this new outlook, one problem was persistent: that of musical form.

When approaching the elusive concept of form in musical works, one needs an analytical or compositional perspective which allows a clear differentiation between all structural levels involved, as the first step to any investigation. Once these structural levels are identified, structural network dependencies can be examined in a proper and meaningful way, in order to relate the musical material back to the entirety of the musical work under investigation. Music is an expression of human nature and, when encoded in the formal proportions of an artifact, and music reflects a strong affinity to human perceptual facilities. This makes sense, as music would otherwise not be comprehensible to

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[98]In post-war Germany, Stockhausen considered this situation as "tabula rasa", a situation without any point of reference.

[99]Elaborating on the relationship between composer and machine, Wilrich Hoffmann has demonstrated how the over-extension of scientific theories into music has caused considerable problems regarding the proper adaptation of means from one system to another during the 1950s. Wilrich Hoffmann: "Komponist und Technik - Die Bedeutung naturwissenschaftlicher Forschung fur die Musik", Schriftenreihe 'Musik und Gesellschaft, Vol. 15, Kurt Blaukopf, Ed., G. Braun, Karlsruhe, 1976, p. 50.

human beings. A composer can address human perceptual facilities only within the boundaries of acoustic communication that are accessible to the human ear and mind. In fact, psychoacoustic studies have revealed that it is not so much the human ear as the neurological processes involved in "hearing" which confine human perception of acoustical artifacts, and this to a surprising degree. Music would not be comprehensible to human perceptual facilities, if it were perceived in terms of space and time only: it would only represent an endless stream of linear acoustical information without contextual dependencies between acoustical events. Memory is what ultimately allows the detection of these dependencies between events, as well as the identification of time-related musical structures as part of a larger patterning process to be summarized in a time-related projection, which creates the impression of musical form.

However, the neural capabilities of the human ear, in combination with those idiosyncrasies of human memory which are involved in the process of listening, show distinct characteristics in how acoustical messages are automatically categorized into three distinct levels of perception: (1) Immediacy (frequency spectrum from 16 KHz to 20 Hz), (2) Present-time awareness (frequency/event spectrum from below 20 Hz to 0.1 Hz[100]), and (3) Memory-related awareness (event spectrum from 10 seconds up to minutes and hours in exponentially decreasing relation). It is surprising to find that musical structures, in fact, clearly reflect these perceptual differentiations: variations in pitch relate to class (1), duration/rhythm to class (2), and aspects of the overall proportions of a musical work are reflected mainly in class (3), with a distinct overlap into class (2) regarding motives, themes, formal segments, etc. Henceforth,

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[100]This is equivalent to a 10 second duration.

I shall refer to these classes as the levels of (1) Micro-structure, (2) Macro-structure, and (3) Form-structure.[101]

However, how are musical structures generated? What are the processes supporting not only the generation of musical textures within each of the three structural levels, but also the way they are connected to give a musical work a homogeneous character? Without going into further detail, it is sufficient to recognize that it is not only necessary to establish a means of structural correlation between events on each of the three levels, but also to ensure that the envisioned structures are self-sufficient. Piaget once defined a structure as a system of transformations of a finite-scheme of a collection of elements and their properties, this system being of a dynamic nature through the involvement of laws. The structure itself is considered self-regulating in that it creates its own structural identity through the internal interplay of transformation laws affecting the distribution of the musical material. The discovery of structures then leads to their formalization through a theoretical system capable of representing structural order and musical material. The type of formalization depends on the choice of the theoretician, and can take the form of a cybernetic model or of mathematical equations.

Consequently, our investigations regarding the influence of information theory shall, from here on, be conducted from the perspective of how both Hiller and Stockhausen articulated the creation of musical structures

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[101]A. Moles, in: "Eine Informationstheorie der Musik", has provided a similar scheme of structural levels according to the above model. However, his illustration incorporates both the aesthetic and the syntactic part of a musical message. To be found in: Abraham Moles, "Eine Informationstheorie der Musik", Nachrichtentechnische Fachberichte, Vol. 3, July 1956, p. 52.

on all three formal levels by means of this theory. Both composers exerted a significant influence on the development of electronic music composition, Hiller focusing especially on the generative aspects of procedural composition with computers, Stockhausen on the development of processes transforming serial patterning into statistical form. Both developments can be directly combined to overcome the crisis of form in the 20th century, which has been commonly tackled from the angle of rule-based compositional design.

3. The Influence of Information Theory in the 1950s

Why, then, did both composers resort to information theory? What made this purely mathematical theory so attractive as to be applied in certain fields of the Arts which seemed to have nothing to do with mathematics or with other scientific applications? And in particular, how could such a mathematically demanding and complex scientific concept be meaningfully applied in the field of music? Did information theory possess a special affinity to the applications involved, or was it just a new fad? How appropriately had information theory been adapted to the field of music? What happened to information theory in the 1950s?

We have already seen in Chapter I that, during the 1950s, some of the most prominent scientists had been engrossed with the application of this new theory in their particular disciplines because they felt that it had a definite intuitive appeal. Reflecting on the use of information theory in the 1950s, J. E. Cohen wrote, in 1966:

> Born of papers by Claude Shannon and the book, *Cybernetics*, by Norbert Wiener, information theory looked then like a young man in a very great hurry who jumped on his horse and rode off in all directions. Standard-bearers of information theory were plunging

> into genetics, neurophysiology, sociology, experimental psychology, linguistics, and philosophy with great enthusiasm and greater hopes. Many problems that had long resisted even adequate formulation seemed about to succumb to information theory.[102]

However, in his conclusion, E. Cohen went on to state that, although information theory seems to have

> . . .stimulated a great deal of highly imaginative and occasionally fruitful analysis in fields other than communication engineering . . . many standard-bearers of information theory either have retreated from their interdisciplinary forays or, sticking with difficult problems, have exchanged information theory for other weapons."[103]

It is beyond the scope of this dissertation to discuss the reasons why information theory, in the end, failed to meet the expectations it created in the 1950s. However, what will have to be discussed is the peculiar kind of relationship between music and information theory as it was proposed by the composers resorting to its use. In this regard especially, the ramifications and implications of matching both systems through an appropriate interface or communication device will have to be investigated. In other words, if a composer utilizes information theory as a means to assist compositional strategies, we can expect at least some reasoning as to why the proposed interaction between both systems was considered beneficial.

F. Winckel, in his book Music, Sound, and Sensation,[104] depicts the process of communication between

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[102]Joel E. Cohen, translator's preface to: A. Moles, Information Theory and Esthetic Perception, transl. Joel E. Cohen, University of Illinois Press, Urbana and London, 1966.

[103]Cohen, op. cit., foreword.

[104]Fritz Winkel: Music, Sound and Sensation: A Modern Exposition, Dover, New York, 1967, p. 45.

human beings as an operation which could be expressed entirely in terms of information theory.[105]
Even if Winckel's scheme grossly over-simplifies the true level of complexity inherent in communication processes of this particular sort, it leaves a clear message regarding the capability that information theory was invested with in the 1950s, encompassing such interdisciplinary fields as music, physics, and biology[106]. I would like to supply two additional statements of this sort, related to the above illustration in a similar manner:

> Information theory is charged to access the communication between human beings which manifests itself as an exchange of signs, or to assist a human's investigation of the world, which amounts to observation, accessible to quantitative and structural registration.[107]

In fact, only a small segment of Winckel's illustration actually relates to information theory as Shannon devised it, but this is exactly the crux of the matter: during this period, many enthusiasts invested information theory with a potential it was never intended to realize. Nevertheless, most applications of information theory outside the margins which were clearly defined by Shannon did exactly this, and

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[105]See Fig. 3. in the appendix.

[106]H. Fack: "Informationstheoretische Behandlung des Gehors", in Impulstechnik, F. Winckel, Ed., Springer, Berlin, 1956. This thorough study of the treatment of the perceptual facilities of the human ear in terms of information theory has been conducted by H. Fack. It is important to note that Fack addresses especially the physiological facilities of the human ear, which he could demonstrate to be capable of processing a much greater amount of information than what ultimately arrives at the level of perceptual awareness, after having passed through the neural network between the ear and human brain.

[107]Max Bense: "Philosophie der Technik", Physikalische Blaetter. 10, p.481-485, 1954.

music was not an exception: some applications in music were carefully justified, others were found to involve "experiments" without much regard to scientific rigor. In order to steer clear of these problems, it will be necessary to find out if the results obtained were within the valid margins of this theory.

4. Information Theory and the Syntactic Study of Music

Weaver stated that information theory could be applied to the study of art, but it was R. C. Pinkerton,[108] W. Meyer-Eppler,[109] and A. Moles[110] who proposed to use this theory in the study of music as well. A. Moles has in fact demonstrated that the structural relations inherent in a piece of art could be divided into two classes: (1) syntactical (and/or internal) relations (Moles calls this "semantic information"), and (2) non-syntactical (or external) relations understood as "aesthetic information").[111]

In music, the first class includes properties which are unique to the medium of the aesthetic object, for example,

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[108]Richard C. Pinkerton: "Information Theory and Melody", Scientific Am^rican vol. 194, Feb. 1956, p. 80. Pinkerton's subtitle starts out with the question " . . . what is it about simple melodies that makes them so widely appealing?" Pinkerton continues: "By considering music as a form of communication such questions can now be discussed in mathematical terms." Pinkerton, p. 77.

[109]Meyer-Eppler, W: Grundlagen und Anwendungen der Informationstheorie, Springer, Berlin, New York, 1959.

[110]Moles, Abraham A.: Information Theory and Aesthetic Perception, University of Illinois Press, Urbana, 1965.

[111]See Fig. 4. in the appendix.

pitch, harmony, rhythm, timbre, melodic contour, instrumentation, form, and so on. The second class includes meaning, emotion, aesthetic values, and other similar commodities not included in class (1). If the ultimate goal of a syntactic study of music is to understand how music communicates, it should be taken as an advantage to know that the results of a syntactic study can be validated by the internal relationships of a musical structure alone, without the interference of external relations (cultural noise). Regarding the validity of this application of information theory, we have learned already, in Chapter I, that the syntactic approach was considered by Shannon to be the only viable one. In other words, to obtain a proper correlation of music and information theory, it would be helpful to establish a valid connection between both communication systems: a more useful framework or common meta-language had to be found. Shannon related his studies of communication to semiotics, the theory of signs. Fortunately, this framework fits easily with music, as long as we consider music to be a stochastic source of discrete events with a limited alphabet. Referring back to F. Winckel's diagram of the transmission of acoustic information, it becomes evident that the functionality of this communication chain depends entirely on the efficiency of the transmission of signs. In fact, each of the participating segments of the communication chain forms its own interconnected system of signs, correlated closely with the neighboring segment within the communication chain.

Without going into further detail at this time, the question of musical score representation and actual sonic realization will have to be briefly addressed to avoid misunderstandings of the application of information theory. Psychological and physiological studies have investigated human perceptual facilities and found them to consist of a limited "alphabet".[112] In a sense, the score of a piece of music is considered to possess a certain "degree of liberty" in that it suggests what pitch, tone color, duration etc. a performer is supposed to play, but we have all experienced situations where the printed instructions had only been approximated by the performer. This didn't mean that we could not recognize the piece anymore, but that we could agree to a certain amount of "flexibility of interpretation or comprehensibility". In this case, musical notation would represent merely a "cultural alphabet", a set of culturally significant sounds. An analogy would be found in the phonemes of spoken languages. What happens then during the listening process? J. E. Cohen stated that:

> "Flexible mappings relate the physical, psychological, and cultural sign systems of music. These dynamic mappings change constantly [during] the listening process. Mathematically, since a many-one mapping applied to the psychological sign system gives a structure isomorphic to the cultural system, the cultural sign system (the score) is a homomorphism of the psychological sign system".[113]

In other words, during the perception of music, there is an overlapping of co-existing levels of measurable, physical

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[112]For example, in psycho-acoustical terms, within the full audible spectrum, only 1200 distinct pitch levels can be distinguished by the human ear, and this only at a certain dynamic level, beyond which the number of recognizable pitches falls considerably. The same is true for dynamic levels: only about 100 can be distinguished; again, only within a certain realm of pitches, beyond which the number decreases as well. However, physically, the alphabet has to be considered much larger, as many sound combinations that are physically different in their composition are perceived psychologically as being the same: they are called "Metameric", according to Meyer-Eppler "Statistische und psychologische Klangprobleme", Die Reihe, No. 1: "Elektronische Musik", 1954, p. 59.

[113]Joel E. Cohen: "Information Theory and Music", Behavioral Science, Vol. 7, 1962, p. 139.

properties, and an idealized, abstract level of a psychological nature. This represents an interesting situation of which we are mostly unaware when we listen to music. However, the scope of this dissertation does not allow for further discussion on this topic, as it was clearly indicated that valid applications of information theory in music can be related only to an investigation of its syntactic properties.

a) Information Content as Applied to Music

According to Attneave, "perhaps the most fundamental concept of information theory is that of a continuum spanning the spectrum from extreme lawfulness, or redundancy, or regularity on one hand, to extreme disorder, or unpredictability, or uncertainty on the other".[114] One end of the spectrum constitutes homogeneity, the other utter chaos. Artifacts of aesthetic value lie somewhere in between these two extremes. In the production of works of art, many different qualitative approaches can be taken, leading from the chaotic to the homogeneous. However, in most cases, strategies that are highly dependent on properties of structural complexity or uncertainty have to be applied.

Information theory, on the other hand, provides the means to quantify the variable of structural complexity in precise, mathematical terms. The syntactical structure of a musical work might therefore be described in a completely systematic and quantitative manner, involving the concepts of information content, entropy, and degree of redundancy. However, a few conditions have to be met before information theory can be applied with confidence to the field of music.

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[114]Fred Attneave: "Stochastic Composition Processes", Journal of Aesthetics and Art Criticism, 17(4), June 1959, p. 503.

According to Kraehenbuehl and Coons,[115] information theory requires the establishment of a probability system which is relatively constant, and event-orders under consideration must possess a number of specific qualities: (1) no event is allowed to occur which is not part of the alphabet, or repertoire specified before; (2) any given event will occur with the same frequency in any large sample of the same size; (3) the occurrence of any given event will always be restricted in the same manner by any selected event-order which may precede it.

In order for the probability system to be of any predictable value, the following conditions applied to the above sets of events also have to be fulfilled: the source emitting the events is (a) truly stochastic; (b) ergodic; and (c) consistent with regard to Markov properties in that ensuing events do not perturb the above conditions of event-order consistency. We have seen, in Chapter I, that the majority of such conditions can be validated only as assumptions (regarding the validity of sources in terms of their ergodic nature), simply because we would require ideally an infinitely large amount of data or an infinite time period of observation to prove the true ergodicity of a source of information. Often, a musical composition, even in its entire length, does not, in fact, provide sufficient data to make such predictions with certainty. However, because these conditions will never be completely met, we are allowed to say at least that they are approximately true, and carefully base the measurement of information content, in terms related to information theory, on a limited set of events. This is exactly what Shannon did in his definition of information theory, encompassing both

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[115]David Kraehenbuehl, and Edgar Coons: "Information Measure of the Experience of Music", Journal of Aesthetics and Art Criticism, 17(4), June 1959, p. 511.

discrete sources with finite alphabets of information, and the information content of continuous wave forms. Providing that music can be represented as a finite scheme of "events", for example, a score, this system could be applied to music as long as the application of information theory was strictly limited to syntactic properties, and as long as the musical sample to be investigated was of sufficiently large size.

b) Music as a Stochastic Source

Besides traditional notational systems, some 20th century music representations refer to formal symbolic specifications used by a computer system to capture musical structure. Numerous types of musical representations of this type have been developed since the 1950s and can be distinguished today, encompassing concepts of "Predicate Calculus",[116] "Set Theory",[117] "Simple Encoding

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[116]According to C. Roads, Predicate Calculus is a system based on binary relations in which statements are either "true" or "false". Simple expressions in the predicate calculus are formed by applying "predicates" to "variables" as in the expression: *E* X. Note(X) > Pitch-C(X) > Loud(X) ; where *Note*, *Pitch-C*, and *Loud* are predicates, meaning <<is a note>>, <<has pitch>>, and <<is loud>>, *X* is a variable standing for an event. Hence we have expressed <<There is an event X that is a note, has pitch C and is loud>> with this little expression. This system has been used by Rothenberg (1975) in "A Nonprocedural Language for Musical Composition", Proceedings of the Second Annual Music Computer Conference, Part 2: Composition with Computers, ed. by J. Beauchamp and J. Melby, Urbana, University of Illinois. It should be added that Set Theory was restricted to the analysis and generation of pitch complexes in Post-Webern musics.

[117]According to Curtis Roads, Set Theory is a related system built out of the predicate calculus. Set theory has been applied to the study of music by Allen Forte, who developed *set complex theory* as a way of looking at atonal music. Set theory has also been used as a "foundation" for the

Programs",[118] "Stochastic Processes,[119] "Systems

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theory of twelve-tone music composition by Babbitt. Motivated by the ideals of the philosophy of logical positivism, Babbitt has proposed set theory as the foundation for a scientific theory of music.

[118]According to Curtis Roads, numerous music encoding languages have been developed for musicological and compositional purposes, for example: "Music V" (Mathews 1969), and "Score" (L. Smith 1972). Both programs address interfacing compositional ideas and computer sound synthesis.

[119]Stochastic Processes have become very popular in music composition since Shannon's and Weaver's formulation of information theory (1949). According to Curtis Roads, this theory was adopted by many scholars as a heuristic for explaining problems in philosophy and aesthetics (Moles 1968). Most of the early researchers in computer-assisted music composition drew on an information theory perspective (Hiller & Isaacson 1959; Barbaud 1968; Xenakis 1971). After drawing an analogy to music, an information theory approach to music became popular in the 1950s and 1960s, in the papers of Moles, Hiller, and others. Stochastic processes are quite useful as representations of cloud-like event formations found in contemporary "sound-mass" music (e.g., some pieces by Xenakis, Ligeti, Penderecki, etc.). Inside computers, stochastic processes are represented as procedures which reference stored probability tables.

Theory",[120] and "Grammars",[121] to name just a few. Curtis Roads explains their coming to existence as follows:

> A main goal of developing more effective representations for music is to improve musician-machine communication, replacing the current rigid protocols and shallow user-interfaces with deeper and richer dialogues.[122]

In our context, music representations in the form of "Stochastic Processes" are the most interesting as they

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[120]Systems Theory focuses on the issue of control regarding how several pieces of automated musical composition are interconnected. Control is exerted through variables which can be interrelated in a variety of ways, including a conditional interconnectedness between automated procedures which, in turn, can be perceived as representing the behavior of a musical variable. Systems theory has been applied for example, by Chadabe (1977).

[121]Grammars have become popular since the modern generative grammar movement was started by Noam Chomsky (Syntactic Structures, The Hague, Mouton, 1957). In principle, Chomsky was able to distinguish four grammar types: (Type 0: FREE), (Type 1: Context-sensitive), (Type 2: Context-free), (Type 3: regular or Finite-state). All of these types of grammar allow specific kinds of "rewrite rules" of the form A -> B, where A (a higher-level syntactic unit) generates B (a lower-level syntactic unit). In music, relevant studies have been undertaken by C. Roads, Fred Lehrdahl & Ray Jackendorff A Generative Theory of Tonal Music, and O. Laske, especially in his article "In Search of a Generative Grammar for Music". Laske stated that the "idea of a generative grammar for music is the outcome of research geared toward the formulation of a system, or set of rules, capable of rewriting the sequence of mental representations (of sound structures) which are assumed to underlay the execution of activities called music". In: Otto Laske, "In Search of a Generative Grammar for Music", Perspectives of New Music, Spring/Summer 1984, p. 351.

[122]Curtis Roads: "An Overview of Music Representations", in: Musical Grammars and Computer Analysis, Leo S. Olschki, Firenze, 1984, p. 7.

proved to be the most appropriate in the attempt to approach music composition by means of computer automation. Or, if a musical score can then be understood as consisting of sequences of discrete cultural symbols, the theory of discrete sources with finite alphabets borrowed from information theory could be applied in the analysis of musical structures. In both cases, musical processes can be understood as a stochastic process, represented by Markov chain processes: musical information is gained or encoded while the Markov chain moves one musical event ahead. The amount of information conveyed would solely depend on the number of n-th order structural dependencies of the musical material involved in this process, the average amount of these sequential dependencies being solely determined by the number of different musical symbols in the alphabet.

c) Music as a Markov Chain Process

Every composer is initially confronted with the problem of choice. Since the acoustical alphabet of a human being comprises a very large number of distinguishable events, a composer's task is, at first, to select the alphabet of signs with which he or she plans to work. Until the arrival of electronic music composition, music of the Western tradition has restricted itself to a rather meager repertoire of about 100 pitches, 9 relative degrees of loudness, and a certain number of possible events within the art of instrumentation. Compared with such limited material, which proved to be sufficient until the beginning of the 20th century, the demands faced by a composer working in the field of electronic music, in terms of governing an immensely increased number of possible events, become overwhelming.

In fact, it is this process of selecting among available possibilities and of imposing some sort of order that characterizes the process of composing, considering the sheer vastness of possibilities, some kind of process of selection of musical material has to be provided. In this case, the generation of musical texture would depend solely on compositional choices made during the process of selection and networking of musical material through syntactical **dependencies** between musical parameters (pitch, duration, etc.) specified by the composer. Thus, the degree of selectivity leaves a distinctive trace of the composer's intention within the compositional structure, often labelled as musical style. Stylistic features of a musical work can therefore be regarded as being imbedded within the structural properties of a musical work. This, in turn, points to the fact that syntactical dependencies of a given structural entity can be expressed quantitatively by tables of probabilities which reflect the statistical data related to style. In other words, if musical compositions are considered as Markov chains, musical style could be expressed by properties affecting the redundancy or structural order of a musical work. All that must be done to justify an application of this sort is to demonstrate that the musical sign system investigated is, in fact, a Markov chain:

> Styles in music are basically complex systems of probability relationships in which the meaning of any term or series of terms depends upon its relationship with all other terms possible within the style system.[123]

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[123]Leonard B. Meyer: Emotion and Meaning in Music, Chicago: University of Chicago Press, 1956, p. 54.

The style, and therefore also the idiosyncrasies of the probability system employed, are manifested in the form of a sign system, presented as a musical score.

5. Methods of Application of Information Theory in Music

In the field of music, three principal approaches to applications of information theory were developed during the 1950s: (1) the analytical approach, (2) the analytic-synthetic approach, (3) the synthetic approach. Each of them has involved information theory to varying degrees, and will be described briefly below in order to complete our survey of the applications of information theory in the 1950s. However, afterwards we will investigate only the synthetic (or compositional) approach in greater detail, as this is the one which essentially reveals the influence of information theory on musical composition. The selection of examples will be mainly restricted to a repertoire of works which had some historical relevance to the birth of computer music, in particular the work of Lejaren A. Hiller.

a) The Analytic Approach

F. Hegel, in his essays on aesthetics, concluded that ultimately matters of aesthetics in the world of art could only be grasped in statistical terms, each particular work of art being solely associated with a "virtual" reality. Although, for obvious reasons, his statement could not have a significant impact on the body of 19th century aesthetics, it becomes increasingly important as the 20th century unfolds with the assimilation of scientific models in the field of art production. Noteworthy studies in aesthetics and statistics include the work of G.D. Birkhoff (1932),[124] who correlated aesthetic perception with Hartley's theorem concerning the statistical information content of messages. During the 1950s, this foundation was expanded by Max Bense, who developed a strong analytical approach to apply information theory to topics related to aesthetics, including music.[125] In fact, investigations of statistical properties were the seed primarily responsible for spawning the analytical applications of information theory in music.

Similar to Birkhoff's applications in the general arts, a pre-information theory statistical analysis of musical works can be found in Schillinger's "Mathematical Basis of the Arts" (1948). The first application of information theory in music analysis was conducted by Zipf (1949),[126] who investigated the soloist's line in Mozart's Bassoon Concerto K. 191. He was able to demonstrate the existence of linear inverse relations between the frequency of an interval and its size, both for descending and ascending

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[124] George Birkhoff: "A Mathematical Approach to Aesthetics", The Rice Institute Pamphlet, 1932, Vol. 19, pp. 189-342. Birkhoff's investigations were clearly drawing their foundations from the work of Hermann Helmholtz, Gustav T. Fechner, as well as Edgar Alan Poe and James J. Sylvester.

[125] Max Bense: Zeichen und Design, Agis Verlag, Baden-Baden, 1971. Max Bense's research has been a fundamental contribution to the application of information theory in aesthetics, founding the "Stuttgart School" of information aesthetics in Germany. Drawing from research conducted by Birkhoff, Shannon and Moles, Bense developed a new view of compositional design, applied to the arts and industrial production processes from the angle of information theory. Bense's publication "Sign and Design" has been influential in this dissertation regarding the application of information theory to disciplines other than music.

[126] G. K. Zipf: Human Behavior and The Principle of Least Effort, Cambridge, Mass., Addison-Wesley, 1949, p. 336.

intervals, and for both types combined. In fact, large intervals were less probable than small intervals. To his surprise, he found analogous distributions in selected works of Chopin and Irving Berlin. In other words, the standard tonal repertoire seems to prefer a similar statistical distribution of intervals. This is one of the reasons why Hiller and Isaacson, in their Markov chain music for the ILLIAC SUITE, have approximated Zipf's distribution of intervals in their "proximity function": they attempted to simulate a "standard" distribution of pitches, according to a main-stream repertoire. Hiller, in collaboration with C. Bean, has conducted information theory-based analyses of four sonata expositions[127] (1966) as well.

An information theory-based analysis of musical style has been performed by J.E. Youngblood,[128] who investigated the statistical aspects of style in a group of selected songs by Schubert,[129] Mendelssohn,[130] and Schumann.[131] Youngblood attempted to "explore the usefulness of

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[127] L. A. Hiller, and C. Bean: "Information Theory Analyses of Four Sonata Expositions", Journal of Music Theory, vol.10, 1966, pp. 99-117. Calvin Bean had formerly worked with information theory and music analysis in his Information Theory Applied to the analysis of a Particular Formal Process in Tonal Music: Concerto Grosso for Flute, Oboe, Clarinet, and Bassoon, and small Orchestra, D.M.A. 1961, University of Illinois at Urbana-Champaign, vol. 22/6 DAI.

[128] J. E. Youngblood: "Style as Information", Journal of Music Theory, 2:24, 1958.

[129] Franz Schubert, from "Die schöne Müllerin".

[130] Felix Mendelssohn-Bartholdy, from "St. Paul".

[131] Robert Schumann, from "Frauenliebe und Leben".

information theory as a method of identifying and defining musical styles".[132] He found Mendelssohn's songs to be syntactically the most redundant, Schubert's and Schumann's less so. Afterwards, he stated that information theory could be used to "measure the constraints under which various composers and groups of composers worked, and can furnish us with figures with which we can more accurately and more meaningfully describe the styles".[133]

The most thorough analyses in terms of information theory have been performed by W. Fucks, R. Mix,[134] and W.

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[132]J. E. Youngblood: "Style as Information", Journal of Music Theory, 2:24, 1958, p. 14.

[133]J. E. Youngblood. "Style as Information", Journal of Music Theory, 2:24, 1958, p. 18.

[134]Drawing from research by W. Fucks, Roland Mix focused his investigation on the decrease of entropy through dependencies between several simultaneous information sources, in association with an increase of m-th order Markov chain processes. Mix compared string quartets by Schönberg and Haydn by means of 1st order Markov process analysis, followed by an investigation of the differences in structural order between three string quartets by Haydn, performed as a higher-order Markov process analysis. While Fucks and all other authors investigated only single voices in selected works, Mix' approach, involving the application of information theory research to simultaneous sources of information (in this case, full-size string quartets) reflected a more complex and realistic method. The results provide interesting stylistic details. For example, Mix could show that while the information-content in Schönberg's quartets is significantly higher than in Haydn's, the dependencies between instruments within the same quartet are higher in Haydn's string quartets than in Schönberg's. In: Roland Mix: "Die Entropieabnahme bei Abhängigkeit zwischen mehreren simultanen Informationsquellen und bei Übergang zu Markoff-Ketten höherer Ordnung, untersucht an musikalischen Beispielen", Forschungsbericht des Landes Nordrhein-Westfalen, No. 124, Westdeutscher Verlag, Köln und Opladen, 1967, pp. 41-80.

Reckziegel,[135] who resorted to the use of computers in order to be able to cope with the extensive volume of data to be processed.[136] Fucks made extensive use of mathematical tools in information theory-based analysis, which clearly set him apart from most other authors in this area. In fact, this can be compared with the distinctive contribution made by Xenakis, who integrated mathematics in his compositional design.[137] Fucks conducted an investigation which included the application of information theory-based study in speech and music,[138] with the latter

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[135]Walter Reckziegel: Theorien zur Formanalyse mehrstimmiger Musik, Westdeutscher Verlag, Köln und Opladen, 1967, pp. 9-37. Using an approach similar to the analyses conducted by Mix, but not as complex mathematically, Reckziegel performed an information theory based structural analysis of four multi-voiced musical structures from Palestrina to Stravinsky. It is interesting to note his results regarding an increase in the statistical density of textural design observed in ascending order from Palestrina to Stravinsky, especially from the viewpoint of including the polyphonic design into the computations, which had not been done before.

[136]However, R. F. Erickson stresses "that a computer may not produce a faster solution to a given problem; rather, its unique value is in broadening the range of problems that can be posed and solved". In Raymond F. Erickson, "Musical Analysis and the Computer: A report on some current approaches and the outlook for the future", Computers and the Humanities, Vol. 3, No. 2, Nov. 1968, p. 89.

[137]See also: Iannis Xenakis: "Free Stochastic Music from the Computer: The paradox - music and computers; using the IBM 7090 computer to compose music", Gravesaner Blatter, 7:26, 1965, pp. 79-92. Interestingly, this article is directly followed in the same publication by W. Meyer-Eppler's essay "Informationstheoretische Probleme der musikalischen Kommunikation".

[138]W. Fucks: "Mathematische Analyse der Formalstruktur von Musik", Forschungsbericht des Landes Nordrhein-Westfalen, No. 357, Deutscher Verlag, Köln, 1958.

being the most prominent. His analyses include the tabulation of musical style according to the statistical distributions of single musical parameters from a selected repertoire of the 16th to the 20th century. The statistical data compounded does in fact reflect a clear relationship between the pattern of distribution and the degree of correlation[139] with the concept of tonality[140].

Even more interesting is how Fucks described the correlation of the entropy of the mean variation in pitch distribution (*S*) as a function of its historical origin (*t*): 29 1st violin parts of representative works of Western music were investigated.[141] The following figure[142] makes a very clear statement regarding the development of the stylistic characteristics of Western music, in that musical examples selected from the same epoch do stay well within a clear demarcation of stylistic features.

_____: "Mathematische Musikanalysen und Randomfolgen", Gravesaner Blätter, 1962, pp. 132-145.

_____: "Über formale Struktureigenschaften musikalische Partituren", in: F. Winckel, Experimentelle Musik, Schriftenreihe der Akademie der Künste, Vol. 7, Mann Verlag, Berlin, 1970.

[139]See Fig. 5. in the appendix.

[140]W. Fucks, and Josef Lauter: "Exaktwissenschaftliche Musikanalyse", Forschungsbericht des Landes Nordrhein-Westfalen, No. 1519, Deutscher Verlag, Köln und Opladen, 1958, p. 14.

[141]W. Fucks: "Über mathematische Musikanalyse", Nachrichten Technische Zeitschrift, 17(2), 1964, p. 43. First presented as a research paper at the NTG conference "Informationstheorie", April 5, 1963, Stuttgart.

[142]See Fig. 6. in the appendix.

Finally, Fucks calculated the transitional probabilities between pitches in Beethoven's String Quartet op. 74[143] with Webern's String Trio op. 20.[144] It is obvious, that Webern's distribution of transitional probabilities is more random than Beethoven's. A criticism could be that, in principle, nothing had been added which we could not have learned already from other types of stylistic analysis. This is true, as Fucks used only musical material which was accessible through a musical score. However, what is new and advantageous in analysis based on information theory is its ability to quantify these syntactic relationships in exact scientific terms. This, of course, is exactly what is considered a minimum and mandatory condition for adequately codifying musical style into a computer program designed to create similar musical artifacts. In other words, the benefit of information theory-based analysis gains significance in context with applications of information theory in music synthesis.

b) The Analytic-Synthetic Approach

The analytic-synthetic approach stresses the statistical investigation of homogeneous bodies of existing musical works first, in order to obtain matrices of transitional probabilities in musical parameters. These matrices would then be used to generate musical samples, assisting the selection of musical material according to the transitional

[143]Wilhelm Fucks: "Über formale Struktureigenschaften musikalische Partituren", in F. Winckel, Experimentelle Musik, Schriftenreihe der Akademie der Künste, Vol. 7, Mann Verlag, Berlin, 1970, pp. 48-49. The figures are actually reproduced from charts first published in: W. Fucks: "Über mathematische Musikanalyse", Nachrichten Technische Zeitschrift, 17(2), 1964, pp. 45-46.

[144]See Fig. 7. in the appendix.

probabilities just obtained. Procedures of this sort would also indicate the order of analysis, meaning the size of the m-gram dependencies considered. The choice of the order of analysis would also influence the degree of structural resemblance to the original music sample from which the transitional probabilities were computed. In other words, stylistic considerations, coded as probability matrices, would be fed into the input of a compositional device, directly affecting its textural output.

The first analytic-synthetic application of information theory to music took place in 1955. According to Quastler,[145] Fred and Carolyn Attneave determined the first-order transitional probabilities of Western cowboy songs. A Markov chain, equipped with the proper transitional probabilities, was created and, after arbitrarily selecting a standard form and rhythm, several melodies were produced by random-walking the chain a couple of times. The musical output resembled, in fact, the standard repertoire originally investigated.

Another approach of this sort was used by Pinkerton (1956).[146] He pursued experiments on the assembly of nursery tunes by means of his "banal tune maker", involving a simple matrix of transitional probabilities regarding pitch selection, derived from statistical data collected from 39 selected nursery tunes transposed to C. Assigning probability values to the seven tones of the diatonic scale as well as to the placement of a rest or hold, he computed a

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[145]H. Quastler: Discussion following "Mathematical theory of Word Formation", by W. Fucks. In: E. C. Cherry, Ed., Information Theory - Third London Symposium, New York: Academic Press, 1955, p. 168.

[146]Richard C. Pinkerton: "Information Theory and Melody," Scientific American, vol. 194, Feb. 1956, p. 77.

melodic redundancy R_1 of nine per cent. Afterwards, rhythmic redundancy was introduced by constructing six transitional matrices related to each of the possible positions of an 8th note within 6/8 time. A circular pattern of "most probable binary choices" was created by selecting either the single most probable or the two most probable transitions out of each of the six transition tables. Since this circular pattern proved to be hardly more inventive than a music box, it was called a "banal tune maker".[147] Again, first-order Markov chain procedures were employed to synthesize melodic samples, using a deck of twelve appropriately marked cards as a random source from which to select the musical material. Pinkerton's scheme (see Figure 8 in the appendix) works as follows: a simple melody is created by following the line in the direction of the arrow. Notes are recorded appropriately. If a node is encountered, the flipping of a coin will determine which direction to follow next. The reader is encouraged to test this system accordingly...[148]

Pinkerton's technique was used soon thereafter by Sowa (1956), who built a machine imitating Pinkerton's scheme, but with more complex musical textures, which he obtained from analyzing pedagogical pieces for the piano. Again the principle of Markov chain processes was used. Later studies were conducted by Havass (1964), who simulated the process of composing folk music by means of a computer as well.[149]

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[147]Pinkerton found that, because of the binary choice restrictions, this device was about 63 percent redundant. This is considerably more than the value of 9 percent, found in the samples originally analyzed.

[148]See Fig. 8. in the appendix.

[149]M. Havass: "A Simulation of Musical Composition Synthetically Composed Folk Music", Computational Linguistics, Vol. 3, 1964, Budapest, pp. 107-127.

Similar experiments were performed by Brooks, Hopkins, Neumann, and Wright.[150] The latter included calculations of transitional probabilities up to the 8th order.[151] The purpose of the experiments was not only the creation of nursery tunes,[152] but the analysis of simple melodies from the perspective of information theory. However, because of the computational power required, the experiments were not performed by hand, but with an automated computer system. The automated composition of melodies was achieved as follows: the melodies of 37 hymns, by various composers, were entered in computer memory for subsequent statistical analysis, all of them having the same metric structure. During the ensuing computations, the probabilities of the various combinations of rows of five notes in all selected songs were determined and recorded into memory. The next stage involved the synthesis of new melodies from all existing five-note combinations according to the following principle: combinations were selected in such a way that the first four notes of each new combination fitted in with the

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[150]F. P. Brooks, Jr., A. L. Hopkins, Jr., P. G. Neumann, and W. V. Wright: "An Experiment in Musical Composition," <u>IRE Trans. on Electronic Computers</u>, EC-6:175, 1957.

[151]In fact, it appeared that transitional probabilities beyond the third to fifth order would not produce better music but would start to hamper the freedom of melodic development by excluding the fluctuating transitions which are often recognized as "creative" in existing examples of written music.

[152]According to Neumann, about 6000 melodies were begun by the computer, and a new batch of 600 melodies was generated after performing a statistical analysis of 37 different standard melodies. The procedure consisted of successively generating samples by means of first-order to eighth-order Markoff processes. In: P. G. Neumann, and H. Schappert, "Komponieren mit elektronischen Rechenautomaten", <u>Nachrichtentechnische Zeitschrift</u>, 12 (8), 1959, p. 406.

four last notes of an already assembled section of the melody. This process was assisted by means of frequency tables which had been previously calculated. The whole process would then move on so that the fifth note contained in the last selected segment would represent a new, additional note of the new melody, moving the entire process one step further. After that, the entire process would continue as before: the last four notes of the new melodic line would again be subjected to a comparison with existing conglomerates from the pool of formerly selected melodic samples, the last note selected now becoming note number four. These experiments can certainly be considered some of the more sophisticated works produced. It is interesting to note that the process of selection of musical events was structured according to the "Monte Carlo Method",[153] a very popular method in the application of information theory in music. Since this was also the method extensively used by Hiller in his ILLIAC SUITE it will be discussed later in greater detail.

Finally, Olson and Belar[154] (1961) programmed a computer to "help a composer to create new music by suggesting variations and new tone combinations based on his

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[153]D. McCracken: "Monte Carlo Method", Scientific American, 1955, 192, 5, 90.

[154]It is little known, that Olson and Belar were actually granted U.S. patent 3,007,362 for their "combination random-probability system", an object of which "is to provide an improved method of and means for composing music". The patent was filed for October 1954. In: F. Olson and B. Belar: "Aid to Music Composition Employing a Random Probability System", Journal of the Acoustical Society of America, Vol. 33, No. 9, September 1961, p. 1164.

original ideas".[155] In this case the computer was supplied with properly encoded musical examples of a certain composer's style, which the computer took as a basis to assemble new variations. The coded variations would be decoded directly into musical sound, providing the composer with a direct, audible feedback. An example of the analytic-synthetic approach was created. Finally, in his COMPUTER CANTATA (1963), Hiller achieved a flexibility in programming the analytic-synthetic approach which represented a new milestone in the development of automated composition by means of information theory. This will be investigated later in detail.

Because most of the above experiments produced only an unarticulated string of numbers as an output, which had to be converted into simple monodic melodies, it was felt that the melodic redundancy introduced by the note probabilities was not sufficient to create comprehensible musical products. A partial solution here was to introduce rhythmic redundancy through metric constraints. Regarding the degree to which information theory was used, it is interesting to note that only some of the above examples used measures of information-content and redundancy. In other words, the operational techniques of information theory could be used in view of a communication process based on probabilities, but, in this case, this was done without applying the formula for information content.

c) The Synthetic Approach

In terms of method, synthetic applications of information theory to music represent merely the second half

[155]As quoted in J. E. Cohen "Information Theory and Music", op. cit., p. 145.

of the analytic-synthetic process which we discussed previously. However, except for serious examples of analytical studies such as those of Fucks, it is the synthetic approach which has been most thoroughly researched through experimental methods. It is this topic which is at the heart of this dissertation, as the synthetic approach to studies in generating music makes the most conscious use of information theory. According to Ashby (1956), a random source could be used to generate all possibilities of events,[156] the random events could then be passed through a selecting device. If composition can be understood as a process of selecting admissible sequences from a source emitting random events, this would imply, in terms of information theory, an imposition of order on a sequence, i.e., introducing redundancy, while reducing information. At the extremes, the possibilities of this spectrum include, on one end, examples of total redundancy versus minimum entropy (silence, or a single sine-tone), and on the other end, an example of maximum possible information content or entropy versus minimum redundancy (white noise). Most musical works can be considered to fall between these two extremes. The formalization of compositional rules could be translated into computer language, producing a device which would act selectively on a sequence of random numbers supplied by the computer itself. This kind of system would lead to the advent of automated composition.

The first experiments with synthetic applications of information theory in computer music were performed by M. Klein and D. Bolitho. They used probability matrices to write simple melodies, using the *Datatron* computer at the

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[156]W. R. Ashby: "Design for an intelligence-amplifier". In C. E. Shannon & J. McCarthy, Eds., Automata Studies, Princeton: Princeton University Press, 1956, pp. 215-234.

ElectroData Division of the Burroughs Corporation.[157] A tune called *Push-Button Bertha* was produced and subsequently recorded and even broadcast.[158] As in the previous experiments, Klein and Bolitho used a method of selecting random numbers according to musical rules coded into arithmetic algorithms: an elementary example of automated synthesis.

Another author, J. R. Pierce, in collaboration with M. E. Shannon, composed examples of stochastic music where common chords were selected in random sequences.[159] A catalogue of "permissible" chords on roots I to VI in the key of C was compiled and brought under the influence of three special dice: sequences of chords were obtained by throwing the dice and using a table of random numbers. An

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[157]"Syncopation by Automation," Data from ElectroData, August, 1956, ElectroData Division of Burroughs Corporation, Pasadena, Calif., pp. 2-3.

[158]*Push Button Bertha* drew comments, one even approaching the subject matter from a rather whimsical point of view: "...the DATATRON, fresh from its activities in the baseball field, launched into the field of popular music. This was done on the supposition that if humans could write miserable music that could become popular, a computer could do it more miserably quicker, thus speeding the evolutionary process. This historic event was recorded for eternity in the words produced by Jack Owens, writer of the Hut-Sut song, for the tune "Push Button Bertha!" And so today we hear from our radios: *She's Push Button Bertha, sweet machine, what a queen. Pay the light bill and you're right, Bill. Ten weight oil makes her loyal*...Music is being further manipulated by Messrs. Smith and Isaacson in the form of string quartets, using a machine known as ILLIAC, which I first though to be a popular presidential intestinal disorder." In: Martin L. Klein, "Uncommon Uses for Common Digital Computers: Computers and Music", Instruments and Automation, vol. 30, Feb. 1957, p. 252.

[159]J. R. Pierce: Electrons, Waves and Messages, Hanover House, Garden City, N.Y., 1956, pp. 271-274.

arbitrarily selected rhythmic structure was added, embedding the obtained strings of pitches into a formal framework. In this instance, we notice a strong resemblance to Mozart's "Musikalisches Würfelspiel".[160] Pierce, also known under the pseudonym J. J. Coupling, provided another example, slightly earlier:

> "J. J. Coupling has discussed stochastic composition of music in 'Science for Art's Sake" in *Astounding Science Fiction*, Nov., 1950. [Similarly] Dr. D. Slepian of Bell [laboratories] experimented with stochastic composition, not using statistics but such ideas of probability as have accumulated in the minds of a group of experimenters. Thus, he had each of a group of men add to a 'composition' after examining only one or more preceding half measures. Tape recordings of the resulting music have been played as a part of a number of talks on information theory."[161]

d) Hiller's Approach: Composition as a Process

One of the most extensive and thorough uses of information theory in musical synthesis, or composition, has been a series of procedural experiments performed by Isaacson and L. A. Hiller. Quickly realizing the serious aesthetic and compositional limitations of the experiments conducted by other authors, Hiller and Isaacson set out to develop a new compositional approach, based on combining relevant concepts of computer programming and of traditional compositional design, which would be correlated by means of information theory. The resulting composition was the

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[160] L. R. von Köchel: Chronologisch-thematisches Werkverzeichnis sämtlicher Tonwerke Wolfgang Amade Mozarts. Ann Arbor: J. W. Edwards, 1947.

[161] J. R. Pierce, letter to Scientific American, 194(4):18, April, 1956, in: Hiller, op. cit., p. 33.

ILLIAC SUITE, consisting of four groups of experiments, expressing an increasing degree of complexity in the compositional application of counterpoint, chromatic 4-part writing (including 12-tone technique), and musical textures based entirely on Markov chain processes in a progressive order. It should be mentioned that, even if only the fourth group of experiments was identified as "Markov chain music" by Hiller, the compositional output of the first three experiments must also be considered as such. However, in this case, the assigned probabilities were either zero (for prohibited sequences), or equal for all permissible choices (random choice).

In principle, Hiller's approach to using information theory in music composition was based on the idea of "extracting order from random chaos"[162] through an arithmetical discarding process involving the sequential selection of musical events: a set of a priori compositional rules was selected as input instructions, and the computer was programmed to sift through the random material in sequential order, accepting only those events which conformed to the rules formerly specified. The computer output was then subjected to an analytical comparison with the musical textures from which the original set of rules had been derived by means of structural analysis. The computer instruction routines involved consisted of the following process: a finite number of random integers would be generated, each integer having been associated beforehand with a particular musical event. These random integers would then be passed through several arithmetic tests, which acted as a "sieve". The structural qualities of this sieve would be entirely determined by the encoded musical rules, which

[162]L. A. Hiller, Jr.,: "The Electrons go around and out come Music", IRE Student Quarterly, Vol. 8, No. 1, Sept. 1961, p. 42.

would or would not allow certain events to pass. Every event rejected by the sieve would be discarded, while the others would go on to a new set of tests and, providing they survived, be incorporated into the final composition by means of a simple transcription process. In other words, a new compositional approach designed according to a rule-based model had been set up.

6. New Formation Concepts

a) Composition Theory

What is composition theory? Laske suggests that:

> Composition theory is a theory of the processes by which imagined (virtual) music becomes materially (sonically) or symbolically (notationally) real. It thus presupposes ways of conceiving music on abstract, 'precompositional' grounds, and the distinction of phases of the compositional life cycle from a compositional idea to its realization.[163]

If Laske's proposed paradigm shift from model-based to rule-based composition can be attributed mainly to procedural advancements in the field of automated electronic composition, my suggestion is that information theory had a distinct influence on the progression of this paradigm shift as well. For obvious reasons, the validity of this statement will be mainly examined in the work of Hiller.

The advent of composing with computers has, in fact, raised many new questions, especially regarding the role of the composer and the fundamental compositional approach to be taken within musical design. In other words, before attempting to generate musical structures, crucial decisions must be made about the suppositions and the questions an

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[163] Otto Laske: "Composition Theory: An Enrichment of Music Theory", Interface, Vol. 18, No. 1-2, 1989, p. 46.

observer will raise regarding the model used for composition.

> To an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A.[164]

Smoliar's intent to first "dig out the questions underlying conventional analytic technique" of existing music, and then to reverse the procedure and model music after these analytical models, is an excellent example of model-based music theory applied to the domain of computer music. However, model-based compositional design requires a clear description of the underlying processes involved in the musical structure in question: in this case, Smoliar suggested the word "musical form" be discarded because of its static connotation, and replaced with the notion of "growth process" which reflects more adequately the vitality and immediacy of its inherent functional approach. If the "growth" of a musical form can be regarded not as a single, unified process, but rather as an interaction of several processes, an actual representation of these processes could be envisioned in the form of a computer program. A model-based approach in compositional technique can then be formalized in terms of a programming language, represented by means of an algorithmic model.[165] In fact, it should be

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[164]Marvin Minsky: Matter, Mind and Models, quoted in Stephen W. Smoliar: A Parallel Processing of Musical Structures, Ph.D. Thesis, MIT, Cambridge, Mass., September 1971, p. 7.

[165]However, a word of caution is in order here, as the "attempt at formulating an algorithm which to a certain extent simulates the process of composing music is very attractive... composing music is an extremely complex process which... cannot be fully formalized" (R. Kh. Zaripow in: "On Algorithmic Description of the Process involved in the composition of Music", Automation Express, Vol. 3, No. 3, Nov. 1960, p. 17). In fact, even if it is feasible to distill certain general propositions governing the composition process

possible to envision computer programs which would no longer be merely concerned with a description of an individual composition, but would be capable of creating generalized structural abstractions based on the original model.

Laske stresses the role of composition theory within music theory as a teleological means of developing virtual (as opposed to existing) music. His writings are based mainly on the principle of a "generative theory of music", wherein the grammar embodies the form suggested by theory, reflecting Chomsky's view, as expressed in "Aspects of the Theory of Syntax":[166] composition theory is ultimately seen as representing a grammar of generative composition processes. On the other hand, musical structures acting as grammar tend to integrate both models (that of composition theory and music theory) into a kind of cognitive musicology: they become associated with the behavior which produced them. However, music theory as a merely theoretical derivative of a perceiver's listening and auditory imagination reveals a weakness in any attempt to isolate these theoretical constructs solely by means of logical deductions from the side of the transmitter of the musical message. Laske argues that a message is considered "apart" from the receiver because its structure, as well as its contents can, in fact, be determined by scientific investigation. The phenomenon of music is therefore

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which a composer follows in order to create music (which will have to be taken into account in formulating the algorithm under investigation), this reasoning process represents only a small part of a special system required to control the musical texture as a whole. This fact was quickly realized by many composers hoping to gain an ultimate control of musical design, particularly since the deepening crisis of the serialist movement by the end of the 1950s.

[166]N. Chomsky: Aspects of the Theory of Syntax, M.I.T. Press, Cambridge, Mass., 1965.

transformed into a musical object which can be determined in terms of scientific "objectivity" without questioning which parts were illegitimately rationalized. It is debatable if theory precedes or follows certain developments in art. However, the point has to be made that its contextual function is dependent on whether the viewpoint is that of an analyst or that of a composer.

Regarding their published output, analysts tend to be "listeners turned analysts",[167] who reside in the musical domain of speech knowledge, trained "to treat listening as a paradigmatic musical activity".[168] Composers, on the other hand, discovered their limited knowledge of compositional speech when they were challenged by the first computer systems: they needed to properly indicate the essential specifications for computational input and output recognition, in order to be able to encode their compositional ideas efficiently. This, in turn, required a re-integration of their cognitive approach to compositional design into composition theory, in order to adapt to the challenge of a mechanical counterpart which behaved as a perfect mirror image of their own creative acts.

Laske acknowledges that composition theory "comprises theories of music based on insight into the music-compositional process"[169] but agrees that this theory is "still in its infancy", and without agreed-upon methodology.[170] But while composition theory has always

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[167]Otto Laske: "Composition Theory: An Enrichment of Music Theory", Interface, vol. 18, 1989, p. 45.

[168]Otto Laske, op. cit., p. 45.

[169]Laske, op. cit., p. 46.

[170]Laske, op. cit., p. 46.

been considered an integral part of music theory (and current composition theory is transferrable into current music theory[171]), one seldom creates virtual music based solely on music theory. Nevertheless, composition theory could act "as a catalyst for capturing and formalizing the composer's insights into his own process, as well as a means of choosing his own process freely".[172] In fact, it is very difficult to produce a short definition of what "virtual music" really is, as the existence of virtual music cannot be segregated from its generative roots, i.e. the model of composition theory from which it stems[173]. Composition theory therefore belongs predominantly in the area of generating and processing musical material. In fact, a computer system represents the perfect means of capturing and simulating processes of compositional planning and problem-solving because of its inherent sequential structure based on computational procedures. Hiller attempted to capitalize on this very fact in his approach to "experimental music", where the emphasis was on consciously replacing model-oriented compositional strategy with rule-based procedural design. In fact, the ILLIAC SUITE and the COMPUTER CANTATA reflect to a certain extent the influence of computers on the formalization of new approaches to compositional design, setting a benchmark example of the

[171]In other words, both models of model-based to rule-based approaches create a Heraclitean return.

[172]Laske, op. cit., p. 45.

[173]I would like to quote David Lewin in Laske's "'Composition Theory": " . . . composers are experts in *possible*, not existing music . . . "

proposed paradigm shift, which was considered to be so crucial during the 1950s.[174]

b) Paradigm Shift from Model-Based to Rule-Based Composition

Indeed, the use of computers in composition signals a paradigm shift from model-based to rule-based composition. Model-based compositions relate to a script-based orientation of compositional processes which usually leads to personal scripts or styles in composition as well as in analysis. This aspect of script-orientation (or script-analysis-synthesis dependence) has been the chief model for composers of Western music since scripts were accepted as proper representations of music. Rule-based designs, on the other hand, in contrast to model-based thinking, are not based on the analysis of existing music, but on an awareness of compositional processes per se. In fact, the paradigm shift from model-based to rule-based design during the 1950s was not prompted by removing all means of model-based composition: rather, it came about as a consequence of a fundamentally changed compositional approach as encountered through the medium of computer music.

This shift had considerable consequences: rule-based composer could free themselves from existing analyses of music or personal style as their sole means of compositional orientation. This objective could easily be achieved through the use of rule-based operational systems like computers to formalize musical ideas. Following the example of John Cage in his refutation of model-oriented art philosophy, a new

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[174]An excellent collection of articles related to this matter can be found in Foundations of Computer Music, Curtis Roads and John Strawn ed., MIT Press, Cambridge, Mass., 1985.

world of possibilities could emerge towards process-oriented, depersonalized manifestations of sound. Thus, the output of musical textures would in fact represent "virtual" artifacts, as they are truly statements of *a whole array of possible* realizations, making the computer program a principal tool in applying composition theory. The creation of "possible musics"[175] would develop along the following (see Figure 9 in the appendix) compositional flow chart. All three pre-compositional schemata (interpretative, designed-based, improvisational) can be regarded as the sets of **rules** (hence "rule-based") which affect them. At least three different ways of developing pre-compositional schemata of musical form are conceivable:

1) Analysis of the structure of musical materials[176]
2) Stipulation of abstract parameter relations[177]
3) Real-time explorations of materials[178].

This is illustrated in the following figure (see Figure 10 in the appendix). The creation of computer programs as a paradigm of music composition can then be based on the pre-

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[175]In: Otto Laske, "Composition Theory", op. cit., p. 49.

[176]This could be an existing computer output or data obtained from existing or imagined musical structures.

[177]For example, establishing structural networks between single musical parameters (pitch - duration, and so forth).

[178]Real-time means the synthesis of musical sound by means of a computer system. Laske: " . . . as in improvisational composition, whether based on a conducting process as in Chadabe & Zicarelli's *M* program (D. Zicarelli <u>Intelligent Music</u>, <u>M</u>, Albany, NY, 1988), or on realizing "compositional morphs", as in Polansky & Rosenboom's HMSL program". (Polansky & Rosenboom: <u>HMLS</u>, Palo Alto, 1988).

compositional schemata obtained through the above processes. Laske also recognizes the existence of a certain cognitive "progression" from model-based to rule-based composition, including improvisational and interpretative modes, ultimately leading towards design-based ways of working.[179] A compositional realization of, for example, the interpretative type, would then take on the following "life cycle" (see Figure 11 in the appendix). Here, a compositional idea passes through two non-overlapping phases of a Data model (generation of material and its subsequent analysis) and a Design model (compositional design and implementation). During the compositional process, "musical meaning" is assigned to preliminary unassigned symbols. Finally, the program generates a list of "events" by specifying certain structural formulas indicating the ***degree of stochastic order/disorder*** in a repertoire of parametric materials.[180] A composer's "interpretative" function is now to analyze the *structure* of the existing event list, in order to transform his imaginary compositional thoughts into appropriate musical realizations. During this process, all parameters (event list columns), except pitch class names,

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[179]In fact, the model of improvisational, interpretative, and design-based pre-compositional schemata do represent a continuum spanning the entire spectrum of possible approaches. However, design-based strategies seem to provide the greatest means of compositional control.

[180]Laske: "Composition Theory", p. 56: "Parameters in [Koenig's] PROJECT 1 are instruments (tone color), distance between two successive attack points (time delay, as distinct from duration), tempo, pitch class, order [optional], register, and dynamics." This is exactly what Hiller did in the COMPUTER CANTATA, and also attempted, to a certain extent, in the ILLIAC SUITE, in essence representing the conceptual shift of compositional approach including its pragmatic consequences: composing composition processes.

are freely interpretable. Consequently, the act of composition

> consists of making local decisions within the framework of the composer's understanding of event list structure and....his design. It is the interpretation of materials *potentially* yielding an infinity of *possible*[181] *musics.*

In summary, this transition from analysis to design (the bold arrow connecting Data and Design Model) can therefore be considered as the *"creative crux" of the interpretative process.*

The principle of the designed-based process can be condensed as follows: its "life cycle" is structured into two interdependent (overlapping) phases, the definition of a *general design* and the definition of *data models* for individual sections of the composition. The generation of a certain section of a definitive score is determined by the composer's input. The composer has to ascertain whether the text score resulting from the output is a true realization of the music he had imagined, as reflected in the specifications he entered as an input to the program. He can utilize this possibility of a feedback loop between input and output to progress towards a more and more faithful representation of his imagined musical ideas[182] (see Figure 12 in the appendix).

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[181]Laske states that in his implementation of Koenig's PROJECT 1, a single structure formula yields 32767 *possible* variants, **each of which** can be interpreted in an almost infinite number of ways. In: Laske, "Composition Theory", op. cit., p. 57.

[182]In other words, a rule-based composer does not have to accept the first results of his imaginings as does the model-based composer, because this feedback loop is a creative part of the compositional process.

The improvisational life cycle is structured into two non-overlapping phases: the process of specifying the entire design of a composition **and** defining a *minimal data model,*[183] and the process of elaborating the former, more general design into a detailed one of real time performances.[184] Laske calls the "creative crux" of this cycle its interaction between general and detailed design.[185] The general design is negotiated on the basis of the data model.[186] In summary, a certain *problem-solving process* is chosen and, in this instance, the results are immediately audible. This technique was used by Hiller in the real-time CSX computer sound generation program of his COMPUTER CANTATA.

c) Hiller's Application of Information Theory

We have seen that every analysis of a creative process involves an unbroken chain of explanatory steps, and that

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[183] I.e., its parametrical repertoire.

[184] Laske in his "Composition Theory", p. 57: "...depending on how open to input from concert participants the composer/performer chooses to be, the general design can be more or less pre-defined..., performances with [Ziccarelli's] "*M*" can be either more **interpretative** (of concert input) or more **design-based** (predetermined)...., the **improvisational** paradigm encompasses the previous paradigms, although understandably not in the complexity set forth separately in Koenig's two PROJECTS".

[185] See the two-way arrow in Fig. 12.

[186] Laske: "Composition Theory", p. 57: " . . . [it is dependent on the composer's] understanding of the chosen parameter repertories (input), or else their sounding form (output)." In contrast to design-based composition, input and output data models go together here.

every act of composing can be represented by a formalization of pre-compositional steps, to be ultimately coded in terms of an algorithmic[187] language. The examination of the compositional system used by L. A. Hiller yields important insights into the compositional and theoretical processes which sparked the advent of computer generated music in the 1950s, as the composer kept a meticulous record of all the procedures involved. Hiller was not only one of the main proponents of the development of computer music at that time, but he also revealed the influence of information theory as the theoretical foundation of a new approach to composition.[188] Hiller stated[189] that his application of information theory to the solution of general music problems was mainly based on Shannon's "The Mathematical Theory of Communication",[190] and Brillouin's "Science and Information Theory".[191] He simply adopted Shannon's use of the word "information" as referring solely to the quantity of syntactic information-content. Having accepted this limitation, it becomes clear that every constraint imposed

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[187]An algorithm is any particular procedure for problem-solving, which, as a rule, involves finding the greatest common denominator, for example FORTRAN, ALGOL etc. in which information is expressed in algebraic notation and according to the rules of Boolean algebra.

[188]Lejaren Hiller: "Informationstheorie und Computermusik", Darmstaedter Beitraege zur Neuen Musik, vol.8, Schott, Mainz, 1964.

[189]Hiller, Informationstheorie und Computermusik, p. 22.

[190]Shannon and Weaver: The Mathematical Theory of Communication, University of Illinois Press, Urbana, 1949.

[191]Brillouin, L. Science and Information Theory, Academic Press Inc., N.Y., 1956.

on the freedom of choice immediately results in a decrease in information-content.[192] If, at the same time, we use the example of random language assembly,[193] a higher degree of structural "meaning" is introduced. This can be done, as we have seen, by altering the probabilities involved in the selection rules, thus introducing a higher degree of Markovian order: freedom of choice is reduced and the results obtained increasingly resemble the stylistic features of the probabilistic system encoded into the rules of assembly. Introducing structural order means introducing structural **redundancy**. When information-content becomes a matter of choice, the information-content of a communication system can be written in the form of algebraic expressions, governed by probability theory.[194] The "orderliness" of a system can be measured according to its **entropy**, expressing the degree of disorder or randomness of a physical system. The concepts of entropy and statistical information are therefore related: entropy is a measure of the **missing**

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[192]See also Shannon's English text experiments, Chapter I.

[193]Referred to earlier as zeroth-degree Markoff order text experiments.

[194]"The information content of [a] system is defined purely in terms of the number of possible choices inherent in the system itself. If we know nothing about the system, in other words, if we are unable to define any of its properties, we must assume that the choice is random, which is equivalent to saying that the information content of the system is at a maximum. On the other hand, if we happen to possess some information concerning the properties of the system, it is probable that we can restrict the choice process to a situation that is less than totally random. This means that the information content of the system has been reduced, or, in other words, we might state that the information we, as observers of the system, have acquired concerning its properties has been obtained at the expense of the information content of the system." Hiller, op. cit., p. 24.

information within a system. However, the reader will remember that "information", in terms of information theory, has nothing to do with the meaning of this word in everyday use. It denotes simply a logarithmic measure of a number of possible choices from a random arrangement of a finite set of elements when making a decision. Finally, if messages are selected in the form of a sequential procedure, this operation is called a **stochastic** process. Stochastic processes can be described as three different types of communication systems, i.e. discrete, continuous, or mixed.[195] By definition, both the continuous and the mixed systems are more difficult to define regarding their repertoire of elementary information segments. In fact, the discrete type of communication system is the easiest one to describe mathematically. Hiller has chosen this particular type of system for his application in music[196] because the desired product of the process of creation was a printed musical score, representing a good example of a discrete communication system.[197]

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[195]A discrete communication system emits messages in the form of single, discrete, and definable elements only. A system can be called continuous if the message flow consists of a continuous stream of data (analog wave forms, for example). A mixed system contains both characteristics to a varying degree.

[196]"We should like to propose that it [music] is effectively a discrete system. It is thus like language, although normally more complex operationally, because in language only one symbol for an operational element is considered at a time. In music, a number of elements are normally in operation simultaneously." In: Hiller, op. cit., p. 30.

[197]Hiller noted however, that this would not be the case for electronic [tape] music. It will be in Chapter V, where we will pick up this notion again and understand how Stockhausen attempted to solve this problem of addressing a physically continuous communication system by by means of a discrete

With regard to the fundamental question concerning the communicational nature of information theory and its relation to musical structures, including various syntactical approaches, we are now in a position to investigate this relationship in concrete terms. The body of work selected to demonstrate the influence of information theory in procedural composition will be Hiller's ILLIAC SUITE and COMPUTER CANTATA. Hiller's true contribution to the advancement of 20th century compositional design was recognizing that computer technology represented an ideal medium for implementing the procedural or algorithmic approach to composition, encoding any kind of musical ideas as software. In fact, the birth of computer music cannot be comprehended fully without acknowledging the influence of information theory, including its historical relevance for further developments in computer music composition.

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compositional design according to specifications based on information theory.

CHAPTER III - L. A. HILLER - INFORMATION THEORY AND THE BIRTH OF COMPUTER MUSIC COMPOSITION

> Systematic permutations of the Tibetan alphabet with an automatic sequence computer aided lamas high in the Himalayan mountains in discovering all the possible names for God, approximately nine billion of them... At work on the project since three centuries, the lamas figured it would require another 15 thousand years to complete the project by hand. However, with the Mark V computer the task was accomplished in 100 days...The chief lama, in a philosophical dissertation given to the technicians, said that God's purpose has now been achieved and the human race has finished the job it was created to perform. What happens next?"[198]

1. Prelude

In addressing the fundamental question concerning the nature of musical communication and its relation to musical structures of form, Hiller and Isaacson[199] attempted to express musical principles by means of a computer generated formalization of compositional design as early as 1955.[200] The results of their experiments have been published in

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[198] The New Yorker, Sept. 21, 1957.

[199] As related to our discussion of "Experimental Music", the name "Hiller" includes, of course, the fundamental contributions of Leonard M. Isaacson to this project, even if his name will not be mentioned from here on.

[200] Both authors collaborated to create a set of instructions designed to cause the Illiac computer at the University of Illinois to create simple *cantus firmi*, employing the "Monte Carlo Method". Hiller attests that a sizable portion of the initial music programming techniques was adapted from earlier research.

Experimental Music,[201] one of the best documented and most influential publications involving algorithm formation and compositional design by means of information theory. Experimental Music will be our main point of reference in our discussion of the influence of information theory in musical composition in the 1950s.

Hiller's experiments were largely based on his preoccupation with findin g a solution to the problem of defining algorithms allowing the automation of the process of creating a musical score by means of "high-speed"[202] computers. The resulting composition was the ILLIAC SUITE for String Quartet, and its accompanying procedural logbook was Experimental Music. The ILLIAC SUITE is the result of an investigation of how musical ideas are formalized into computer language and, at the same time, represents the inauguration of the first musical score entirely conceived by a computer system.

It is important to note that Hiller's experiments involved information theory on so many levels of compositional design that the birth of computer music cannot be comprehended fully without acknowledging the historical importance and influence of this theory on later developments of computer music composition as well. These experiments are a good example of the paradigm shift in compositional design from model-based to rule-based

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[201]Hiller, Lejaren J., and Leonard M. Isaacson: Experimental Music - Composition with an Electronic Computer, New York and London, 1959.

[202]Hiller's reference to "high-speed" computers is related to large system computers such as the IBM-7090 or, as in his case, the ILLIAC system at the University of Illinois in the 1950s, in contrast to smaller computer systems existing during that particular decade.

compositional systems based on the new scientific concept of communication theory.

It is the intention of this chapter to summarize and emphasize the immediate character of some common relationships between compositional procedures and information theory. A discussion of how far general aspects of the science of communication have entered compositional procedures will be included, pointing to its relation to the seminal role that information theory played in shaping the creation of music in the latter half of the 20th century.

2. The Nature of the Problem

Hiller[203] described the process of musical composition as involving a series of choices of musical elements from an almost infinite variety of available sonic material. He goes on to state that the act of composing can therefore be seen as a strategy to extract order out of a chaotic multitude of available possibilities. He concludes that the extraction of order can be quantitatively described by applying mathematical operations stemming from the theory of probability, including certain general principles of analysis. Because some aspects of the process of composition can be formalized in terms such as those mentioned above, but require immense computational power, computers seemed the most appropriate means of automating the process of compositional design.

a) Programming a Computer to Compose Music

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[203]Lejaren A. Hiller: Experimental Music, p. 1.

Addressing the question as to whether it is possible to compose music with a computer, Hiller maoe the following proposition:

- Music is a sensible art form. It is governed by laws of organization which lend themselves quite well to exact codification.
- One of the features of digital computers is that they can be efficiently used to 'create a random universe' and to select ordered sets of information from this random universe in accordance with imposed rules, in musical terms or otherwise.
- Since the process of creative composition can be similarly viewed as an imposition of order upon an infinite variety of possibilities, the analogy between the two processes seems evident, and the opportunity exists for a fairly close approximation of the process involved in composition through the use of . . . a computer.[204]

Hiller has examined this proposition experimentally in great detail, especially with regard to the aspect of music generation which depends solely on general instructions derived from various specified 'rules' of composition:

> ...this is done by letting the control of the musical output be limited solely by the input instructions, and leaving factors not specifically accounted for in the input instructions entirely to chance...this appeared to be an attractive new **nonmathematical** application of...computer operation which could be of interest not only as illustration of the versatility of these instruments but also in terms of its possible effect on the fields of musical composition and analysis."[205]

The following figure (see Fig. 13. in the appendix) will illustrate Hiller's block diagram used for his computer music composition experiments.

Hiller's choice of the computer as an instrument to govern the process of selection and assembly of a set (or

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[204]Hiller: op. cit., p. 2.

[205]Ibid., p. 2.

alphabet) of pre-determined musical elements into a full musical score was mainly based on the following consideration: only a high-speed computer system would be capable of handling the massive data computation involved in extracting "order" through a process of selection from random numbers generated by means of conditional transfer operations. In other words, from the universe of random integer generation,[206] a given computer program would allow only some elements to pass to the next selection pool, i.e. those which satisfied certain compositional rules previously installed into the computer program.

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[206]Here is a simplified illustration of the technique used to propagate pseudo-random integers in the ILLIAC during the composition of the ILLIAC SUITE for String Quartet using the Monte Carlo Method: " . . . in the first operation, the computer is programmed to propagate pseudo-random integers which are considered as the equivalents of notes of the musical scale, rhythms, and so on. These integers are permitted to have values from 0 to n-1, where n represents the desired range of random integer values. The sequential generation of these integers is carried out by multiplying a random fraction by n, separating the integer part of the product as the usable random integer and multiplying the residual fraction once again to produce yet another random integer for subsequent use":

```
      0.2718
         x 7
1./    .9026
         x 7
6./    .3182
         x 7
2./    .2274
         x 7
1./    .5918
         x 7
4./    .1426
         x 7
```

. Random Integer Sequence: 1, 6, 2, 1, 4, ...
Quoted from: Lejaren Hiller: "The Electrons go around and come out Music", IRE Student Quarterly, 8(1), Sept. 1961, p. 42.

This operation, defined as a 'conditional transfer' process, involved essentially a yes-or-no choice operation.[207] The program structure involved acted normally in sequential order, beginning with the selection of random number integers, making a choice of "pass" or "fail" solely depending on whether the generated numbers had a negative or positive prefix attached. However, depending on whether a selected set of "elements" satisfied another set of instructions set out by the computer program, further levels of conditional-transfer order could result, shifting the sequence of operations to another part of the program. This specific type of procedure, involving constantly repeated sequential choice operations where integers are initially selected according to specific, pre-determined rules, is defined as the "Monte-Carlo Method"[208] and was explicitly used by Hiller in the ILLIAC SUITE.

> These integers, as they are produced, are examined and sorted according to the needs of the problem to be

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[207]This process resembles a simulated structure of choice wherein, for instance, each single grain of sand on a proposed (limitless) beach is investigated according to the characteristic of, for example, size. Only grains which satisfy certain specifications will be collected into a collective pool, all others will be rejected. Assuming that the size of the grain has been chosen with realistic proportions according to grains found at various beaches on planet earth, the collection pool will fill slowly. Another conditional transfer process can now be used to select only those grains from the pool which have a certain distinctive colour, and so on.

[208]Used to allow the development of a hypothesis in the so-called real-world of events, the Monte Carlo Method is operationally based on the laws of chance, involving in principle an examination of sets of randomly selected numbers. These numbers will be seen as representing a set of events from some model universe (the method) which can then later, presumably in a manner analogous to similar events, be extrapolated to answer questions related to the real-world universe.

> solved, until gradually a better and better approximation to the answer to the problem is obtained[209]. To do this, the laws of probability are applied within the restrictions of the particular problem being studied . . .[210]

As the success of this particular method depends largely upon the generation of random integers in great numbers (see our example), computers seemed the only means to achieve results in reasonable time. Composing music according to the Monte Carlo Method involved basically two operations in Hiller's experiments: first, the computer had to generate random sequences of integers which were equated to musical parameters such as pitch, rhythm, dynamics, and articulation. Secondly, each integer in the data obtained was subjected to a screening process involving arithmetic testing of the expression of various rules of composition. Thirdly, if not rejected, the random integer was used to consecutively build up a 'composition' file, to be eventually be printed out at the end of the experiment. Integers were treated consecutively on a one-to-one basis; that means, one integer had to pass all tests in order to successfully enter the composition. Following successful entry, the rules might change to reflect the new situation created within the compositional structure just obtained. This opened exciting possibilities in terms of how the computer could adjust its own compositional procedures within the same program. However, there seem to have been many instances where not a single integer could be found to fit the required answer to the question posed by rule-based

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[209] D. D. McCracken: "The Monte Carlo Method," Scientific American, 192(5):90, May, 1955 as quoted in Hiller, op. cit, p. 3.

[210] Hiller: op. cit., p. 3.

compositional principles: a dead-end had been encountered[211]. This particular situation was understood to be a direct result of one major penalty attached to the Monte Carlo Method: unless the process under investigation happens to be truly and completely random, many superfluous events can occur, leading to the above situation. Nevertheless, with a mechanical device at hand which was capable of processing millions of operations per second, the simulation of a completely random source of events could be approximated: the solution was to compensate the drawback of this method by the sheer size of numbers, thus allowing the projection of a close "real-world" model simulation. This is why Hiller has chosen this particular method for the creation of computer music.

b) An Experimental Proposition: The ILLIAC SUITE

It seems that one of the main obstacles Hiller had to overcome, during the initial phase of the experiments, was to optimize the translation of musical ideas to the existing purely technical set up of computer programming. At first, aesthetic considerations were therefore seen as subordinate to the objective of the initial phase of the project, proving that it was possible to program a computer to compose music. Later on, however, a more advanced level of compositional design was desired. To sum it up, one had to consider not only the written record of Experimental Music, which accompanied the creation of the ILLIAC SUITE, but also the composition itself, which took on a distinct procedural character, chronologically moving through all stages of

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[211]In this case, the 'composition' so far composed was automatically erased to allow a fresh start.

compositional design. The ILLIAC SUITE therefore represents not only a musical composition, but also a unique compositional protocol of experimentation with computer music programming. In this piece, Hiller pursued the following objectives:[212]

> - To select a simple but well-known style of writing and use this as a basis to build up an elementary technique of polyphonic writing. A simplified version of first-generation strict counterpoint was utilized for this purpose.
>
> - Then, once many technical problems of coding had been worked out. . . , to demonstrate that standard musical techniques could be handled by computer programming, so that [a] conventional musical output, recognizable to musicians, is produced. The solution of the basic problems of first-generation counterpoint was, therefore, carried out to produce *cantus firmus* settings which were academically correct in all their most important details.
>
> - To demonstrate that a computer can produce novel musical structures in a more contemporary style and to code musical elements [parameters] such as rhythm and dynamics. This was done to show that computers might be used by contemporary composers to extend present compositional techniques.
>
> - To show, lastly, that computers might be used in highly unusual ways to produce radically different types of music based upon fundamentally new techniques of musical analysis. In this last experiment, a complete departure from traditional compositional practice is illustrated.

The computer output of all four groups of experiments was simply transcribed by hand and arranged for String Quartet. The project was initiated in September 1955:[213]

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[212]Hiller, op. cit., p. 4.

[213]"With these thoughts in mind, we started, in September, 1955, an investigation of techniques to enable ILLIAC, the computer located at the University of Illinois, to generate various characteristic species of music subject only to general instructions derived either from well established logical rules of composition or alternatively from more

and by July 1956 the first three experiments were completed, except the coda in the third movement, and a first public performance followed. The suite was finished in November 1956, and subsequently published as a full score. It is interesting to note that Hiller obtained a lot more material during the experiments than was ultimately used for the final version of the ILLIAC SUITE. For example, the final version represents actually the result of 'unbiased' sampling procedures, embodying therefore more a representative than a selectively chosen 'best quality' version: "Thus, it is important to realize when examining this score that our primary concern was not the presentation of an aesthetically unified work of art. This music was meant to be a research record - a laboratory notebook."[214]

c) The Logic of Musical Composition

How then does music acquire "significance"? Music, with its inherent communicative properties, carries both syntactic and semantic significance. However, Hiller's procedure required that musical properties be translated into a programming code of some sort without regard to any inherent semantic properties. His experiment in music composition was simply meant to codify strictly syntactic

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arbitrary and experimental speculative procedures based upon a theoretical extension of traditional concepts of musical structure." In: L. A. Hiller, Jr., and L. M. Isaacson, "Musical Composition with a High-Speed Digital Computer", Journal of the Audio Engineering Society, Vol. 6, No. 3, July 1958, p. 154. Original version delivered at the Ninth Annual Convention of the Audio Engineering Society, New York, Oct. 9, 1957.

[214]Hiller, op. cit., p. 5.

information, and as such is similar to Hartley's and Shannon's understanding of coding acoustical information. We have seen that Shannon's investigation of information theory was solely concerned with syntactic properties from the transmitter's side only, excluding any notion of meaning. By using this premise of information theory, Hiller was able to stay clear of notions of "musical meaning", in formalizing a compositional system which would allow the coding and de-coding of musical properties strictly through quantitative data. He was in fact developing music composition entirely from the transmitter's perspective. Five basic principles involved in musical composition were mentioned, which were considered of primary significance:[215]

> i) The first principle is that the creation of a piece of music is an ordering process in which specific musical elements are selected and arranged from an infinite variety of possibilities, i.e., from *chaos*.
>
> ii) The second principle recognizes both *order*, and also the relative lack thereof, and even, in certain extreme cases, the absence of order, namely *chaos*, as elements of a musical structure; that is to say, the degree of imposed order is itself a significant variable.
>
> iii) The third principle is that the two most important dimensions of music upon which a greater or lesser degree of order can be imposed are *pitch* and *time*.[216]
>
> iv) Because music exists in time, the fourth principle is that memory, as well as instantaneous perception, are required to understand musical structures.
>
> v) Lastly, as a fifth principle, it is proposed that *tonality*, a significant ordering concept, be considered

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[215]Hiller, op. cit., p. 16.

[216]Hiller considers other dimensions such as dynamic level and timbre, to be considered less significant "for purposes of simplification". Hiller, op. cit, p. 16.

the result of establishing order on the level of pitch, in terms of memory recall.

3. Towards Information Theory

Having stated the overall principles, we shall now investigate aspects of their application, particularly the aspect of information theory as a means of codifying the process of compositional design, as illustrated in Hiller's ILLIAC SUITE.

a) The First Principle

If the formation process of a composition resembles an ordering process in which specific musical elements are selected or discarded from an infinite variety of possibilities, it requires a distinct system to impose this order on chaos. This process of "extracting order from chaos" has been followed in all of Hiller's experiments in ILLIAC SUITE.

b) The Second Principle

If we assume that any selection of musical material ranges between the two extremes of total order and total chaos, according to the musical style chosen, we need a precise definition of what order is, quantitatively, in musical terms. This issue has to include a view from the angle of the characteristics of the different parameters involved as well. Hiller proposed the parameter of pitch as the most prominent, founding his argument on the assertion that most of Western music is primarily based on pitch recognition and notation. Certain limitations inherent in pitch selection, caused by fixed pitch scales, temperament tuning, etc, in turn impose increased restrictive limitations upon the random choice of pitch during the initial selection process of musical elements. Stylistic concerns, such as choosing a certain harmonic style, limit the choice of pitch even further, and so on to the extreme of complete order where selection is limited to only one pitch. Restrictions imposed on pitch selection could lead to scales and ultimately, the traditional concept of harmony.

c) The Third Principle

Music, being a chronological art form, as opposed to the spatial perception of painting, depends upon a series of successive selections of sound elements *in time*.[217] This concept is applicable to language generation as well. Restrictions imposed on time selection would lead to the selection of definite patterns in meter and rhythm. The composition of a single melodic line, for example, if entirely executed by an automated mechanism, would involve the following procedure: it would start with the choice of pitches according to a fixed tuning scheme in sequential order. As the specific profile of a melody is characterized

[217] It is this concept of distinguishing time and pitch as two distinct parameters which classifies Hiller's approach as still model-oriented according to traditional belief. It was Stockhausen, however, who proposed the "unity of time and pitch" in that physically, in fact, there really is no distinction between them: music can be entirely coded in time only, representing the ideal environment for applications in electronic music composition. Seem from this angle, music is entirely time-art, an environment perfectly suited for accessing the random universe of sound without the restrictions imposed by the perceptual classification limits of the human receiver.

by intervals rather than pitches, successive interval selections will be determined by the set of compositional rules codifying a certain musical style, hence producing the desired melodic profile. Organizations of higher complexity, such as polyphonic writing, would require additional successive selection processes according to rules derived from harmony and counterpoint.

d) The Fourth Principle

Hiller pointed out that, because music exists in time, one cannot understand musical structures without involving memory, as well as instantaneous perception, especially when they require recognition of larger musical form sections. In fact, this statement enhances our comprehension of the concepts underlying all music and harmony.

e) The Fifth Principle

Surprisingly, Hiller's experiments involved considerations of tonality to a great extent. He stated that there is no "good" or "bad" tonality but simply a treatment of tonality as a parameter to be measured and controlled, according to the desired level of dependence in fixed-pitch reference point relationships set out within the compositional rules: "It is these long-range intervallic relationships that require memory for their recognition and which are used to build up both small and large-scale musical structures depending upon tonal coherence as an organizational principle".[218]

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[218]Hiller, op. cit., p. 21.

4. Computer Programming and Music

a) Coding and Programming Procedures

Before we tackle the question of how to program a computer to write music, the following general procedures of computer programming have to be taken into consideration. Every computer follows an automatic process of sequential selections of operations according to a list of instructions. The process whereby a programmer prepares the list of instructions is called coding or programming and the final outcome is called a code or program. In order to solve a problem by means of a computer program, one must reduce the pattern of the problem in question to match the computational facilities of the system. As computers deal with problems arithmetically in sequential order, coding design causes sequential instruction patterns in the form of 'loops',[219] i.e., an integer selected by the computer will be subject to an automated arithmetic investigation at the end of which the integer will be rejected or maintained. Coding therefore becomes a tool for decision making. Coding decisions, however, require the existence of an established order or a set of rules of some sort. In other words, the selection or rejection of an integer during the cycle of 'investigation' depends solely on the encoded pattern within the list of instructions. If an integer passes a loop, i.e. it was not rejected, it then transfers or 'jumps' to another part of the list of instructions. This process is called 'conditional transfer order'. Successful integers are held in memory banks from where they can be selected again according to a further set of coded instructions. Communication between the computer and the outside world is

[219]This principle of 'closed loop control' is also essential to automation theory, bearing many aspects of man-machine control in Wiener's 'cybernetics' as well.

usually facilitated through hardware interfaces: the 'Illiac II', the machine Hiller used communicated through punched Teletype paper tape.

Nevertheless, how is the routine of the first selection of events structured? With the Monte Carlo Method (as a model of the random universe), samples are selected according to their properties of interest, and then placed into their appropriate categories. Taking the classical example of collecting samples from an urn,[220] representing a sequential chain process, theories of chance and probability have to be introduced.

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[220]Hiller submitted the following example: ". . . an urn containing five white balls, three black ones, and two red ones. Attempting to sample the balls according to their colours, we could associate this experiment with a mathematical model in which events (the outcome of each sampling procedure) are represented by points. The collection of all points constitutes the event space *s*. This space *s* is governed by a law of probability called 'probability distribution function', which defines the probability *p*, for each point of *s*. The function which associates numbers with points of *s* is called a stochastic variable, thus resulting in the following probabilities of encountering a certain coloured ball: *f*(Event white) = 0.5; *f*(Event black) = 0.3; *f*(Event red) = 0.2. Considering now that balls will be selected on the condition that, after each draw, the ball will be replaced or, if the colour of the ball is the same as the one of the preceding draw, the ball will be returned without the result being recorded, a simple 1st-order Markov chain is generated, and the distribution of probabilities, now depending on the directly preceding draw, will adjust accordingly:

p(white) (Event white) = 0
p(black) (Event white) = 5/7
p(red) (Event white) = 5/8

p(white) (Event black) = 3/5
p(black) (Event black) = 0
p(red) (Event black) = 3/8

p(white) (Event red) = 2/5
p(black) (Event red) = 2/7
p(red) (Event red) = 0

Quoted from: Hiller, op. cit., p. 70.

> The important step...is, to build up a theory to analyze both the distribution of samples and how this distribution is affected by the particular restrictions placed upon the rules governing the sampling process itself.[221]

In terms of information theory, the chain of events involved in the above procedures reflects in an ideal sense the situation outlined in the quantitative description of discrete-channel type communication systems. In fact, Shannon and Weaver had already defined their terms of information as pertinent to sequential operations while using the concepts of stochastic variables and n-th order Markov processes, otherwise known as stochastic processes.

While the above examples fall well within very simple descriptions of a two-dimensional process of delineation of mathematical functions, the description of a system capable of producing veritable data for music composition, for example, requires a descriptive system which is more complex in nature. Often, the 'real-world' example of the diffusion of gas molecules is used to serve as a descriptive model accessible to quantification:

> Since diffusion depends upon the random motions of molecules, the method of *random flights* might be used to simulate this process. A random flight is defined as a particular species of Markov chain in which equally weighted a priori transition probabilities are assigned to all possible choices for each successive event...This is again a situation we have encountered previously in the discussion of information theory and is the situation characterized in information theory as having the maximum entropy content.[222]

If restrictions are imposed upon the randomness of choice, i.e. the weighting or exclusion of transitional probabilities, a lower entropy content is simulated, thus

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[221]Hiller, op. cit., p.70.

[222]Hiller, op. cit., p. 72.

resulting in a change of information content. In fact, Hiller used his former research methods[223], where elementary models for flexible long-chain polymer molecules[224] were generated by means of "random flight generation" Markov chain processes, as a starting point resembling the particular programming used for musical composition. This seems a rather odd association, but, as Hiller explained:

> the process of composition can be conceived as a complex random flight through a tonal universe, with dimensions of pitch and time subject to restrictions we normally associate with rules of composition.[225]

b) The Monte Carlo Method

Hiller's first experiment consisted initially of assigning integer values to the white notes of the musical scale. This was followed by the generation of random integers, which were then to be processed, ultimately building up to a machine representation of extremely simple melodic structures.[226] Hiller divided the technical problem of coding into four strategies: first, one had to generate random sequences of integers, previously equated to the

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[223]F. T. Wall, L. A. Hiller, Jr., and D. J. Wheeler: "Statistical Computation of Mean Dimensions of Macromolecules-I," Journal Chemestry Physics, 22:1036, 1954. Also mentioned in: "Electronic Brain Composes at University of Illinois", Illinois Music Educator 16(1), Sept.-Oct. 1956, p. 17.

[224]i.e., such as rubber and other plastic materials.

[225]Hiller, op. cit., p. 73.

[226]This was the level formerly investigated by Klein, Bolitho.

white notes from C below middle C to C above middle C, resulting in a range of values from zero to fourteen (two octaves=15 keys). A print-out of compositional results revealed random-type "white note" music, as anticipated. Secondly, these randomly generated events were then made to pass through a sorting procedure or 'sieve', according to specified coded instructions.[227] Thirdly, accepted note events from above were stored in computer memory and later assembled successively into the machine representation (data collection) of a 'composition'. And finally, the composition was then converted into number or letter representations, to be finally transposed by hand into a musical score.

Whenever a rule was violated, the melody was terminated and the entire process repeated. Hiller could demonstrate that, in fact, a reasonable number of melodies would be completed successfully, depending on their overall length: the longer the melody, the less likely its chances of being completed, given the increasing probability of a rule violation which would terminate this 'random-flight'. However, Hiller realized quickly that the introduction of new, more restrictive rules would evidently minimize the probability of generating longer musical examples. A 'try again' method was therefore introduced, allowing only the note which violated the rule to be rejected, not the entire 'composition'. The entire process would then continue until a new, successful note could be obtained or it became clear that no such note event existed, in which case the entire 'composition' was erased and the process started anew. Hiller set the number of trials to a maximum of 50. Reflecting on this type of compositional procedure, Hiller remarks:

[227]Hiller considered this to be, by far, the most complex part of the problem of generating computer music.

> [This] is actually a closer simulation of actual composing procedures than the 'discard' method, since a composer does precisely this. He tries again until a note fits, and if this fails to work, only then does he go back and erase some of the completed work. This is a major point of comparison between what the machine is capable of doing and what a composer normally does.[228]

In the following sections, we will examine the entire body of Hiller's ILLIAC SUITE, ordered according to the development of experimental details as published in Experimental Music. The purpose of Chapter III is therefore to serve as a point of reference concerning Hiller's well publicised experiments involving information theory in computer music composition. For obvious reasons, the investigation of the four movements of the ILLIAC SUITE will be restricted specifically to experimental details related to the influence of information theory.

5. Hiller's Four Experiments

Four distinct experiments can be identified in the ILLIAC SUITE. The first one pursuing the objective of developing a technique for simple monophonic melody writing, followed by a rudimentary polyphonic assembly by means of strict counterpoint rules. Three computer programs were used to achieve this objective, creating first a monody, then two-part and ultimately four-part writing, using only white keys and a limited set of rules in order to simplify coding.

a) EXPERIMENT ONE: Monody, Two-Part and Four-Part Writing

The first program allowed the automated writing of *cantus firmi* melodies, while the second one, involving two-

[228] Hiller, op. cit., p. 76.

part writing, contained investigations into the more complex situation of contrapuntal relationships, both vertically and horizontally. The third program attempted to code three-way and four-way note interactions leading to the construction of a larger musical arrangement.

b) EXPERIMENT TWO: Four-Part First Species Counterpoint

In order to achieve the objective of automated writing of correct four-part first-species counterpoint, Hiller had to implement a substantially larger number of compositional rules than he had used thus far. In fact, he decided to completely re-write the code assembled for Experiment ONE, proving that it was, in fact, possible to create an output which resembled common existing musical examples of this sort. Experiment two was special in the sense that its coding design allowed the removal or addition of extra rules simply by altering the code. Depending on the operational device used to control the degree of rule restrictions, the output results varied from totally random to highly restricted settings applying all rules at once. Following speculations involving a further development of this approach towards second-species, third-species, or even florid counterpoint, Hiller realized that this approach would require a time-consuming effort of extensive coding merely to simulate a specific historical style. By that time he had also discovered that other types of codes could provide a more effective way of writing music of greater contemporary stylistic interest. This marked the beginning of Experiment THREE.

c) **EXPERIMENT THREE: Experimental Music**

Building upon the first two experiments, Experiment THREE included a method of assigning values for rhythm, dynamics, and articulation symbols, independently for each voice (this parallels the notion of orchestration). More importantly, the "white note" selection process of Experiment ONE was now modified to include all notes of the chromatic scale:

> Initially we generated purely random chromatic music in order to have examples of the most chaotic starting tonal materials, that is, materials of the highest **entropy** content within the framework of the chromatic scale.[229]

In the next part of the experiment, through modifications to the code governing the selection of the previously specified parameters (rhythm, dynamics and articulation), one could affect more than one voice at a time, no longer leaving the matching of the above parameters entirely to chance. Hiller, combining a random-type code with the above modification, was now in a position to create rhythmic, randomly pitched music. Following this, restrictions through additional rules were re-introduced, leading to a texturally more emancipated style of free chromatic writing, prompting Hiller to finally include code provisions towards a design reminiscent of dodecaphonic style. Finally, the question was asked whether to adapt the existing compositional system to include formal principles of organization other than the ones ruled by traditional technique. Hiller grouped these experiments together as Experiment FOUR.

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[229]Hiller, op. cit., p. 80.

d) EXPERIMENT FOUR: Markov Chain Music

Experiment FOUR was designed to apply the principles of Markov processes. In order to determine a starting point from which to experiment, Hiller first established a series of studies, resulting in:

> . . . two sets of numbers for assigning values to both absolute and conditional transition probabilities for successive note selection. One set of values was based on the overtone series and permitted the assignment of probabilities for melodic intervals related to their order of occurrence in the harmonic series and, hence, to their relative degrees of consonance. The second set of numbers was used to extend the idea of a leading-tone function.[230]

Values obtained by this procedure governed the relative proportion of intervallic melodic parameters:

> Transition probabilities derived from these two sets of integers were combined in various ways to produce melodic output in which the proportion and character of skips and stepwise motion, the proportion of consonant to dissonant intervals, and the resolution of dissonant to consonant textures, or vice versa, were controlled by rather simple means.[231]

Hiller completed Experiment FOUR by applying the concept of Markov chain transition probabilities towards automated writing of generalized cadences.[232] A summarized outline of all experiments, in chronological order, can be found in the following table:[233]

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[230]Hiller, op. cit., p. 81.

[231]Hiller, op. cit., p. 81.

[232]In this case, I-IV-V-I respectively.

[233]See Table. 2. in the appendix.

6. Compositional Design

During the planning stage of his compositional design, the codification of composition rules first took the form of block diagrams, outlining a generalized scheme to reach a compositional objective. Then came the stage where the operational process was encoded as an actual program in computer assembly language. First-species counterpoint rules directly derived from J. J. Fux[234] were applied, conveniently grouped into three categories: (1) melodic rules, (2) harmonic rules, (3) combined rules. Hiller illustrates the collection of rules as follows.[235]

It is not important here to investigate the characteristics of the above rules for a composition *per se*. It is, however, important to note how far Hiller's Experiments ONE and TWO attempted to create automated style writing by means of a rule-based compositional principle directly derived from an analysis of style. Hiller did not completely abandon model-based compositional design: on the contrary, his traditional understanding of the concept of operational space led to a process of creating an operationally mixed overlay of both model-based and rule-based approaches in the assembly of musical textures.

a) Coding Patterns: EXPERIMENT ONE

We have now understood the general procedures involved in Hiller's solution to the problem of adapting musical

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[234]Hiller mentioned the following source on page 82 in Experimental Music: J. J. Fux: Gradus ad Parnassum (trans. and ed. by A. Mann, with collaboration of J. St. Edwards), W. W. Norton & Company, Inc., New York, 1943.

[235]See Fig. 15. in the appendix.

ideas to automated composition procedures. However, experimental details, such as coding algorithms, have to be investigated now in greater detail, as this level represents the most influential core of compositional design in structural terms.

i) Processing Rules for Coding

The previously outlined block diagram of computer operations specified rules of counterpoint which were classified as follows. CLASS1:[236] one voice at a time; CLASS2:[237] two voices at a time; CLASS3:[238] four voices at a time. Secondly, the selection of individual notes could be divided into three classes of operation: class (a) initial

[236]CLASS1 included all melodic rules.

[237]CLASS2 rules exclude harmonic dissonance.

[238]CLASS3 contained complex rules affecting contrary motion and other operational characteristics.

notes; class (b), intermediate notes;[239] class (c), cadence notes.

ii) The Try-Again Subroutine

If a note was rejected by the main routine outlined above, a replacement note had to be selected by means of a sub-routine inserted into the program. If no fitting note could be found, the entire 'composition' was erased after 50 counts.

iii) Compositional Direction

In order to give the composition a 'direction' in terms of harmonic progression, Hiller decided that the best procedure was to assign the first note in four-part writing to the voice of the cello (voice 1), followed successively by filling in the notes for viola (voice 2), violin II (voice 3), and violin I (voice 4).

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[239]However Hiller observed that, for the sake of efficiency, three basic sub-classes of intermediate notes could be created to choose from, replacing the original selection process ruled by random integers. In subclass (1) [tritone-resolution notes] ". . . the notes to be used were predetermined by the fact that a tritone would have occurred which requires a particular solution. In such a circumstance, the generation of random notes would have been wasteful, and it was far simpler to supply the required note directly. Subclass (2) [skip-stepwise notes] notes were required whenever a melodic skip occurred. Here again . . . it was more efficient to restrict the note selection to the few possible choices. Since there are permitted only two possible stepwise motions plus the repeat of a note, it was convenient to generate randomly only one of the three increments -1, 0, +1 equivalent to these melodic intervals and add it to the previous note. Subclass (3) notes, that is, all other intermediate notes, were generated purely randomly." Quote from: Hiller, op. cit., p. 89.

iv) Note Indexing

The notes of the (white key) scale were indexed according to simple numerical values, starting with (0) for the lowest note (C) and (14) for the highest (c"). However, while Experiments ONE and TWO use a simple numerical or stochastic representation of pitches, Experiment THREE - after the revision which was to include the full chromatic scale - represented a somewhat different stochastic representation of musical material. It was this difference between any of these stochastic representations which finally allowed a numerical representation associated with specific musical intervals. It was therefore possible to add numbers representing certain intervals arithmetically in order to obtain correct musical representations following the operation. In other words, the block diagrams for Experiment ONE could now be conceived.

v) Simple Monody: Coding the *Cantus Firmi*

The lengths of the *Cantus Firmi* were simply determined by a counter in the program and, as was specified to begin with, they ended on C. Hiller described the process as follows:

> Thus for the *cantus firmus* containing *n* notes, this counter was set at $-n+1$, and after each note was selected...unity was added to this quantity to yield the successive values $-n+2, -n+3, \ldots, -n+n$. This last value, occurring after the note $n-1$ had been selected, is, of course, equal numerically to zero, the lowest possible positive number in computer calculations. The change in sign from a series of negative numbers to a positive number was detected by a conditional transfer order, which was then used to shift to the instructions used to terminate the *cantus firmus* with the note C and begin a new *cantus firmus*. The number of *cantus firmi* of each given length (from 3-12 notes respectively), was controlled by another counter working on the same

> principle. Lastly, the lengths of the various *cantus firmi*, denoted by the function *n*, were obtained by means of a series of preselected stored parameters used for *n*.[240]

Hiller created fifty samples of each *cantus firmus,* from three to twelve notes, totalling an output of five hundred rudimentary melodies.

vi) Two-Part Writing

Following the above procedures, the same melodic writing routines were used, except that they now included more rules, to prevent the writing of concurrent dissonances, to avoid parallels, etc. This part was later to become a subroutine in Experiment TWO. Because this routine was intended to include some harmonic references, a subroutine for generating leading tones was introduced. This procedure was carried out through binary random-choice operations, which were dependent on rules governing voice-leading practices. Again, Hiller obtained five hundred samples of two-part writing to prove that the application of his method was successful.

vii) Four-Part Writing

Four-part writing turned out to be a challenge due to the complexity of the rule interactions being considered. However, Hiller started with a minimal set of restrictive rules, and gradually added new rules of operation, including rules of 'liberation', i.e. 6/4 chords were allowed again. One of the main problems to solve was that of cross-checking

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[240]Hiller, op. cit., p. 91.

between voices regarding their harmonic and parallel-moving status throughout the piece.[241] This subroutine was included in Experiment TWO, to be called up six times to verify the new entry. Finally, a routine for properly simulating a cadence had to be programmed, leading to a full set of new 'rules' and 'liberations', not to be further specified by the composer. Again, five hundred samples of computer output were obtained.

b) Coding Patterns: EXPERIMENT TWO

i) Flow Charts

Following the description of Experiment ONE, Hiller provides the reader with a block diagram which he uses in the creation of musical samples in experiment TWO.[242] As an example of how coding specifically affects the selection process of musical events, I would like to walk the reader briefly through Hiller's block diagram, in this case representing the main routine of selecting notes for four-part first-species counterpoint:

INITIAL ENTRY represents routine instructions to load the program into the computer while performing such routine operations as clearing memory, setting counters, parameters, etc. This is the location where instructions regarding a desired length of *cantus firmi* are included as a start-up condition. Following the flow chart, the setting of initial notes is to be determined, in this case not by random number selection, but from a small table of variables containing numerical values 0, 2, 4, 7, 9, 11, 14, respectively

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[241]A group of four possibilities exists here, so pairs of six computations had to be absorbed to verify each note selection (voices 1-2,1-3,1-4,2-3,2-4,3-4).

[242]See Fig. 16. in the appendix.

representing the notes C, E, G, C′, E′, G′, C″: the ′composition′ was supposed to start on the chord of C major in a root position.[243] This operation was performed by a subroutine, and had to be done only once: at the start of the composition.

SET CADENCE represents the next logical step, to ask whether the next-to-last chord had been reached and the cadence routine would have to be invoked, or whether the principal part of the program, used for generating intermediate notes, was to be entered. Depending on the desired length *n* of the *cantus firmus* of a given setting, which was determined under SET INITIAL NOTES, a cadence routine would be required after *n-2* notes had been generated for each voice. Without going into specific details, Hiller managed to ensure, through simple arithmetic operations, that the numbers associated with *n-2* changed sign polarity from negative to zero, the smallest positive number. At this point, the conditional transfer order would be activated, shifting the entire sequence of operations to the special cadence routine.[244]

The next set of six blocks of instructions were executed similarly for voices 1 to 4 successively, with minor variations in the operations involved. It is here that intermediate notes were selected, mostly on the basis of a single or one-to-one voice relationship. However, more complex interactions could only be tested after all four notes had been selected.

SET TRITONE RESOLUTION represents an instruction subroutine activated whenever a tritone had occurred between

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[243]The root position setting was achieved by automatically assigning C, C′, or C″ to voice 1 (cello) during the "operation of initial notes" process.

[244]See Table. 3. in the appendix.

any two voices in the previous chord. Where the tritone had occurred between voices, was also recorded, and this particular information was stored for all voices in this block as well. This block then eliminated all tritones between more than two voices. Before setting the tritone-resolution notes for the next chord, an examination by the **MELODIC SUBROUTINE** was required. If the notes were found unsatisfactory, the **TRY-AGAIN SUBROUTINE** was activated, the chord erased and the procedure started anew. This block was used only

> whenever a tritone had occurred between two voices only, and only when one of the tritone intervals notes had occurred in the voice for which a new note was being generated. If the tritone note in the previous chord happened to have been F or F′ (index number 3 or 10) or B or B′ (index numbers 6 or 13), the notes in the new chord were automatically inserted as E or E′ (2 or 9) or C or C′ (7 or 14), respectively. Otherwise, the operation was bypassed.[245]

SKIP-STEPWISE MOTION, related to rule 3, found on table x, was set up to determine both modes of motion. When the computational arithmetics were done, based on a comparison of the numerical relationship between the sum of the two notes previously selected and the new note just received and under investigation, and if their outcome was positive in sign, it was clear that a stepwise motion had occurred. In this case, the positive integer sign activated the conditional transfer order of bypassing the special skip-stepwise routine, and advanced the entire operation to the block **GENERATE RANDOM NOTE**. If the integer carried a negative sign, **GENERATE RANDOM NOTE** was bypassed and the process went on for further testing in **THREE NOTE REPEAT**.

The elimination of multiple repeats of the same note followed next. This was done by the simple procedure of comparing the numerical difference between all intervallic

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[245]Hiller, op. cit., p. 97.

events. If the numeric quantity of all events was found to be unequal to zero, this instruction loop was completed. In other words, this meant that the melodic interval had not been repeated: consequently, the entire operation would be referred to **MELODIC SUBROUTINE**. However, if the difference equalled zero, the second last interval backwards had to be initiated. The difference between the former and the second last interval would then be computed. If the result was again unequal to zero, proof was provided that the second melodic interval back in line had not been repeated either. Referral of the entire operation to **MELODIC SUBROUTINE** was initiated in this case. However, if this particular difference turned out to equal zero, two repeats in the succession of three notes must have occurred. In this case, the entire procedure was redirected to **TRY-AGAIN SUBROUTINE** and the process started anew.

MELODIC SUBROUTINE, already known from Experiment ONE, and considered Hiller's first music-generation code written for the Illiac computer, involved the screening of forbidden intervals between successive notes and of long-range relationships between notes contained in a melodic line. Testing intervals between notes involved simple additive arithmetic processes.[246] According to Hiller, initially, $[N_i - N_{i-1}]$ was computed and the quantity 7 subtracted from this absolute difference

> ...each time we tested, this yielded one of a series of integers which could then be checked to find the exact magnitude of the melodic interval. Since the only forbidden melodic intervals were sevenths and tritones, only these had to be screened out. Therefore, it was possible to test immediately for whether an interval was an octave or larger, and if so, the interval was conditionally accepted.[247] Since intervals larger than

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[246]See Fig. 17. in the appendix.

[247]And the process returned to the main routine.

> an octave were automatically eliminated by the test to follow for the octave range rule, the octave was, in effect, being detected by this first screening operation. Directly thereafter, it was possible to test for the seventh. If a seventh was found, the try-again routine was entered, and the whole process started over again.[248]

Hiller went on to say that if a seventh was not found, all remaining intervals were accepted except for the tritone and, consequently, the screening process for sixths could be omitted operationally. The next step would be the detection of fifths and fourths. If one of these intervals was found, a tritone was possible, and had to be checked in the **TRITONE PRESENT** routine. If positive, the entire procedure would then be re-directed to **TRY-AGAIN SUBROUTINE**; if negative, the operation would continue towards the **OCTAVE RANGE** block.

The **OCTAVE RANGE** block deals essentially with the formerly specified rule 1 which did not allow the melodic line to span more than one octave. The position of this block had been chosen to come structurally this late in the subroutine because a specific range of melodic 'register' was not intended to be defined at an earlier point in the process. It therefore gains flexibility in accepting all possible registers and serves solely as a guard to keep track of whether a new note was not more than an octave higher than all other preceding notes up to this point of the compositional process. Subsequently, if the new note exceeded an octave, the **TRY-AGAIN SUBROUTINE** was initiated, while successful notes would be referred back to the main routine.

Going back to the main routine flow chart, the purpose of the **HARMONIC SUBROUTINE** block was to screen out harmonic dissonances and to restrict chords to perfect triads, or their first inversions, allowing also the dissonance of

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[248]Hiller, op. cit., p. 99.

VII_6, containing the interval of a tritone. Parallel to the flow chart's melodic subroutine, Fig. x depicts the block diagram for the harmonic subroutine.[249] In this figure, the 'delta' symbol signifies the representation of the absolute numerical difference between notes in two different voices at the same time, i.e. its vertical interval. Remembering that six pairs of voices had to be taken into consideration successively during this procedure,[250] the actual testing had to be done six times before the subroutine could advance to the next step. Its real computational flow chart was therefore far more complex than depicted in the above figure. The **RECYCLE** function allowed much more efficient testing of all four voices by means of the melodic and harmonic subroutines since it could re-use some of the material which had already been successfully tested before, but which might have just been placed at the wrong time. This was a true improvement in the selection procedures.

The purpose of the **HARMONIC SUBROUTINE** was clearly also (1) to eliminate vertical intervals of sevenths and seconds; (2) to eliminate parallel unisons, fourths, fifths, and octaves; (3), to monitor situations where one of the former intervals had been previously formed by two voices moving in the same direction by contrary stepwise motion, or a merely stationary attitude without change; (4) to test whether a tritone had occurred. If one realizes that this situation of complex relationships is a reality, especially in the vertical direction, it becomes clear why this chart seems to be even more complex than the one depicting the melodic subroutine. Without delving in further detail into the arithmetic procedures involved, we can also see that

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[249]See Fig. 18. in the appendix.

[250]Voice pairs 1-2; 1-3; 1-4; 2-3; 2-4; 3-4 respectively.

both the melodic and harmonic subroutines have been conceived with a similar structural design.

Returning to the main routine of Experiment TWO, the notes obtained (or left over from the model universe) were now subject to be tested regarding their acceptance according to new rules related to the combined interaction of the remaining voices 2, 3, and 4. The first test, **AT LEAST ONE VOICE STEPWISE**, required that at least one voice out of all four would have to move stepwise (according to rule 15). The next test, **THREE OR TEN BETWEEN LOWEST NOTES**, was installed to evaluate whether a numerical difference of 3 to 10 existed between the lowest notes and any of the other three notes. If the test was negative, Hiller knew that a $^{6}_{4}$ chord did not exist here, allowing the procedure to advance to **CONTRARY MOTION**. This test verified if at least one voice - whenever a unison, fourth, fifth, or octave had occurred by moving in the same direction - had reacted with contrary motion. If no contrary motion had occurred, the chord in question was referred back to the **TRY-AGAIN SUBROUTINE**. The next step was to re-introduce the previously described procedure of **TRITONE RESOLUTION**, dealing with the proper treatment of chords bearing the interval of a tritone.

RESET-SHIFT TO NEXT CHORD, finally, had two settings: (1) would allow the shift to assemble the next chord of the given *cantus firmus* setting; (2) represented a clearing operation for re-setting the entire routine to the initial setting of the entire program. This final block also made sure that appropriate chords were stored in memory, to be later printed out and transcribed into a musical score by hand, or, in the case where they were assigned to the **TRY-AGAIN SUBROUTINE**, to be erased. The last step was for Hiller to write a final subroutine in **SET CADENCE**, allowing additional rules to be applied and checked:

> The extensive set of rewrite orders required for this cadence subroutine involved the adapting of test procedures from the other parts of the computer program for Experiment TWO. A complicated bookkeeping operation was needed to set up the testing procedures for the cadence and to reconstruct the test in their original form for the next *cantus firmus* setting after the cadence had been selected. The details of these instructions need not be considered here since, although complex, they were entirely routine in nature.[251]

Whenever a *cantus firmus* setting was completed, print-out instructions were activated, reading the obtained results from a table stored in memory. These results were further directed to Illiac's subroutines in printing, or, in this case, punching a computer output tape. Finally, after printing, the memory was cleared for a new round of creating counterpoint samples.

ii) EXPERIMENT TWO: A Turning Point for Information Theory

At this point, it would seem reasonable to ask what all of this has to do with information theory. In fact, we have not referred to it even once during our analysis of Hiller's research. What happened, we might ask, to Hiller's intention to base his compositional design on procedures related to information theory? Do we have to delve even further under the surface of what Hiller presents to this point? Or did the entire issue get completely lost in experimental details? Has Hiller perhaps even abandoned this idea of information theory being at the root of his entire development of coding musical rules into computer language?

It is significant to note that Hiller did not continue to refine his initial program design of selecting random

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[251]Hiller, op. cit., p. 109.

events by means of the Monte Carlo Method any further from here on, beyond increasing the general restraints of the musical rules. In fact, Hiller could show that, especially in Experiment TWO, any further implementation of new, restrictive composition rules would merely result in the creation of a monotonous musical output, a single repeated event - left over from the universe. Considering that random integer creation deals with a theoretically unlimited size of alphabet, this result would be rather sensational, if ever it were obtained.

On the other hand, the design of Hiller's experimental approach must then be seen as extremely effective in encompassing the full spectrum of compositional control, embracing both extremes of a random universe on one hand and a single, solely possible event on the other. We are well aware that, up to this point, Hiller's approach was somewhat limited to a small number of events taken from a universe of possible sound creations: a small selection of discrete pitches of the chromatic scale. However, what would happen if there was to be a considerable increase in the musical material permitted, including microtonality, or, even the entire universe of conceivable sound? Would the controlling computer program ultimately grow larger in complexity than the material to be controlled? In other words, what amount of complexity in instruction routines can we expect a computer program to handle in its attempt to write "real music"? It is interesting to note that, progressively from Experiment ONE, Hiller seems to have lost touch with applications of information theory, as he approached the micro-structural level of programming computer routines. But how did this elusive influence of information theory manifest itself before? Did it manifest itself in the way which we expected? Or do we have to assume that we have moved even further away from its operational range by increasingly focusing on smaller musical details, main routines, subroutines, single events, nuclear particles of sound?

At this point, we have to remember that Shannon's and Hartley's definition of information is truly not concerned with single events, but focuses rather on their relationship with the entirety of the repertoire of all possible events, representing the maximum of information the entire information system can reach. Taking this into account, we have to realize that an investigation of the influence of information theory in music can only become meaningful when more than single events with the entirety of a possible repertoire are correlated. We have seen in Chapter I that the strength of information theory lies particularly in its ability to make precise, quantifiable predictions from the input of massive data, rather than from single events which tend to produce subjective results. In other words, we have to learn again to access the special capability of this theory in relating single musical events to the entirety of a composition in a meaningful way.

How shall we then continue to explore the influence of information theory in music composition? Exactly as described above: by means of increasing the number of events to be investigated at one time. This is precisely what Hiller did, following the statistical results obtained at the end of Experiment TWO. After having successfully implemented a maximum set of operational rules leading to the production of extremely restricted musical textures, accompanied by a distinct increase of programming complexity, Hiller proceeded methodically backwards towards his initial position: experimenting towards the pure random version of the Monte Carlo Method from where he had started out in selecting his musical events. In fact, he began to gradually remove rules imposed on the automated composition process and analyzed the resulting changes affecting the compositional output. Restrictions were varied from most restricted writing to purely random white-note writing (see Tab. 2. in the appendix).

> Actually, the experiments were carried out in reverse order. The most complicated program, the one we have just described, was written first. After this was in working order and producing output, it was then a simple task to reduce its complexity by means of over-write orders which inserted bypass, or "unconditional transfer orders" into the program in front of the tests to be eliminated. When a sufficient number of these bypass orders had been inserted, the program was reduced to the simple process of generating random white-note music. The total number of individual arithmetical instructions required by this program for writing strict counterpoint exceeded 1,900 individual operations.[252]

In short, Hiller claimed that the program used in experiment TWO was the "most complex single music generation program"[253] he had written for the Illiac computer. Having reached a point of investigation from where we must now pursue our methodical approach in the opposite direction, i.e. towards the inclusion of music entirely created by random processes, we will now investigate Experiments THREE and FOUR, expressing this new direction in detail. As our investigation proceeds toward the end of this chapter, we will be increasingly made aware of the return of information theory, which becomes an indispensable tool to securely steer our vehicle of investigation through systems of an increasingly complex nature, including probability, chance, and random events. "Random flight" experiments can be entirely simulated by Markov chain processes, an indispensable component of information theory.

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[252] Hiller, op. cit., p. 109.

[253] Hiller, op. cit., p. 110.

c) Coding Patterns: EXPERIMENT THREE

Taking a distinctly different approach from the one he used before, Hiller developed experiments summarized under the heading "THREE" with a modular approach in mind: technical problems would be conveniently broken down into separate sections and investigated individually before describing how these various elements would be combined. By tracing Hiller's experimental blueprint as closely as possible, we will once again be in a position to clearly track the influence of information theory not only by mere speculation, but by means of a demonstrated experimental strategy as described in Experimental Music.

i) Rhythm

Hiller felt that the parameter of rhythm was too important to be left out any longer during his development of a fundamental compositional technique by means of computers in Experiments ONE and TWO.

> It was our purpose to write a practical computer program for generating rhythms so that a fundamental technique might be demonstrated which in turn could form a basis for the further elaboration of rhythmic devices in more complex contexts.[254]

Drawing a parallel with the way he previously allotted discrete integers to particular pitches, Hiller concluded that it was possible to symbolize rhythm numerically. Taking advantage of the existing binary coding structure of the computer, he assigned the numerical value of "1" to represent a "sounding" of a note, and "0" to represent a "rest", or "holding" of a previously played note. Short

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[254]Hiller, op. cit., p. 110.

sequences of integers zero and one could then embody a sequence of note values, each sequence capable of precisely representing a personally assigned duration, be it quarter note, whole note, etc. Since rhythmic patterns are generated in interaction with values of meter, meter had to be defined as well in numerical terms in order to be properly encoded into the program instructions. In order to keep this issue as simple as possible, Hiller adopted the 4/8 meter as the best matching with regards to the existing coding structure in binary terms:[255] by assigning four eight notes to the measure, and restricting the smallest rhythmic value to that same value as well, simple permutations of four binary digits could be used to depict the four beats of a measure in 4/8 signature. Table 4 depicts Hiller's assignment of values, ordered according to a system of numerical representation.

Hiller was now able to generate random integers between 0 and 15, pouring the required rhythmic pattern into the mould of each measure. It was now easy to create random integers for different types of meter as well: if a triple meter was required, random integers ranging from 0 to 7 were requested;[256] quintuple meter required random integers between 0 and 63.[257] This setup would, in fact, produce a different type of rhythm for every single bar of the 'composition'. However, taking some stylistic considerations (model-based) into account, rhythm had to be subject to some rules in the compositional design as well. On one hand,

[255]The binary system is able to depict numerical values up to a maximum of 16 bits, conveniently depicted with a maximum of only four integers, in this case: 1111.

[256]A permutation of 3 equals eight possibilities.

[257]A permutation of 5 produces 64 possibilities, etc.

in order to gain a musical profile beyond its most rudimentary expression, the scale of integers had to be sufficiently wide to allow the generation of the smallest useful time increments. However, on the other hand, a certain amount of repetition seemed desirable. Therefore Hiller, in order to produce even more challenging results, proceeded from here on to include a second subroutine which controlled the number of measures assigned to a particular rhythmic pattern before being allowed to switch to a new pattern.

> Since the simplest form of rhythmic **redundancy** is literal repetition, the first step we utilized to reduce further the randomness of the rhythm was a simple random repetition scheme. In each voice, a rhythmic pattern was generated according to the method outlined above and then a subsidiary random integer, which was permitted in our particular experiment to have values between 1 and 12, was generated. This subsidiary parameter was used to control the number of measures a particular rhythmic pattern would be sustained before a new rhythmic pattern was generated for the voice in question...This was the first and simplest of the rhythm codes we produced.[258]

Hiller's next step was to introduce some horizontal and vertical **redundancy**: this was accomplished by writing a second rhythm code, including the aforementioned second subsidiary random integer, but in this case the random process would accept values from 0 to 15. The procedure, which was analogous to the selection of rhythm integer sequencing, involved notation in binary form. Hiller described the procedure as follows:

> This time, in this new subsidiary random number, "ones" [1] were used to represent voices required to play the same rhythm for the number of measures determined by the first subsidiary random integer, the lower voices being used as the master voices, whole zeros [0] were used to represent voices for which rhythms were generated independently. Thus, the representation of

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[258]Hiller, op. cit., p. 113.

> 0000 meant that all voices would have independently generated rhythms, so that vertical duplications would occur only by coincidence. On the other hand, the representation 1111 was used to mean that all voices would have to play the same rhythm, the rhythm being generated by the lowest voice. In between these extremes, a representation such as 0101, for example...indicated that voice 2 and 4 would play the rhythm generated for voice 2, while voices 1 and 3 would be rhythmically free.[259]

Certain integer combinations, however, would not produce meaningful results at first and had to be eliminated within the routine.[260] Further problems arose while combining both redundancies, especially with regard to the question as to which of the two should take precedence in case of conflict. In this case it was decided to give precedence to the vertical-combination rule. Finally, the rhythm code would be printed out in binary sequence form by Teletype tape, and the corresponding rhythmic values would again be transcribed by hand into musical notation.

ii) Dynamics

While he used a very rudimentary table, involving a four-integer instead of a random-integer matrix, in order to assign dynamic markings to the individual voices outside the programming routine during Experiments ONE and TWO, Hiller, in Experiment THREE, attempted to integrate the creation of this parameter into the computer routine, including dynamic processes such as *crescendo/diminuendo*. In assigning values for dynamics, Hiller worked out a similar set of operations

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[259] Hiller, op. cit., p. 113.

[260] For example, 0001, 0010, 0100, and 1000, producing three voices free, and one the same.

as for rhythm, but with only six values (*pp, p, mp, mf, f, ff*). Further dynamic variations were induced by a second subroutine, which determined changes through a process of random integer selection of numerical values 0, 1, 2, representing *dim, no change, cresc.* The two unacceptable possibilities of *cresc.* following *ff*, and *dim.* following *pp*, were eliminated by a screening operation imbedded into the subroutine as well. The problem of assigning duration to the dynamics for each voice independently was solved by setting up a scheme of random integer operations similar to the one previously conceived for rhythm. Hiller decided, just for the sake of convenience, that the dynamics code, even while embedded in the same computer program, should not in any way be coupled with the rhythm code: both operations were driven by independent sets of parameters. The output was printed using the letters F, P, and M; other dynamic markings were [,], [=], or[()], used for *cresc., constant level, or dim.* respectively.

iii) Articulation

When assigning values for individual timbre, sound colour, and type of attack, Hiller again limited his choice of performance instructions to 16. In cases where certain instructions would be impossible for musicians to perform, Hiller offered a synopsis of alternatives.[261] Once again, Hiller applied a coding technique similar to the one used for rhythm and dynamics, except that the hexidecimal system, rather than the binary code, was used for random integer generation (probably just for the convenience of clearly distinguishing this particular output from other types of computer output presented in binary form). As a result, it

[261]See Table. 5. in the appendix.

was also possible to compute the assignment of articulation modes to individual voices, taking into account the aforementioned collaborative schemes for the horizontal and vertical organization of the score. This was done in a manner similar to the instruction routines for rhythm and dynamics. Increased vertical **redundancy** was achieved during a revised second code which caused a more uniform coordination of articulation between voices. An example of a direct computer output can be found in the following table, followed by its (hand-assisted) transcription, both provided by Hiller.[262]

iv) Random Chromatic Music

Hiller decided that the program design for the selection of pitch, in the examples mentioned above, should follow a different route from the one chosen for strict counterpoint as in Experiment TWO. His objective was to offer a more liberated base for note selection in order to allow music writing in a more contemporary style. Although the same random-integer selection operation was used as in Experiment TWO, instead of using only the white keys representing the repertoire of the C major scale, a basic chromatic scale from C to F#" was chosen, represented by integers from 0 to 30. The printout format was improved to allow the representation of pitches by letters A to K, including accidental modifiers X (for "sharp").[263] The results were printed along with the corresponding rhythm

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[262]See Fig. 19. in the appendix.

[263]FX would then mean F#. Because of enharmonic exchangeability, a modifier for "flats" could be eliminated.

code, all output therefore conveniently lining up in blocks of four-to-one segments.

v) Simple Chromatic Music

> It was of interest to carry out at least one experiment with random chromatic music to illustrate how a degree of order might be imposed upon this elementary material by simple means. Therefore...four compositional rules were imposed on the selection process. The particular rules selected for this purpose were employed because it was felt that these rules would impose a relatively high degree of order with a minimum of actual instructions.[264]

The following section summarizes the four rules employed:

Rule (1): the same rule as originally selected for Experiments ONE and TWO, but augmented to include the chromatic scale.

Rule (2): the melodic octave-range rule, ranging back to a maximum of 24 preceding notes, with a revision so as to include modification options as early as after 12 tones, if the last 12 notes contained melodic matter spanning less than an octave.

Rule (3): a more complex operation to address the problem of tritones-complex because it provides the only harmonic control over the musical material being generated. It is not necessary to explore this area in greater detail, since we are using Chapter III mainly as a point of reference for further investigation of information theory.

Rule (4): To quote Hiller:

> ...whenever the octave-range rule was violated by a tritone resolution, the resolution was permitted, and the reference point for the octave range was moved up time-wise in the musical structure so that the rule

[264]Hiller, op. cit., p. 118.

> would again be satisfied; that is to say, a new octave range was set by the tritone-resolution note. It should be noted that this fourth rule is of considerable interest (themes ?). It is a simple example of a built-in rule-revision process.[265]

A summary of the actual composing process according to the above four rules is depicted as a flow-chart in the following figure.[266] In fact, the organization of the operational flow chart depicted above parallels the logical outline of the flow chart in Experiment TWO in its principal details. Many operations are indeed based on similar routines, with some modification in the coding to accommodate the expected greater complexity of rules involved. At this point of our investigation, it will be easy for the reader to follow the routine without additional explanation, starting with **INITIAL ENTRY**, and finishing with **PRINT AND STORE LAST 12 NOTES**, as a new cycle is initiated by **RESET/NEXT CHORD**.

At the end of Experiment TWO, our investigation regarding the influence of information theory had been given a new perspective and direction. It was found that Hiller had covered the area of compositional strategy involving the extreme restrictions of random-generated musical material very well. Nevertheless, it also became clear that any further research in this direction would merely produce similar, monotonous results. It was therefore concluded that any meaningful research towards the detection of distinct applications of information theory had to be pursued in a direction opposite to that of the preceding analytical process, initiated at the beginning of this chapter. In fact, it became clear that a dead-end situation had actually

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[265]Hiller, op. cit., p. 120.

[266]See Fig. 20. in the appendix.

been reached on the micro-structural level of single-event calculations, which was not consistent with the concept of information theory. Reversing the direction of our investigation, we gradually developed an understanding of the influence of larger sections again, progressively moving towards the random-based model universe, simulated by the Monte Carlo Method, on the other end of the spectrum.

At this point, I would like to propose that, once the inert operation of a particular flow chart is understood in whole detail, it is no longer necessary for the reader to follow the same analytical process every time a new random integer is tested. Especially in cases involving the restrictive type of compositional model, as in Experiment TWO, it will be sufficient to understand what the entire system can do, and what it cannot. As a matter of fact, it will be quite sufficient for our purposes to be able to predict the amount of differentiation with regard to input(coded rule structure) and output (musical composition) in a given "system". We have, in fact, actually created a situation reflecting the model of a "black box", which corresponds so well to the characteristics of cybernetics and automation theory, the latter being closely related to computers. Having learned that Hiller's flow chart for Experiment THREE (depicted above) employed a similar general logical outline as the one used in Experiments ONE and TWO, we can now consider the above illustration as sufficiently well defined for our purpose, allowing us to move on to the next subject: Hiller's attempt to code interval rows and tone rows.

vi) Interval Rows and Tone Rows: An Excursion into Serialism

One simple way to initiate a study of the relationship between **entropy** and melody is to consider a twelve-note melody. If we were to tabulate all possible twelve-tone

> melodies, we would see that the number of possible melodies could be expressed in terms of elementary permutation theory. Thus, [if] we require only that the twelve notes be selected from twelve possible tones with no restrictions in regard to repeats of tones being required or forbidden, we observe that we have defined the condition of random music within this limited situation. If this condition applies to all twelve notes, 12^{12} melodies are theoretically possible -an enormously large number.[267] This is the situation of **maximum entropy**, or **information content**, in terms of the choice process..., but it is not necessarily the condition of **maximum entropy content** in terms of tonality.[268]

We can define both extremes of the spectrum encompassing all the possible types of 12-tone melodies. On one end of the spectrum, all the notes of the melody are the same, and on the other, all the notes are different. In the first case, a minimum of **entropy** or maximum of **redundancy** exists,[269] constituting an extreme of tonality. In the second case, however, where all tones are different, Hiller continues: "...each tone of the chromatic scale is sounded just once in some specific order which may or may not be randomly produced. This is, of course, the tone-row concept first significantly exploited by Arnold Schönberg."[270]

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[267] 12! = 479,001,600 possibilities, to be precise. However, as common writing strategies often use compositional means to induce redundancy by means of, for example, inversion, retrogression etc., the number of practically available tone rows will be significantly lower.

[268] Hiller, op. cit., p. 125.

[269] In this case, there will be a maximum of 12 melodies (if full freedom of choice is granted for the first tone), and only one if the choice is restricted to a specific pitch.

[270] Hiller, op. cit., p. 125.

Going back to our definition of structural redundancy, the situation involving an atonal row exhibits a minimum level of redundancy. This leads to the suggestion of a coding strategy which would have the construction features of atonal tone rows ruled rather by the model of random music than by the strategies employed thus far, calling for restrictive devices by means of coded rules. If pure tonality and atonal row technique can be considered as the extremes of a spectrum spanning all possibilities in between, it should be easy to obtain any location within this spectrum simply by means of appropriate coding, using an almost identical overall programming strategy. This, as a matter of fact, is why Hiller could easily adapt the flow charts of Experiments ONE and TWO to produce Experiment THREE, an application ranging from random chromatic music to interval rows and tone rows, with only a minor change in compositional strategy.

Now if the melodic profile depends "not upon the succession of the twelve tones of the chromatic scale as such...but upon the mutual interrelationships between the twelve notes in terms of intervals",[271] Hiller concludes that the melodic profile can be expressed in terms of intervallic relationships with any of the twelve tones as a possible point of reference. Thus, it contains a series of all possible intervals related to a chosen point of reference. However, if intervallic relationships between successive tones are considered, it can be deduced that a certain redundancy of repeating intervals might occur. It is also possible to construct tone rows which exclude this possibility of repeating intervals within the successive structure of the row: this would result in an "all-interval row". Going back to the question of coding, we notice that

[271]Hiller, op. cit., p. 126.

eleven choices of intervals are initially allowable. However, every time one interval is chosen, it has to be excluded from the pool of choices as repeated intervals are not permitted.

This, however, if scheduled to be coded in one of the above programs, would constitute an entirely new situation regarding how the formerly used random integer emission process would be generated: balls, once taken from an urn during the process of successive selection of elements, would not be allowed to be returned back into the urn, as was permitted before (simulating a choice procedure of a totally random nature). In other words, the moment we have selected a specific element and taken it out of the urn without permission to return back into the pool, all probabilities concerning the remaining elements in the pool are destined to change as well. The former model of constant replacement symbolizes an equi-probable source of information, the latter a stochastic type of information source. Hiller, instead of modifying the existing initial code used in Experiments ONE and TWO, set out to simulate the situation of a random universe through a more appropriate and effective mathematical representation: n-th order Markov chain processes.

The last three tests performed in Experiment THREE went beyond what was presented in the final results (as embodied in the final score of the ILLIAC SUITE), and it is not necessary for our purpose to discuss the setup of the specific algorithms in further detail, except to recognize that Hiller used a similar block diagram for testing procedures as in all his former experiments which we have already discussed. The print-out of the experiments involving tone row construction was conveniently arranged to consist of a block of four lines, containing: (1) the row itself, (2) its inversion, (3) its retrograde, (4) its retrograde inversion, with lines (2) to (4) being conveniently derived from simple arithmetic calculation based on (1).

d) Coding Patterns: EXPERIMENT FOUR

While Experiments ONE, TWO, and THREE were primarily designed to create a musical score which would fit, in principle, the requirements of the "traditional music" approach (strict counterpoint, chromatic writing, and atonal style), the objective of Experiment FOUR was to develop a new code which would allow the exploration of more abstract musical forms. There was still some influence which could be traced to existing compositional strategies addressing tonality or melodic profile, but in principle Experiment FOUR was intended to seek new possibilities of compositional design and theory.

The objective of this dissertation being to detect performance indicators where information theory could have played a major role regarding the development of innovative compositional design, a comprehensive coverage of the experiments conducted by Hiller as part of Experiment FOUR will be attempted only where it is found to contribute significantly to the aforementioned objective of the thesis. While Experiments ONE to THREE were primarily concerned with the "traditional" approach,[272] Experiment FOUR tackled a decisively innovative approach, one of great interest as an application of information theory. Hiller states the

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[272]Respectively: (1) Variation of a zeroth-order harmonic probability function from complete tonal restriction to "average" distribution; (2) Variation of a zeroth-order harmonic probability function from random to "average" distribution; (3) zeroth-order harmonic and proximity probability functions combined. Please refer to Table 2. in the appendix.

objective of this particular last set of experiments as follows:

> . . . simpler and perhaps more fundamental means of musical construction were investigated than those studied previously. This was done in an attempt to find more inclusive concepts to work with, and, in particular, concepts which might be thought of as a geometrical analogy of musical form.[273]

Hiller goes on to describe the experiment as follows:[274]

> The fundamental geometrical picture selected was an abstraction of the calculating technique used in the three previous experiments. The generation of four-part musical structures was pictured as a restricted random-flight problem in which four trajectories are traced simultaneously upon the rather unusual coordinate system of pitch versus time. This geometrical structure...can be subjected to mathematical definition, as we have already indicated...It is particularly characterized in terms of Markov chain processes, i.e., sequences of events in which the choice of each new event can be made dependent upon previous events; or, in musical terms, the choice of each new note or interval in a given melodic line can be made dependent upon previous notes or intervals in the same melodic line. Utilizing this simple picture, we wrote computer programs for generating a series of samples of what we may call *Markoff chain music*[275].

In developing an elementary concept for a structural framework within which melodic and harmonic representations could be implanted, Hiller claimed that melody construction and tonality depend both on successive and long-range intervallic relationships. In order to add formal structure (to induce redundancy, that is) to the process of melodic composition, he introduced two operational sets of functions related to melody construction, termed *Harmonic and*

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[273]Hiller, op. cit., p. 132.

[274]See Fig. 21. in the appendix.

[275]Hiller, op. cit., pp. 132-133.

Proximity[276] *Functions*. Both functions were based on the following concepts: (1) In order to recognize a harmonic function, the melodic profile could be related to the overtone series, worked into the overall construction design. (2) Stepwise motion in successive progression of melodic pitches tends to correspond to a higher order of harmonic content than larger leaps. These melodic intervals could then be quantified according to their absolute size. (3) Hiller claims that a "well-balanced" melody contains "sequences of intervals which balance the tendencies to order and disorder by balancing harmonic clarity with ambiguity, and stepwise melodic movements with larger skips".[277] Hiller calls these the "*harmonic*" and "*proximity*" functions, implying that the presence of both functions constitutes a successful operational principle for writing even the most rudimentary type of melodies.

i) Weighted Probabilities

As he attempted to expand his experiments toward the formalization of larger and more complex compositions, Hiller found that using the elementary model of a structural framework worked best in terms of an easy assembly of melodic lines. The musical output would solely depend on assigning quantitative values to both of the functions described above, defined as x_j (harmonic function), and y_j (proximity function). Using Markov chain processes as an algorithmic tool, Hiller performed experiments to investigate the assembly of melodies with these functions as

[276]...or neighbour-note relationship function.

[277]Hiller, op. cit., p. 133.

operators. Beforehand, a reference table for weighted probabilities had to be designed and placed into the computer program.[278] In order to avoid the massive data storage required by a table of this sort during computational processes, Hiller would undertake that

> this table [have] as few bits of basic information as possible, but that this information be of as fundamental significance as possible . . . Therefore, the table was constructed for arranging all successive melodic intervals from the unison to the octave.[279]

The following table shows a listing of intervals in order of increasing dissonance from top to bottom. The coding required that a stochastic variable v_j, increasing from 0 (unison) to 12 (octave), be associated with each interval. These stochastic variable values could then easily be added or subtracted from each representative tone value of a melody in order to define the next tone in the melody line. This, however, amounted to an arithmetic process of

> moving through the interval represented by the variable. A melody could, therefore, be symbolized by a sequence of values $v_i = v_1, v_2, \ldots, v_n$, added successively to the first note of the melody. ...intervals, rather than tones, were used as the determining functions for assembling melodic structures".[280]

Hiller's table is given in Table 6, depicting the harmonic function ranging from 13 to 1 in descending order

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[278]Hiller mentions, during experiment FOUR, that this strategy had been used, in essence, during experiments ONE to THREE as well, except that either the transitional probabilities were set to be random-choice (equiprobable choice), or some choices were given zero weight, i.e., the numerical value of zero was given (the coding of counterpoint rules, for example, were often achieved by this alone).

[279]Hiller, op. cit., p. 136.

[280]Hiller, op. cit., p. 136.

of consonance. Hiller defined this particular sort of arithmetic ordering as an "unperturbed" set of weighted probabilities for the harmonic function x_j, as it was expected to reflect standard distributions of probabilities such as those found in conventional music textures. Hiller goes on to state that,

> ...if these values are used directly for interval selection, this brings out, *on the average*, the selection of repeats thirteen times as frequently as the tritone, and so on. It was believed that this simple arithmetic scale of relative weights for the harmonic function would be an adequate representation of a neutral or mean position in terms of the imposition of tonal order. It is upon these values that we had to operate in order to perturb the *mean* harmonic texture, and thus achieve a higher or lower average degree of tonality.[281]

The values for the third column (proximity function y_j) have been derived from the following distribution: all values would run down from 13 to 1 as in x_j. However, the order of the stochastic variables was changed, resulting in the highest perturbed weight being assigned to the unison, the next lower one to the minor second, and so on. The "combined function" z_j represents the sum $x_j + y_j$, expressing a scale of weighted probabilities closely resembling qualities found in conventional melody writing. The equations supplied at the bottom of the table provide the sum of the weights of each of the functions described above, which were required to determine the average frequency of occurrence of each interval.[282] A full spectrum of compositional choices

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[281]Hiller, op. cit., p. 137.

[282]If x_j alone were used, a relative frequency of, for example, 10% could be expected:

$$\frac{x_4}{\sum_{j=0}^{12} x_j} = 9/91 = 0.1$$

ranging from fully tonal to anti-tonal (tone row) examples of writing could be established, owing the amount of consonance or dissonance solely to the weight of their given transitional probabilities.[283]

> Thus, the simplest order is imposed upon random-note music by weighting certain zeroth-order transition probabilities more heavy than others. In terms of information theory, random-note music is characterized by maximum entropy content, while the weighting of transitional probabilities in any direction...decreases entropy by increasing redundancy.[284]

This is indeed a clear statement of the influence of information theory in generating musical textures.

ii) First Order Markov Chain Music

Musical structure can be subjected to further levels of order by using the aforementioned strategy of making the selection of events or intervals I_i dependent on a chosen event or interval I_{i-1}, which is the case in first-order Markov chain music.[285] Using in principle the same transitional probability functions as before, Hiller specified that the weight assigned to the choice of the new

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[283]However, as tonality is defined as recalling events before note N_{n-1}, in our example, the degree of consonance or dissonance has nothing to do with a commonly established model of tonality, but rather with the type of consonant or dissonant intervals chosen during the assembly of the melodic line.

[284]Hiller, op. cit., p. 142.

[285]For instance, an example of compositional rules of the type involving first-order Markoff processes was the skip-stepwise rule formerly employed in the strict counterpoint experiments.

interval I_i should take precedence over the previously selected interval I_{i-1}, and should favour the interval being most different from that particular interval I_{i-1}: a decision clearly designed to preclude intervallic repeats. Again, simple arithmetic addition was used to modify the same table containing the weighted transitional probability functions with which we are now familiar. Again, three samples of first-order Markov chain music were generated, in the same manner as the samples obtained for zeroth-order Markov chain music.

iii) Higher Order Markov Chain Music

Instead of imposing additional levels of structural order onto musical texture simply by successively increasing the n-th order[286] of Markov processes,[287] Hiller decided to combine the formerly mentioned first-order Markov process with the concept of defining the notes which are structurally more important and less important according to their position within the timing structure of meter: first-order or zeroth-order Markov chain music processes were used

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[286]For example, a third-order Markoff process results when the choice of a new event is made dependent on the previous three events, and so on.

[287]As mentioned before, this experiment had been conducted shortly before Hiller's ILLIAC SUITE project commenced, by Klein and Bolitho, who wrote melodies reaching 8th-order Markov processes, whereas Hiller found no advantage in terms of improving the compositional method and creating more interesting musical textures. On the contrary: because of the long-ranging dependencies of notes, the entire texture thus created became devoid of any possibilities to offer sudden changes in harmonic progression, which is considered so important for aesthetic gratification.

to assign notes to the strong beats,[288] while weak beats received allocated notes derived from the underlying functions themselves.[289] Concerned as he was with his objective to produce music with a greater resemblance to existing, "normal"[290] musical structures, it is here that Hiller, for the first time, clearly compromises the logical extension of the compositional principle which he had followed consistently to this point. He simply stated (see Fig. 22. in the appendix):

> In this elementary way, we built up simple structures analogous to those suggested by the analysis of conventional musical structures. Specifically, the harmonic function was used as a longer-range structural function to block in larger tonal relationships, while the proximity function was used to provide melodic filler inside these larger units.[291]

The last sample generated for Experiment FOUR dealt with the problem of the persistent non-tonal content of an entire melodic composition where each selected note related only to the preceding selected note (in this case, if a first-order Markov chain process was selected). In order to eventually force tonality into the concept, a rather rigorous change of procedure was introduced to relate all newly selected notes not to the preceding ones alone, but to the initial note of the entire melodic line, thus resulting in the algorithm N_i-N_1, rather than N_i-N_{i-1}, as was previously obtained. The consequence was, of course, immediate tonal control at a very basic level. Again, on strong beats, the

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[288]Here, arbitrarily chosen to be 6/8 meter.

[289]Harmonic function, or proximity function, respectively.

[290]Hiller, op. cit., p. 146.

[291]Hiller, op. cit., p. 146.

harmonic function was used, employing the same time structure of 6/8 meter. As the overall tonality of the ILLIAC SUITE was chosen to be C, the initial and last note of this last experiment was set to C as well. Weak beats were again ornamented with melodic fillers, dependent of ne proximity function alone.[292]

A scheme for block-wise modulation was introduced by setting new reference points in an *i*-th order Markov chain process. This was done by simply letting a random-generated subroutine decide after how many bars a new point of harmonic reference should be set. By leaving the number of bars to be chosen at random, but specifying the tonality that the melodic writing would switch to (for example, from C to F), simple cadences could easily be imposed on the musical output of the computer. Following a model-oriented approach to compositional strategy, Hiller's objective was from now on to produce a clear result without additional coding in the original instruction program:

> However, instead of rewriting the instructions, a simpler method involving the printout routine was employed, (<u>themes</u> ?) it was evident that modulation is really nothing more than a transposition of the printed results. Thus, to shift from C to F, all we needed to do was to add the number 5 to each note while it was still in the machine as a number. This converted a C to an F upon printing...and yet did not disturb the basic note-generation process. It is seen that this is effectively what is done by any musician or composer in effecting a transposition or a modulation.[293]

That Hiller hastily equates transposition with modulation, even if it would only be valid if seen as a structural procedure, could be forgiven in view of his objective to bring the last movement, and the ILLIAC SUITE to a quick

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[292]See Fig. 23. in the appendix.

[293]Hiller, op. cit., p. 149.

end. However, in view of his intention to access structural principles of a higher order in terms of formal proportions by means of an automated computer procedure alone, the methodical rigour to which he had so thoroughly adhered thus far has clearly been abandoned at an early stage. It was replaced with a pattern adapted from outside influences (formal conventions, based on analytical studies of traditional sources of music): another model-based approach has evidently been chosen to replace composition theory.

From here on, Hiller proceeded to impose structures of a larger formal order by means of a harmonic device called "tonal drive", claiming that a carefully planned sequence of progressions tends to give the listener a sense of completion after modulation. Quoting the structural principle involved in the classical sonata form as an example of tonal drive, he proceeded to approach the final tonality of C by simply reversing the process previously utilized to generate the first example of Markov chain music. The instructions were incorporated into the program, and this was achieved by simply specifying the values of transitional probability functions which were not to be added as before, but subtracted as unity values after every six notes (two beats): after twenty-four measures, melodic repeat (unison) was reached automatically, as the first-order Markov process involved allowed *i*-th harmonic order only on the strong beats, forcing the final resolution to the key of C. Melodic skips became automatically smaller toward the end of the composition, as the first-order proximity function affected the weak beats only.

> Therefore, the application of the harmonic function as an ith-order Markov chain process on the strong beats and the proximity function as a first-order Markov chain process on the weak beats, along with the process of shifting the tonal reference point after every six measures and the shift of the transition probabilities after every two measures by unit subtraction until only a melodic repeat could occur, permitted the production

of a simple closed structure of twenty-six measures, which represent an extended cadence leading to a final close. This structure was utilized as a *coda* for the last movement of the ILLIAC SUITE to serve as a simple prototype for building up more complex structures, such as conventional musical forms.[294]

7. Final Assembly: The ILLIAC SUITE

The ILLIAC SUITE was formally assembled as a four-movement suite, each movement containing and paralleling the results of one of the four major groups of experiments (ONE, TWO, THREE, FOUR). The resulting composition, entitled ILLIAC SUITE, in direct reference to the name of the computer which generated the experiments, represents *in toto* a chronological research record of the experiments performed. All four movements correlate with details of the experiments.

The performance medium chosen for the sonic representation of the piece was that of a string quartet, for the sake of relative homogeneity with regard to timbre, but mainly also for pragmatic reasons: a university string quartet was available at that particular time and location.[295] As we previously mentioned, score arrangement was performed by hand, transcribing computer printout samples into a readable score format. In order to be able to claim the maximum involvement of an automated compositional procedure, the most direct transfer of musical data was the preferred method. However, sometimes it took human judgement

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[294]Hiller, op. cit., p. 150.

[295]"The use of electronic or other synthetic means was eliminated in our case, since equipment of this type was not available". In: Hiller, op. cit., p. 153.

to decide which elements of the score had to be adjusted or inserted in order to present a score of practical performance qualities.

Furthermore, as the number of musical samples produced by the computer output exceeded what was required for the final suite, Hiller resorted to a kind of "unbiased screening procedure" to select representative musical specimen. He set up certain selection procedures to prevent any infiltration of aesthetic choice: retaining every n-th example, using a random-integer table, or arbitrarily selecting the first or last number of a series of experimental outputs. The overall formal scheme was predetermined by hand, except for the last section in Experiment FOUR (the Coda) which was, as described, entirely produced by the computer. Tempo markings were chosen by hand as well. Further adjustments included an adaptation of the range set for the instruments: Voice 1, assigned to the cello, was transposed two octaves down; Voice 2, the viola, one octave down as well; the registers of violins I and II, on the other hand, were left unchanged.

In Experiments ONE and TWO, dynamic markings were again selected according to some subsidiary random-integer tables. Towards the end of the suite we find a reduction of four voices into two: an arbitrary choice made by Hiller, to "add some variety" to the musical texture of Experiment FOUR. Finally, the selection of meter occurred during the transcription process as well. The formal structure of the ILLIAC SUITE reads as follows.[296]

a) Scoring EXPERIMENT ONE

Within movement No. 1, the score shows a clear progression from a monodic to a four-part writing style,

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[296]See Fig. 24. in the appendix.

structurally marked by three different tempos. The first section (Presto) was created by stringing together five samples of different lengths obtained[297] in the context of various experimental settings: these were arbitrarily chosen from 50 samples originally produced. The distribution of the monodic passages was determined by means of a four-choice random-integer table provided by the computer: the assignment of instruments went according to the number chosen, including the situation where the repeat of a random integer would be read as one integer value only. Dynamic markings (4 values) were assigned by the same procedure involving a random choice table.

The last chord ("pizz") of movement No. 1 was an arbitrary insertion to formally mark the beginning of the second section (Andante). This movement consists of an assembly of samples containing two-part *cantus firmus* settings, again ranging from 3 to 12 notes: these were first compiled successively, then in reversed order to accommodate the desire to change the musical texture in relation to the Presto; the other variables of part assignment and dynamics were obtained by means of the same procedure as described above.

The third part (Allegro) follows the structural design of the first section by assembling a group of *cantus firmus* settings of increasing length, even allowing tie-overs of many notes, in clear violation of the rule against successive repeats. Finally, the entire movement, "Experiment No. 1", concludes with the insertion of a *pizzicato* chord, suggesting the notion of formal symmetry.

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[297]Fifty samples ranging from 3 to 12 notes were produced.

ii) Scorinj EXPERIMENT TWO

The sequence of Experiment No. 2 takes the writing of first-species strict counterpoint from a textural state of random music (no rules), to the imposition of a maximum number of rules with sequences consisting of 12 notes. The first two samples selected represent purely random music, followed by the successive addition of a new set of rules according to the following formal scheme.[298]

The final four cadences were devised by the cadence subroutine described earlier. Values for dynamics were obtained by a random-integer table as before. With regard to the influence of concepts of information theory, I would like to quote Hiller:

> A comparison of these settings illustrates how order can be imposed upon random music by...logical processes...Experiment TWO, therefore, is a simple musical illustration on how the introduction of **redundancy** into a structure with a relatively high **entropy** content brings about a clarification of texture...Since the settings also became progressively more difficult for the computer to work out, this experiment also shows how **redundancy** reduces the **information** which may be communicated and how increasing the **redundancy** can only be brought about by increasing the amount of material which must be rejected.[299]

Remembering the pivotal situation reached in Experiment TWO, and taking the above quotation into account, Example No. 2 exemplifies very well how Hiller was able to gain control over the micro-structural and macro-structural consistency of a musical texture through general aspects of information theory.

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[298]See Table. 7 in the appendix. According to Hiller. In Experimental Music, p. 158.

[299]Hiller, op. cit., p. 158.

iii) Scoring EXPERIMENT THREE

To summarize the first movements of Experiment THREE, the first three sections stemmed from the three codes affecting dynamics, rhythms, and articulation. However, the selection of pitches, which was not part of these experiments, was achieved by means of an arbitrarily chosen tone row; all other material used was directly transcribed from the computer output. Section [C] represents an example of random chromatic writing, followed by an even higher degree of complexity of rhythm, dynamics, and articulation in Section [D]. The musical texture of section [G] is a direct result of rule imposition upon random chromatic music. [H] appears to be rather dissonant as a result of the combination of the material with the second code affecting rhythm, dynamics, and articulation. The coda which follows, in [K], features the three sample tone rows of an interval row, a tone row, and a restricted type of tone row. Arbitrarily, the cello was assigned to play all three tone rows successively, with the remaining musical structure to be set as accompaniment with its geometric variations (inversions, retrograde inversion, and inversion) easily obtained by changes entered into the printing instructions.

iv) Scoring EXPERIMENT FOUR

Tempo and meter were again arbitrarily chosen for the last movement of the ILLIAC SUITE, and samples which were obtained from the computer printout in blocks of four (monodic) lines at a time, were directly transcribed into a musical score. The first two sections show clearly how varying transitional probabilities (which are here dependent on the harmonic function) directly affect the type of music texture obtained. In this case involving a zeroth-order

Markov chain process, the transition probabilities are altered every two bars, beginning with sections of unperturbed, "average" distribution, and eventually covering the entire range to the point where only repeats are allowed. From section [A], a similar process of structural change occurs, but reversed in the direction of increasing order, ranging from total random distribution of intervals to what was formerly marked as "average" distribution: structural redundancy had thus been introduced into the musical texture. Sections [B] and [C] have been devised by means of operations influenced by the harmonic function, or the proximity function, respectively, while Section [D] was a transcription of the results of the combined functions.

Sections [E], [F], and [G] involve similar compositional strategies as above, but were created by means of first-order Markov chain processes, some of which were arbitrarily chosen to present themselves in the form of two-part writing only, except in Section [G], which involves the implementation of the combined functions. The following short sections, from [H] to [L], show examples of the formerly described strong/weak beat strategy, first for zeroth-order, then for first-order Markov processes. Hiller concluded the description of the coda as follows:

> The coda of Experiment FOUR appears to disclose in a satisfactory way all the features expected of it as described...The modulations worked out as planned, and the harmonic and melodic simplification develops measure by measure as planned until the end of the movement is approached...All of this worked out in accord with the computer programming and indicates that the design of more complex closed musical structures might be started by using this simple prototype as a point of departure.[300]

So now, was Hiller able to stand back and say: Mission accomplished?

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[300]Hiller, op. cit., p. 164.

8. Summary of Results

At this point, having been able to program a computer to write music, Hiller had accomplished his initial objective. Through proper coding, he was able to simulate compositional techniques ranging from strict tonal counterpoint to examples of random generated music - in fact, encompassing a broad spectrum of established as well as innovative compositional strategies. However, as we evaluate the significance of Hiller's contribution to the birth of computer music, it becomes evident that his strongest point was not the fact that he devised new coding processes and their ensuing output of musical textures, but the uniqueness of his approach in developing a new point of view from which various musical forms and compositional processes could be explored: it was the relationship between information theory and the musical problems encountered in coding a computer system to write music that started this important endeavour.

With regard to our subject, we can see that, in fact, some fundamental concepts of information theory had considerable repercussions in the overall design of Hiller's new compositional strategy. As our investigation progressed, tracing the creation process of the ILLIAC SUITE meticulously, we also found that the impact of this theory was weakest on the elementary level of micro-structure, and gradually became more significant as we moved towards compositional strategies affecting the level of macro-structural design. In fact, we did not discover a dialectic principle of application, but the continuum of a full spectrum of stronger or weaker forces, affecting the process of compositional creation on all levels throughout the assembly of the final score. Music, as a special case within the broader concept of acoustic communication, could actually be treated as such: a concept of communication.

Even if Hiller had addressed only those parameters of acoustic communication which could more easily be quantified (such as pitch and rhythm), the quality of the musical output produced was sufficiently promising to encourage further research in computer music composition, and not just for Hiller: the ILLIAC SUITE marked the beginning of a development which has, in many respects, already surpassed most of the predictions he made in 1959, in his publication "Experimental Music".

Adopting Shannon's idea of a basic model of communication, Hiller developed his compositional design from the standpoint of the rule-based compositional strategies which we have discussed: starting with the technique of restricted random integer processes [in the case of an equi-probable source of communication], he went on to extract orderly structures from this random universe, inducing redundancy by means of computer instructions acting as algorithmic sieve modules. The effectiveness of these modules, consisting merely of numerically encoded instructions (representing and expressing musical rules), could then easily be studied in their reaction to added numerical input and the resulting changes in musical texture.

Having been able to simulate traditional compositional design through such strategies, he attempted a more abstract formalization of musical composition in terms of probability theory and information theory, which resulted in creating musical texture through Markov chain processes.[301] As it turned out, it worked, and the musical output of all his experiments was assembled, resulting in the final version of

[301]"This last project was carried out to initiate a study of whether a more fundamental basis than the conventional rules of composition might exist for imparting order to musical structures". In: Hiller, op. cit., p. 178.

the ILLIAC SUITE. Even if not considered as a great artistic success, Hiller's experiments were of extraordinary importance,[302] opening the door to new vistas in developing the potential of the computer as a unique musical tool.

[302]David Cope: New Directions in Music, op. cit., p. 190.

CHAPTER IV - THE COMPUTER CANTATA: A STUDY OF COMPOSITIONAL METHOD

1. Improvements in Rule-Based Compositional Design

The purpose of Chapter IV is to investigate certain aspects of the influence of information theory on computer music composition in Hiller's work that could not be discussed in connection with the ILLIAC SUITE. Indeed, the experiments leading to the SUITE - as groundbreaking as they were from a developmental point of view - did not include strategies to address one of the most pressing issues concerning compositional methods directly related to information theory: that of the generation of the overall form.

Beyond some preliminary arrangements in coding structure, and with some exceptions in the final coda, the overall musical form of the ILLIAC SUITE took shape mainly through arbitrary decisions on the part of the composer, not through the computer program, which merely supplied musical textures. In other words, in terms of the compositional method and its consequences, the ILLIAC SUITE is a compromise, a compositional hybrid, where rule-based strategies were employed to create musical texture on the level of micro-structure, while, on the other hand, features of overall form were imposed through a model-based stylistic analysis of traditional music. This is not to say that such a status quo reflects an inferior brand of music writing: in fact, most music of quality has been written in this manner. In terms of method, the ILLIAC SUITE is an example of a scientific investigation which has not been brought to a true final conclusion, in the sense of a unified concept of structural integrity, such as that for which the serialists clamoured. In other words, the project was brought to a premature end before its inherent compositional devices had reached the level of macro-structural impact, affecting the overall form of the entire piece.

Careful observation of the unfolding of Hiller's experiments reveals that he resorted rather hastily, from a certain point on,[303] to filling traditional molds with the collected experimental samples. The urge to present the entire collection of experiments in a finished musical form is overwhelmingly evident: while the chosen form of a suite is, in fact, most forgiving regarding the compromises that can be made in terms of its formal integrity, Hiller could well have presented the entire work in the form of a sonata, considering the number of arbitrary choices involved. However, this deviation from the process of automation cannot be criticised because in terms of its methodological completion, and despite its final presentation in a finished form, the ILLIAC SUITE was only a beginning, an initial exploration of a new compositional method. Subsequently, in 1961,[304] Hiller proposed a new project (referred to as the "SECOND ILLIAC SUITE"):

> We hope eventually to group these new studies together into a *Second Illiac Suite* [italics supplied]. This time, we are starting from an even more random situation than before - wider pitch range, more rhythmic possibilities, etc.- and plan to produce more

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[303]The first indication of change regarding the initial compositional strategy seems to emerge in his "Higher-order Markov Chain Music" and other experiments from then on, where he introduced the arbitrarily chosen strategy of "defining [the] structurally more important and less important notes", assigning the harmonic function x_j to the strong beat, and the proximity function y_j to the weak beat, respectively. However, in the last section involving the assembly of the entire structure by means of manipulations occurring during the final transcription process, it becomes clear that a change, indeed almost a reversal, in compositional modelling has occurred.

[304]Lejaren Hiller: "The Electrons go around and come out Music", IRE Student Quarterly, 8(1), Sept. 1961, pp. 36-45.

> elaborate musical structures. In doing this, we are writing a computer program which we hope will represent to a considerable extent the logic of music writing itself and which will therefore be a master program for writing many kinds of music, independent of specific style or structure...At the time of writing this article, we have much of this program running and soon expect to obtain output from it. The kinds of music we now hope to produce include some complete conventional musical structures such as four-part fugue form written in a modern harmonic idiom, some rather complex probability music in which successive note choices are determined by probability distributions, and some music based on twelve-tone techniques as originated by Arnold Schoenberg and as since developed into the highly elaborated mathematical form of music labelled by musicians "totally organized music."[305]

Interestingly, the title of this second suite has been quite elusive in its publication[306] except for the following figure[307] supplied by Hiller.[308]

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[305]Lejaren Hiller: "The Electrons go around and come out Music", <u>IRE Student Quarterly</u>, 8(1), Sept. 1961, p. 42. Hiller mentions subsequently that graduate composition students actually performed the major part of coding the computer program, a situation he took as an indication "that the techniques of computer programming can be readily acquired by composers." Hiller, op. cit., p. 42.

[306]What Hiller refers to in 1961 was probably his ELECTRONIC STUDY NO. 4, which was composed in collaboration with Robert Baker. While it was expressed in a figure in his publication "The Electrons go around and come out Music", this short study, unnamed as yet, addressed all 88 notes of the chromatic scale available on a full-size keyboard, as a repertoire from where intervals could be picked arbitrarily within each bar of the score, up to an arbitrary total of 96 bars.

[307]The resulting two-part score resembles the highly articulated, jagged, and rhythmically extremely intricate style of many serial compositions for piano dating from the mid-1950s, as written, for example, by Boulez, Stockhausen, and Nono.

However, in his article "Computer Cantata: A Study in Compositional Method", published in 1963, Hiller made the following statement which finally clarified the issue: "The present COMPUTER CANTATA is the same composition as the projected "Second Illiac Suite" referred to in earlier publications".[309] As a matter of fact, following the publication of this article, COMPUTER CANTATA had an interesting history: having first referred to it as the "Second ILLIAC SUITE", Hiller felt the name had to be changed, because the Illiac computer, which had been used to write the first ILLIAC SUITE, was removed from service in 1963. As some of the routines for the "Second Illiac Suite" were already written, the removal of the computer required an extensive re-writing of the entire program to match the computer protocol used for the IBM 7094.[310] After this, the "Second Illiac Suite" was immediately renamed COMPUTER CANTATA and published in 1963. As we have a genuine interest in following the continuation of Hiller's studies in compositional method in the late 1950s, after the ILLIAC SUITE, especially the issue of governing the compositional aspects of larger musical forms, we will approach Hiller's COMPUTER CANTATA[311] as the appropriate sequel to the

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[308]See Fig. 25. in the appendix.

[309]Lejaren Hiller and Robert A. Baker: "Computer Cantata: A Study in Compositional Method", <u>Perspectives of New Music</u>, vol. 3-4, Fall 1964, p. 63.

[310]Hiller specifies an IBM 7090 in his article in <u>Perspectives of New Music</u>, and an IBM 7094 in his publication "Informationstheorie und Computermusik". I assume it was an IBM type 7090, the same type Xenakis used in his ST-10.

[311]The COMPUTER CANTATA was, in fact, a collaboration between Hiller and Robert Baker, who was at that time a technical assistant at the University of Illinois. From here on, Baker's name will be omitted to keep the text simpler,

research work carried out in that context. While it should be perceived from a developmental point of view as an extension of Hiller's ground-breaking work, it incorporates numerous structural features of the ILLIAC SUITE regarding compositional method (see above quotation!).

Independently of any historical context, the COMPUTER CANTATA would also have been chosen because of the even more prominent role of information theory, with regard to the concept of its overall formal structure, than was evidenced in the ILLIAC SUITE. However, the coding structure and the computer routines involved on the micro-structural level seem not to deviate significantly from compositional methods which we have already investigated in detail, and we can also assume that the involvement of information theory in these processes parallels this strategy in essence.

Therefore I would like to investigate the COMPUTER CANTATA only with regard to issues that are distinctly different, thus furthering our research on the influence of information theory. We will also explore new tendencies in this work to approach the medium of electronic music synthesis from an angle of information theory, and this area of investigation will become our major focus in this chapter.

a) Historical Context

In an investigation of the historical context of computer music writing in the 1950s, the ILLIAC SUITE and the COMPUTER CANTATA are clearly positioned on either end of

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but, whenever the name of Hiller is mentioned in connection with the COMPUTER CANTATA, the name and contribution of Robert Baker will automatically be implied, as in our discussion of the ILLIAC SUITE, which omitted the name of Leonard Isaacson.

a spectrum of experimentation.[312] In addition to the above pioneering efforts in computer composition, a recording of early computer music was produced by the Bell Telephone Laboratories, containing "Cyclic Study",[313] Pergolesi Development",[314] Substitution Study,[315] and Masquerades[316]

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[312]See Table. 8. in the appendix.

[313]Max Mathews, in his "Computer Music Record Supplement", describes the experiments as follows: "Cyclic Study" is an experiment in which the computer develops a single voice by means of a cyclic algorithm. The original theme consists of a sequence of 44 frequencies and a sequence of 40 durations. The computer emits a note by associating the first frequency with the first duration, the seed frequency with the last duration, etc., until it associates the saved frequency with the 40th duration. The computer then recycles in durations and associates the 2nd duration with the 42nd frequency, and so forth, until it reaches the 44th frequency after which it recycles in frequency and plays the 1st frequency with the 5th duration, and so forth. The cyclic algorithm can go through eleven cycles of durations after which the composition will return to its original phase and repeat itself. In addition to the cyclic algorithm which is applied completely automatically by the computer, certain other transformations of tempo, loudness, and average frequency were applied with malice and forethought". In: Max V. Mathews, "The Computer Music Record Supplement", <u>Gravesaner Blatter</u>, Vol. 7, 26, 1965, p. 117.

[314]The "Pergolesi Development" was generated by applying the cyclic development process simultaneously with three voices from a composition by Pergolesi. The development is run through 11 cycles of 1/2 duration so that it finally returns to its original form. As in the "Cyclic Study", transformations of tempo and frequency range were applied in addition to the computer's development. In: Max V. Mathews, "The Computer Music Record Supplement", <u>Gravesaner Blatter</u>, Vol. 7, 26, 1965, p. 117.

[315]The "Substitution Study" is an experiment concerning the interchange of frequencies and durations between four themes. Each of the themes contained 40 notes. The sixteen possible melodies which could be generated by associating the durations from one theme with the frequencies of another were played... The interchange of frequencies and durations was

by Max Mathews, a veteran in computer music composition. We must acknowledge, however, that Hiller's attempts to investigate compositional methods through systematic experimentation were, besides Koenig's development of "Project 1",[317] the most comprehensive and thorough until the mid-1960s.[318]

b) Coding Procedures

The COMPUTER CANTATA was Hiller's first large-scale composition the ILLIAC SUITE. As in this earlier work, the COMPUTER CANTATA was a direct outcome of a series of computer music experiments, in this case carried out with a

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done by means of an automatic computer algorithm. In: Max V. Mathews, "The Computer Music Record Supplement", Gravesaner Blatter, Vol. 7, 26, 1965, p. 117.

[316]"Masquerades" is a composition which makes use of both the frequency and duration interchange developed in the previous study as well as the cyclic algorithm. The next to last section is a particularly good example of the cyclic algorithm. Here, about twenty original notes were expanded into the approximately 1200 notes which make up the section by means of the cyclic algorithm. In: Max V. Mathews, "The Computer Music Record Supplement", Gravesaner Blatter, Vol. 7, 26, 1965, p. 117.

[317]The first version of "Project 1", Version 1, was developed in 1965. Published as "Project 1", Electronic Music Reports, Vol. 1, No. 2, 32, 1970.

[318]Xenakis' composition, ST-10, reported to be the first example of stochastic music, has to be mentioned in this context as well.

new computer programming language: *MUSICOMP*.[319] While similar to the procedures discussed in the context of the ILLIAC SUITE, the new coding procedures involved in the COMPUTER CANTATA were designed to investigate how formerly encountered coding restrictions might be overcome in order to allow further levels of generalization and programming flexibility. MUSICOMP was a computer program designed in the wake of the search for a more powerful means of composing music, beyond the limitations encountered in the ILLIAC SUITE. In short, the objective was to create a completely generalized programming scheme for compositional design in music. It is interesting to note that the COMPUTER CANTATA, like the ILLIAC SUITE, was again a compromise with regard to its final overall form:

> Indeed, in some instances, sections of the COMPUTER CANTATA were completed before the final version of MUSICOMP had been decided upon, and changes, additions to, and deletions from the MUSICOMP process resulted from these initial "field tests"... Since our primary purpose was to demonstrate the flexibility and generality of MUSICOMP, the COMPUTER CANTATA presents a rather wide variety of compositional procedures...the interested composer should find these studies of significance as a concrete demonstration of the broadening of the research area of experimental composition techniques made feasible by computers and by a program such as MUSICOMP."[320]

MUSICOMP was a direct result of years of experimentation in compositional theory, exploring systems

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[319]"**MU**sic-**S**imulator-**I**nterpreter for **COM**positional **P**rocedures". The composer interacts with MUSICOMP through a computer protocol, or language, called SCATRE (**S**hare-**C**omputer-**A**ssembly-**T**ranslator), used by computers of the type IBM 7094. For his research purposes, Hiller preferred SCAT to FORTRAN, another type of computer language.

[320]Lejaren Hiller and Robert A Baker: "Computer Cantata: A Study in Compositional Method", Perspectives of New Music, Vol. 3-4, Fall 1964, p. 62.

of logical design, with the overriding objective of developing complete independence in terms of any specific style or historical reference. The COMPUTER CANTATA also includes two experiments involving computer sound synthesis,[321] using the CSX-1[322] computer.[323]

2. Organization and Overall Form

Much like that of the ILLIAC SUITE, the overall form of the COMPUTER CANTATA resembles a suite-like structure: eleven separate sections are grouped into a blueprint[324] for a five-movement performance plan.[325] Ordered according to movements developed in succession, the COMPUTER CANTATA is presented as a symmetrically organized structure, consisting of a sequence of strophes preceded or followed by a prologue or epilogue, respectively. However, even if all

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[321]Both computers were functionally linked together by means of an output routine written into MUSICOMP. This routine allowed compositional results to be directly converted into sounds generated by the CSX-1 computer.

[322]This computer was built as a special purpose project at the University of Illinois Coordinated Science Laboratory. Source of reference: R. M. Brown, R. D. Jenks, J. E. Stifle, and R. L. Tragden: Manual for the CSX-1 Computer, Report R-136, Coordinated Science Laboratory, University of Illinois, Urbana, Illinois, 1962.

[323]J. L. Divilbiss: "Real-time Generation of Music with a Digital Computer", Journal of Music Theory, 8:99-111, 1964.

[324]See Fig. 26. in the appendix.

[325]Lejaren Hiller: "Programming a Computer for Music Composition", in: Papers from the West Virginia University Conference on Computer Applications in Music, Gerald Lefkoff, Ed., Morgantown, 1967, p. 71.

strophes are related to a similar compositional method, a compositional logic in which the stochastic order progresses from zeroth-order to fourth-order stochastic approximation creates a notion of formal direction.[326]

Contrary to the compositional procedures used in the strophes, all epilogues and prologues are arranged in mirror-like order around the formal centre of the COMPUTER CANTATA, as we can easily see in the above outline. In order to access a most interesting spectrum of acoustic representation, the instrumentation selected for the COMPUTER CANTATA encompasses a wide range of instruments, including a theremin, as well as sounds produced by the CSX-1 computer.

The selection of electronic sounds is particularly interesting in that it includes three distinct types of sounds: first, three types of elementary signals - sine waves (fundamental only), square waves (fundamental plus odd partials), and sawtooth waves (fundamental plus all upper partials); second, two types of noise, one "white", the other "coloured",[327] third, sounds directly obtained from the CSX-1 computer. The electronic sounds were transmitted through a 2-channel tape, with five cues prepared.[328] Before we proceed to investigate in further detail the musical texture of selected parts of the COMPUTER CANTATA - focusing in particular on the influence of information

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[326]See Fig. 27 in the appendix. According to Hiller, "Computer Cantata", op. cit., p. 64.

[327]"Coloured" noise was represented by eight pre-recorded, 'concrete' signs, marked by Hiller as: CLICK, CLACK, SISS, CRACKLE, SNAP, POP, BANG, BOOM.

[328]Cue 1 accompanies Strophe I, Cue 2 accompanies Strophe II, Cue 3 and 4 are the Prologue and Epilogue to Strophe III, Cue 5 accompanies Strophe IV.

theory - I present a table[329] of the formal distribution of electronic sounds, to complete the picture and to provide a point of reference.[330]

Paralleling former tendencies to arbitrarily organize the overall structures of the ILLIAC SUITE and the COMPUTER CANTATA according to geometric principles of symmetry, the above table of spatial distribution of electronic sounds reveals similar traits.

3. The Strophes: An Experiment in Speech and Information Theory

While the six movements, three marked as "Prologue", and three as "Epilogue", structurally resemble Hiller's experiments in the context of the ILLIAC SUITE (involving the model of rule constraints imposed on random material, in this case especially serial techniques), the "Strophes" can be considered to include the most interesting experiments regarding the influence of information theory. The application of information theory is particularly evident in Hiller's treatment of speech, which approaches the results of Shannon's experiments. If one compares Shannon's table (zeroth-order to third-order approximation of **written** English text, p. 36) and Hiller's table (zeroth-order to fourth-order stochastic approximation of English text **phonemes**), one can appreciate the similarity of the means used by both authors regarding the use of probability and information theory.

In these particular segments of the COMPUTER CANTATA, Hiller has, for the first time, achieved the initial

[329]Hiller: "Computer Cantata", op. cit., p. 68.

[330]See Table. 8. in the appendix.

objectives which he had pursued in the ILLIAC SUITE: a successful implementation of a compositional method which would be capable of independently creating and furnishing its own overall musical form. Each of the five strophes contains text reflecting various degrees of five successive stochastic approximations of spoken English. The results were obtained through a computer synthesis of stochastic phoneme sequences, prepared by the Illiac computer from a quantity of English text selected at random from the magazine *PLAYS, The Drama Magazine for Young People.*[331]

The next step was to compute the transition frequencies of the selected phonemic structure from zeroth-order through to fourth-order correlation.[332] Having obtained the transition probability tables for the text thus selected, Hiller reversed the process of analysis, and successive approximations of phonemic English from zeroth-order to fourth-order were synthesized from scratch. Sample results of this experiment were then adopted as text assigned to the five strophes of the COMPUTER CANTATA.[333]

Hiller chose to parallel the successive imposition of constraints on the choice of phonemic signs by means of a simple stochastic technique: selecting the appropriate accompaniment of musical elements, i.e. pitch, duration, dynamics, articulation, and choice of "play" and "rest". A system of correlating both systems of text and music was devised by following similar procedures, which were first subjected to the randomly selected body of text and musical

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[331]Published by Plays, Inc., Boston, Massachusetts.

[332]This was done by J. B. Carroll of Harvard University, and Joseph Allen, Jr., Lee S. Hultzen, and Murray Miron of the University of Illinois.

[333]See Table. 10. in the appendix.

material: a short example of music (Ives, "Three Places in New England", second movement, mm. 14-39) was (randomly) chosen, and tables of the frequencies of the various events (with regard to pitch, duration, rests, dynamics, and articulation) were computed. Computations could be carried out only to the level of second-order (digram) stochastic approximation, as the sample taken from Ives was found to be too limited in size to produce enough output to work with. The relative frequencies from zeroth-order to second-order stochastic approximation were then computed and subsequently used as probability distributions governing the choice of musical elements. The first strophe would therefore use a random distribution, while the second strophe selected elements according to a first-order analysis, using the probabilities $p_{(i)}$. The third strophe used conditional probabilities $p_{i(j)}$, according to the distribution of a second-order analysis. In effect, the structural order increased by means of redundancy imposed through the loss of entropy.

With Strophe III, Hiller had arrived at the symmetrical centre of the COMPUTER CANTATA. Third-order and fourth-order stochastic approximations could not be obtained from a musical sample of such limited size, yet further compositional strategies were needed to continue the development of the process imposing increased order on the musical structure. Therefore he decided to change the originally charted course of compositional strategy (continuing to move towards third-order and fourth-order stochastic processes): beginning with Strophe III, order would again be allowed to decrease, according to a new mathematical model, "but with the reduction occurring more gradually than did the increase during the first three strophes."[334] This effect of a gradual release of order was achieved by means of a "weighted averaging process":

> ...given any sequence of *n* preceding choices, the choice of a succeeding element was made dependent on each of the *n* foregoing elements by obtaining the weighted average of the second-order probabilities for each possible outcome that might arise from each of the preceding outcomes. For two preceding elements, this is expressed mathematically as:
>
> $$p(k) = c_1 p_i(k) + c_2 p_j(k)$$
>
> where i and j are the preceding elements, and c_1 and c_2 are arbitrary constants. This represents, of course, the probability of only one out of all possible outcomes. The probability distribution for all outcomes can be expressed as follows[335]:
>
> $$\begin{aligned} p(k_1) &= c_1 p_i(k_1) + c_2 p_j(k_1) + \ldots + c_n p_n(k_1) \\ p(k_2) &= c_1 p_i(k_2) + c_2 p_j(k_2) + \ldots + c_n p_n(k_2) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ p(k_n) &= c_1 p_i(k_n) + c_2 p_j(k_n) + \ldots + c_n p_n(k_n) \end{aligned}$$
>
> Thus, the column on the left of the equal sign represents the probability distribution for the k^{th} choice point, with each member of the column representing the probability of one out of the *n* possible outcomes.[336]

This is illustrated in the following figure supplied by Hiller.[337] In short, all single probabilities in each of the above columns will be equal to 1. All constants are now chosen so that

$$\sum c_1 = 1$$

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[334]Hiller, "Computer Cantata", op. cit., p. 70.

[335]Hiller, "Computer Cantata", op. cit., p. 70.

[336]Hiller, "Computer Cantata", footnote, p. 71.

[337]See Fig. 28. in the appendix.

We remember that Shannon defined information content as follows:

$$H_n=-\sum p_i \log_2 p_i$$

In other words, the information content increases to a maximum as the probability distribution approaches uniformity (and structural order or redundancy reaches a minimum): all possible outcomes are then equally probable. However, if for the entire repertoire of events the weight of probabilities was condensed at a few points, the information content would decrease again, structural order would then be induced. Furthermore, since the process of concentrating probability at particular locations necessitates an adjustment of the distribution of the weight of all other probabilities (because the total sum has to equal 1, see above), it follows that the reduction of information is accompanied by an increased variance of the probability distribution, and vice versa. Thus, the relative amount of influence of an i-th preceding event on the current probability distribution is determined by all the constants c_i. Making all the constants equal would result in an unweighted, average distribution: the choice of the current outcome would be equally influenced by all preceding outcomes. In order to reach a reasonable, controlled decrease of structural order, Hiller chose the following strategy:

> For our purposes, we arbitrarily chose the constants [c] such that the first preceding outcome was given twice as much influence as the second, the second twice as much as the third, and so on. Thus, for the fourth-order strophe the constants were 4/7, 2/7, and 1/7.[338]

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[338]Hiller, "Computer Cantata", p. 71.

Hiller assigned constants of 2/3 and 1/3 for the third-order strophe. In other words, Hiller was expressing a common observation in standard communication systems: the influence of past choices on structural order fades with the distance of that choice from the choice about to be made.[339]

> For any set of constants in which at least two are unequal to zero, our mathematical model can only result in a decrease in the variance of the probability distribution, since any **resultant** $\underline{p}_{(i)}$, representing an average of two or more values of $p_{(i)}$ given [in] the preceding outcomes, must take a value between the extremes of the individual values from which the **[resultant]**$\underline{p}_{(i)}$ is calculated.[340]

In brief, the variance of the probability distribution will decrease through the above procedures and yield an increase in information content: structural order will thus be removed. However, the decrease in redundancy is less effective when using this procedure than when applying strategies involving stochastic processes, since changes in stochastic order define the selection of transitional probabilities more rigorously. The Strophes (I-V) of the COMPUTER CANTATA, plotted according to structural order versus formal design can therefore be illustrated as follows.[341]

Hiller supplied the following example and the resulting table of changes in probability distribution, brought about by the procedures described above, for strophes I-V: zeroth-order to fourth-order distribution tables related to a situation in which a new pitch is chosen, according to the transitional probabilities of the three preceding pitches

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[339]In: J. R. Pierce, <u>Symbols, Signals, and Noise</u>, Harper and Bros., New York, 1961, Chapter 5.

[340]Hiller: "Computer Cantata", p. 72.

[341]See Fig. 29. in the appendix.

B_b, E_b, and C (already chosen), with B_b being the most remote relative to the new pitch in question. The three upper examples (a direct result of Hiller's statistical analysis) determine the likely results, based on each of the three preceding events.[342]

The five remaining tables determine the resultant distributions used to make a choice among zeroth-order to fourth-order selection processes. It is particularly interesting to note that the degree of variance increases most rapidly from zeroth-order to second-order processes, significantly tapering off thereafter. This is a typical characteristic of stochastic order processes, imposing the most restraint on lower-order procedures, relative to a random choice situation. In fact, this was probably one of the key reasons why Hiller did not consider structural processes higher than the third-order in both the ILLIAC SUITE and the COMPUTER CANTATA. His critical comments regarding Klein and Bolitho's experiments, who used up to eighth-order processes to increase structural order in writing nursery rhymes, address this issue clearly: he found the resulting musical textures to become void of unexpected moves, i.e. too predictable. In fact, even if the mnemonic interface of MUSICOMP allowed one to specify up to sixth order processes, it seems that Hiller preferred to effect the compositional selection processes by means of lower-number stochastic processes, mainly for aesthetic reasons. Again, structural procedures, which are strongly influenced by principles related to information theory, have clearly found their way into Hiller's compositional design.

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[342]See Table. 11. in the appendix.

4. Prologue to Strophe I: An Experiment in Mixed Communication Systems

However, the COMPUTER CANTATA also contains a small section which is of particular interest beyond the perspective of a communicative system of transmission of discrete signal sources: rather than addressing musical textures syntactically as a discrete type of message, the section entitled "Introduction to Strophe I" actually attempts to impose structural control on the information content of a continuous type of signal source. This is not considered as part of the compositional domain, an area characterized up to this point by a defined scalar system. Following the introductory Rhythmic Study for Percussion, this section appeared to be an exciting perspective of formal design: i.e. to arrive at Strophe I through a little prelude, exemplifying the decay of acoustical information from maximum possible content down to a sonic texture that eventually would allow a seamless acoustical transition into the beginning of Strophe I. This little prelude was composed according to a zeroth-order approximation of English text and music. In the context of the initial objectives and the type of approach taken, this was Hiller's solution to the problem of creating an acoustically smooth transition from a continuous spectrum filled with white noise to the discrete system required at the beginning of Strophe I. It can only be labelled experimental, as it approaches the subject of overall form and structural design solely from the angle of information theory. However, considering the complexity of the problem of imposing order within the environment of mixed communication systems, information theory seemed to provide, for this particular situation, a powerful means of gaining structural control with remarkable efficiency.[343]

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[343]See Fig. 30. in the appendix.

Taking a closer look at the Prelude, we see that it begins with a statement of the random universe with the maximum possible amount of acoustical information, i.e., with white noise. Since white noise consists of all possible frequencies, its frequency spectrum can be considered as finite. On the micro-structural level, however, it must be considered infinite with regard to the number of possible frequencies. From the angle of information theory, taking these two definitions into account, white noise represents an ideal example of an ergodic source of information. The important question facing every composer when attempting to apply various means of imposing structural order is: to what degree should the resulting texture be random or determinate? Any attempt to approach the acoustical universe of white noise by means of stochastic processes requires a closer look at the particular compositional method employed in imposing order. This is the strength of information theory: it supplies answers to problems related to a specifiable quantity of information, any kind of information, regardless of its meaning. In other words, information theory allows a quantitative and dependable access to the complexities of the microstructure of sound. It is for this reason that Hiller's experiment of the Prologue to Strophe I is the most daring, ambitious, and successful in terms of information theory, even if enacted only on the superficial level of a rudimentary constraint in textural form.

Let us follow his procedures of reducing the entropy (or information) from here. Starting from white noise, Hiller managed to differentiate this total spectrum bit by bit (!) into discrete acoustic events producing, at first, coloured noise (on tape).[344] This was followed with a segment of percussion instruments, which are the closest acoustical match for the aforementioned coloured noise. A couple of measures later, sounds with inharmonic partials were allowed, followed by sounds permitting harmonic partials. The next transition featured electronic sounds, consisting of a precisely fixed composition of overtones, finally bridging the sonic gap with the human voice entry at the beginning of Strophe I. From here on, zeroth-order stochastic procedures, still allowing a considerable amount of high entropy content, affect the sonic spectrum of the voice by means of zeroth-order approximations of English text phonemes and musical texture, progressing gradually towards the highest structural order in Strophe III. It is here where, for moments, through the effects of second-order approximations of speech phonemes, "real" words can emerge in Gestalt form, evoking the meaning and significance of human expression.

On the other hand, arriving at the fourth-order music in Strophe V, while the vocalist is just beginning to get some sense of intervallic preferences, she has still not found a correlation between her part and the various melodic lines. For example, at the end of the COMPUTER CANTATA, the flute part still has no direct textural relationship with the vocal part. Both parts relate, as a matter of fact, only in terms of the probability distribution. Hiller has labelled this situation "heterophony". Is there a problem with contextual order between the parameters involved?

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[344]Coloured noise involves discrete frequency bands and transients, in contrast to white noise, which exhibits an even distribution of probabilities over the entire frequency spectrum. Coloured noise events include the formerly mentioned sounds of CLICK,CLACK, SISS,CRACKLE, SNAP, POP, BANG, BOOM, which Hiller used in the COMPUTER CANTATA.

Why, might we ask, was the resultant musical texture still completely lacking any kind of contextual correlation at a point where Hiller's method of horizontal writing had already reached fourth-order stochastic processes in selecting musical material? We have seen that increasing the degree of stochastic order quickly brings about a level of saturation beyond which the differentiation regarding the rules imposed tapers off quickly. In other words, stochastic music composition, inspired by Shannon's and Weaver's (1949) formulation of information theory, appears to have some drawbacks. Hiller made the following observation in 1982, in his publication "Stochastic Generation of Note Parameters for Music Composition":

> The application of stochastic processes to language systems (and this would include music) was first expressed in the mathematical theory of communication as developed by Claude Shannon some thirty years ago. *However, exploitation of stochastic models in music composition has so far been haphazard and unsystematic* [italics supplied].[345]

5. **Critique: Hiller's Use of Information Theory as a Compositional Method**

In Chapter I, we found that, in the history of the development of communication sciences, information theory represents a major outcome, indeed a very powerful means to describe, in simple mathematical patterns, the macroscopic functioning of the phenomenon of communication, as exemplified in Shannon's famous block diagram. We also became aware that, due to the sometimes elusive true nature

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[345]Lejaren Hiller: "Stochastic Generation of Note Parameters for Music Composition", in: Thomas Tomes, and John Strawn, Eds., Proceeding of the International Computer Music Conference, Venice, 1982, p. 623. Thomas Blum, and John Strawn, Eds., p. 623.

of communication processes, many applications of information theory outside Shannon's scheme have shown serious limitations, depending on the discipline or the particular problem chosen.

Having clarified some basic principles which are at the heart of information theory at the end of Chapter I, we focused on defining the limitations of some of its applications in music, beginning with music analysis. Our investigation in Chapter II has confirmed our impression that this theory, if properly adapted to the problem posed, does produce some valuable and interesting results which could not be obtained through any other known form of analytic investigation: statistical analysis of musical textures has become an established and well respected branch of musicological research.

Focusing on the 1950s, our discussion regarding the validity and relevance of this theory in assisting the process of musical composition has revealed some interesting initial designs, resulting from several studies in this direction, as a historical reference. It then became obvious that a thorough investigation of the influence of information theory on music composition had to involve a far more substantial body of work: that of Lejaren Hiller, one of the most prominent and ardent users of this theory in music composition.

In order to establish a clear point of reference on how information theory can lead to the creation of musical textures, we demonstrated, in Chapter III, that Hiller's ILLIAC SUITE not only represents a veritable and surprisingly thorough application of processes derived from information theory, but also that it represented at the same time a major breakthrough in compositional method. This body of work, besides the fact that it stands out as an example of a thorough discourse on new compositional approaches, was also a landmark of great historical significance as it initiated the development of computer music.

Following our detailed investigation of the compositional makeup and results of the ILLIAC SUITE through to the COMPUTER CANTATA and its Prologue, spanning a developmental period of seven years, we are now in a position to summarize and critically evaluate Hiller's studies in compositional method. While the historical significance of Hiller's contribution for the birth of computer music is evident, I will reserve the final evaluation of the influence of information theory on both the ILLIAC SUITE and the COMPUTER CANTATA until the conclusion of this dissertation, as I feel that another, crucial point of reference is necessary in order to give this discussion a dialectic perspective: the treatment of speech within the musical structure of Stockhausen's "GESANG DER JÜNGLINGE", which we shall deal with in the following Chapter V.

At this time, a comparison between the ILLIAC SUITE and the COMPUTER CANTATA will be made only in so far as it is essential in clarifying questions of immediate relevance to the topic. Both works must be viewed as a progressive collection of experimental findings wrapped into two major works, rather than as finished "masterworks", as we have seen, Hiller certainly never regarded them as such. However, he insisted on their value as an experimental chronicle of the compositional methods which he had investigated. At this point of our study, we must focus on the following question: can information theory really assist in programming a computer for musical composition? Has the application of this theory perhaps been overstretched? Curtis Roads, in "An Overview of Musical Representations" states:

> In information theory [the] view of a piece of music in terms of some number of bits per second is, in general, somewhat macroscopic. That is, it cannot be used for music generation or parsing without adding other rules.

> Information theory by itself does not attempt to account for linkages between musical parameters, or the context in which idiosyncratic but highly significant structures will occur. A fundamental problem is that information theory accounts for the amount of information without specifying which information is musically important.[346]

Regarding the stochastic routines employed in musical composition, he remarks:

> Unadulterated stochastic routines for composition can suffer from similar deficiencies. Although they can be made to conform with statistical norms on a broad scale, local level details handled by stochastic routines often do not sound convincing for well-understood musical styles . . .[347]

Before we discuss the above statements, we shall first look at how the composer perceived the process of programming a computer for music composition,[348] and then confront his statements with the actual body of works, the ILLIAC SUITE and the COMPUTER CANTATA in progressive order. And finally, we shall address the important question of his utilization of information theory.

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[346]Curtis Roads: "An Overview of Music Representations", in: Baroni, M. and Callegari, L.: Musical Grammars and Computer Analysis, Leo S. Olschki, Firenze, 1982, p. 14.

[347]Curtis Roads: "An Overview of Music Representations", in: Baroni, M. and Callegari, L.: Musical Grammars and Computer Analysis, Leo S. Olschki, Firenze, 1982, p. 14.

[348]In the following section, I refer mainly to Hiller's introduction to "Programming a Computer for Music Composition", in Papers from the West Virginia University Conference on Computer Applications in Music, Gerald Lefkoff, Ed., Morgantown, 1967, pp. 65-88.

6. Summary: The Application of Information Theory in Hiller's Work

Hiller considers that to write music with a computer is "*to throw away undesirable choices made in a stochastic process*". In fact, this was Hiller's initial strategy in the ILLIAC SUITE, and continued to use in the COMPUTER CANTATA: he was adopting the Monte-Carlo Method as a model universe of random events from which to choose musical material. In principle, this model universe is a perfect parallel to Shannon's idea of a discrete source producing random events at a maximum rate of information. Choosing a stochastic process as a musical representation makes sense, as music can only exist in time and is a special form of acoustical message which is reminiscent of Shannon's model of an ergodic source of information, be it of the continuous, mixed, or discrete type.

Choosing stochastic processes means working in the world of probabilities, and leads to the next question: does the process of composing mean that a musical structure must always be some sort of deterministically conceived entity? Hiller proposes that

> we can also define other classes of musical communication systems in which a particular composition is but one example from a large class of essentially similar compositions. If certain elements are changed within the matrix of elements making up a system of this sort, a different composition in terms of fine detail may be produced, but its gross properties taken as a whole remain essentially the same, and its effect upon the listener also remains essentially the same."[349]

This is essentially true for all experiments performed according to the Monte Carlo Method: we remember that every experiment performed in the ILLIAC SUITE produced a very

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[349]Hiller, "Programming a Computer", p. 65.

large number of similar looking (and sounding) samples, out of which only a few eventually found their way into the ILLIAC SUITE by means of arbitrarily applied selection processes. The COMPUTER CANTATA uses this same principle, especially in the textural generation of the Strophes: even if based on a different English text sample from another source, a similar compositional texture would have resulted. In brief, the compositional "module", i.e. the routine, essentially determines the overall textural features of a composition, not the musical material supplied to fill it out. However, regarding the effect of a given compositional procedure, what Hiller essentially did was to replace the 'deterministically conceived entity' with a compositional module, which would perform the same function as it became the entity of determination: compositional theory had replaced compositional **models** of form, and thus the paradigm of model-based composition had been replaced with rule-based composition. The thoroughly procedural character of the ILLIAC SUITE is an impressive example of this shift, despite the incompleteness of its compositionally derived overall form.

Hiller, at this point, draws an analogy with the kinetic theory of gases: while the macroscopic properties of a body of gas can easily be predicted, the particular position or energy of individual molecules within the total body of the gas cannot be predicted accurately. Referring to the example of the problems related to predictions on the radar screen, which were ultimately resolved by Shannon and Wiener through applications of information theory, Hiller brings up the concept of information within the mathematical theory of communication. In "this theory . . . information is defined as a quantitative measure such that high information content is associated with a relative degree of disorder, unpredictability or even randomness, and that order is measured by the opposing conjugate property of redundancy".[350]

In short: notions like high information, entropy, and disorder are simply a statement as to **how much** information is displayed, not whether the information content is "good" or "bad" in a semantic sense. Hiller stresses this point, especially when he asks: "How can you get a computer to write a piece of good music?" and responds: "I reply that if I can be told what "good music" is in terms of precise and quantitative algebraic statements, I can produce good music." The type of compositional output Hiller was able to generate shows clearly that he had, in fact, not found a precise and quantitative algebraic statement which would allow him to write "good" music. An overall look at the ILLIAC SUITE and the COMPUTER CANTATA rreveals that from the outset, Hiller's ultimate objective was not to write "good" or "bad" music, but music that is indifferent to value judgements of any kind. This obviously gave him additional freedom of choice in a medium that is usually charged with value judgements (since the subject here is music).

However, we have also observed that Hiller, as impartial as he could be regarding the generation of microstructural components within the composition, also exhibited tendencies to adopt traditionally sanctioned forms (suite, sonata, geometric permutations, etc.) when his compositional methods failed to generate a larger form while assembling the final score. The end-result sounded "better", in terms of what we might expect from a traditional viewpoint, than just a collection of samples, but what purpose did this serve? Although this aspect improved considerably with the COMPUTER CANTATA, the general problem of form assembly remained unresolved. Why was this so?

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[350]Hiller, "Programming a Computer", p. 66.

It seems an appropriate time now to discuss Curtis Roads' statement about music representations: it is true that addressing music from the angle of macroscopic form, in terms of information theory, will allow one to determine its overall statistical shape. However, the moment a small amount of a musical message is retrieved (analyzed) and looked at without constantly correlating the results obtained with the information related to the system in its entirety, an essential bond within the structural connections is lost. As we have seen, the quantity of bits obtained cannot carry the semantic information considered so essential for establishing links between musical parameters, as these parameters possess the power to evoke a "meaning" in the sense of the psychology of human perception.

Music represents, for human beings at least, a very special kind of message, as do languages. Information theory, with its purely mathematical nature, has been developed solely in the wake of solving problems related to technical communication systems. However, Hiller used the feature of indifference to semantic information to his advantage: as imperfections within a texture of random distribution can be interpreted as preferences, and preferences can mathematically be made to constitute transition probabilities between successive events, the indifference of (statistical) information, in terms of information theory, is preferred on the level of random-event creation. The creation of order or "meaning", in a generalized form involving the geometrical positioning of a single event, was achieved by imposing musical rules, encoded in the form of stochastic processes.

Abraham Moles[351] stated that a "good" piece of art or music does have a certain balance of semantic and syntactic information encoded within its structural design. If this is true, the imposition of rules through a compositional method will have some effect on changing the ratio between entirely syntactic information (white noise, random events), and semantic information (unwillingly) induced through increased redundancy. This includes the case of a maximum of redundancy creating an information content of zero regarding its syntactic value, as well as a maximum of semantic "meaning". In such a case, there is no uncertainty left at all as to the occurrence of a particular event.

On the other end of the spectrum, in the realm of micro-structural relationships, stochastic routines have their strongest virtue in setting up event relationships in a very predictable and easily quantifiable way. Untainted stochastic routines for composition can suffer from the same deficiencies as those observed with applications of information theory. The problems here do not reach the same proportions as in the above situation where the two systems of information theory and music are matched as a special type of communication. Stochastic routines, however, even if they conform to statistical norms on a broad scale (i.e., can be made to match a desired musical output), are not designed to affect the micro-structural texture beyond a pre-defined near-field relationship between local level details.

We have already seen that the inclusion of an increasing number of preceding events does not significantly improve the aesthetic design of the resultant musical output, but tends to make it too predictable. Regarding the

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[351] Abraham A. Moles: Information Theory and Aesthetic Perception, University of Illinois Press, Urbana, 1965, Chapter V.

generation of form, we perceive that what is truly missing is a set of mathematical devices that would particularly affect the middleground of compositional design. This is evident particularly in the ILLIAC SUITE (except for experiments involving the composition of tone rows),[352] during the final Coda, and, to a certain extent, in segments involving an arbitrary correlation of parameters.

As already mentioned, the compositional methods devised in the ILLIAC SUITE covered only the particular areas of micro-structural or macro-structural processes (one rule-based, the other model-based) within the full spectrum of formal design. The COMPUTER CANTATA, on the other hand, genuinely attempted to fill this gap of missing correlations between the micro-level and the macro-level of compositional design by introducing a new assembly language: MUSICOMP. As far as our objective is concerned, i.e. that of confirming the influence of information theory, it is not necessary to explore in further detail the computer programming routines addressing the micro-structural level of music creation. What is important here is to acquire a clear picture of its organizational design, especially regarding the question of which computer instruction routines work best in establishing linkages between musical parameters. For example, MUSICOMP contained a large number of mnemonic symbols stemming from conventional music, including a stock of previously punched chords labelled with the names of certain instruments, containing all the restraints of acoustical properties in coded, computer readable form.

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[352]However, this can simply be attributed to Hiller's correlation of melodic design by stochastic processes on one hand, and the geometrical design of formal relationships **among entire tone rows** of some length on the other hand, thus constituting, in developmental terms, the creation of a higher level of formal relationships between larger entities.

Reflecting on music composition in terms of programming, Hiller started from the hypothesis that

> ...the procedural logic for composition can be distinguished, at least to a first approximation, from all the specific decisions we must make in reference to establishing any particular musical style we might desire to work with...when one thinks musically, one uses a process which can be abstracted as pure musical logic as such...If this hypothesis is valid, we can build a general compiler for music composition and utilize this compiler to write programs which will assemble music compositions which can range from highly unpredictable to completely deterministic in content.[353]

In other words, the assembly of a musical composition could be simulated in the form of a series of decisions, set up in an appropriate operational sequence of computational procedures. However, before a decision could be handed over to a computer routine, a series of reference statements had to be consulted every time (for example, the punched cards for various instruments had to be inserted into the computer system). In a manner reminiscent of procedural strategies employed in the ILLIAC SUITE, MUSICOMP stresses the development of compositional design from the most general to the most specific question, successively breaking the decision process down to a specific set of "sub-decisions". For example, the first question regarding a new compositional design might solely address the structural level, be it an entire form section, or a single sonic event. The next question might address structural aspects within the above chosen area, to be followed by more questions regarding its micro-structural level of textural design. Questions are followed by decisions, which are legitimized by references stored in computer memory in the form of data. The condensation of this procedural scheme is

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[353]Hiller, "Programming a Computer", p. 67.

well reflected in the overall structure of MUSICOMP: major decisions are first sorted out in the "Main Routine", which then hands procedures over to a number of "sub-routines" in standardized formats, to be called up from a subroutine library. "Choice functions" allow the composer's input in the form of subordinate instruction tables in MUSICOMP assembly language, which are ultimately followed by "modification functions" which are capable of fine-tuning already existing subroutines. In MUSICOMP terminology, the program structure would include the following stages:

> Main Routine - Subroutine - System Regulatory Routines - Internal Music Library Subroutines - Choice Functions - Choice Order Code - Modification Functions - Nomenclature: Instruments and Parameters.

Hiller provided a simple flow-chart[354] of the organizational process of MUSICOMP that was accessible to the composer.[355] A comparison of both flow charts of MUSICOMP and the ILLIAC SUITE reveals, in principle, more similarities than differences in terms of compositional

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[354]On the far left side, a number of MUSICOMP subroutines are called into operation, preparing the loading of data, selected procedures, etc., in short, getting the program ready for action. FORMAT addresses the storing of musical choices in a stereotyped memory allocation pattern, and allows their standardized alphanumerical print-out if required. CSX sets up some real-time sound generating processes, if desired. ACTION stands for starting the actual composition process, referring directly to the C.O.C. (**C**hoice **O**rder **C**ode), a collection of different tables of instructions or 'macros', featuring both types of 'choice' or 'conditional transfer' routines, written in SCATRE. If the calculations have produced valid results, they will be printed out. Otherwise, the problem in question will be reverted to another round of trial, starting again with ACTION.

[355]See Fig. 31. in the appendix.

modelling. MUSICOMP can be considered as a matured version of the prototype of compositional design developed in the ILLIAC SUITE. In the light of this fact, let us again quote Hiller, as he recollects his ideas on the processes involved in writing music with a computer:

> We first generate random numbers in the computer and associate[356] each random integer with some particular element of a musical structure. . . Second, we subject the chosen random numbers to many tests that are rather like sieves through which the random number must be strained. These tests might reflect the constraints of the usual compositional rules, *a priori rules* [italics supplied] which merely strike one's fancy, the results of statistical analyses that provide frequency distributions to which one can refer, or even self-generating rules produced in the computer in such a way that the structure is generated and then investigated in order to draw inferences from it to cause the structure to be extended by means of new rules in some sort of logical manner. Third, we assemble our results into units of music or proportions thereof. **Thus, we are really applying some of the ideas of information theory in an operational and practical way.**[357]

Referring to the overall form of the COMPUTER CANTATA, a graphical representation of the Prologue to Strophe I, written entirely in terms of an information theory model, would then read as follows.[358]

It has become clear by now that both the ILLIAC SUITE and the COMPUTER CANTATA reflect an extraordinary number of operational and practical principles derived from information theory. Hiller's application of this theory therefore represents one of the most thorough and convincing

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[356]Please refer to above statement by Curtis Roads concerning missing linkages of musical parameters.

[357]Hiller: "Programming a Computer", p. 66.

[358]See Fig. 33. in the appendix.

studies concerning a new development in compositional method: generating musical texture by means of computers. This development could not have taken place without a clear influence of information theory, marking the beginning of a new brand of compositional method by means of a scientific discipline applied to the field of music.

CHAPTER V - KARLHEINZ STOCKHAUSEN: "GESANG DER JÜNGLINGE"

1. Speech Experiments as a Study in Compositional Method

Through systematic permutations of a biblical text, Stockhausen was able to approximate all the possible exclamations for praising God in the acoustic universe, an almost infinite number. The currently existing body of work, GESANG DER JÜNGLINGE, took nearly 1 1/2 years to complete by hand and remained unfinished, due to the sheer complexity of the compositional procedures involved. However, in retrospect, Stockhausen's objective of attempting to encompass the entire continuum of structural sound representations within the spectrum of the acoustic universe - spanning both the microscopic and the macroscopic dimensions of compositional method - had been achieved: GESANG DER JÜNGLINGE had fulfilled the purpose for which it was created.

A closer look at the compositional approach used in GESANG DER JÜNGLINGE reveals many striking features related to information theory, and similar to those encountered in Hiller's works. GESANG DER JÜNGLINGE is certainly extraordinary in terms of its author's ambition to establish acoustical communication over the entire spectrum of sound. If we accept the suggestion that GESANG DER JÜNGLINGE was conceptually communicational in nature, it will be useful to include this point of view during our investigation, especially with regard to the influence of information theory. Our approach will be to gradually follow the compositional process involved, which have an interesting genesis, especially regarding its connection with development processes related to total serialism and "Elektronische Musik" in Cologne. As far as the influence of information theory is concerned, we will first highlight the particular development which led from the genesis of serial technique to aleatory design, this being of crucial importance with regard to the role of some concepts of information theory in Stockhausen's work, particularly in GESANG DER JÜNGLINGE. This matter will be examined in detail, especially from the viewpoint of the progression from serialist procedures toward the integration of aleatory technique.[359]

2. New Terms in Music Theory: The Components of Serial Composition

First of all, what is meant by serial technique? It is a term with many variations in functional scope, especially regarding the operational networking of more than one musical parameter at a time by means of a row technique: serial music attempts to extend its rational control over the entire spectrum of musical elements. Koenig writes that

> Serial composition technique presented itself as a control system that had become more or less codified both in instrumental and in electronic music of the first years in Cologne. However, serial technique was to a great extent understood as...a sort of *ersatz* for the lost art of motivic or thematic composition because of the fact that the tones or intervals in a "series" could be arranged according to principles which could hardly be accounted for outside motivic relationships, and the permutations of such a series could also be

[359]Another thorough account of this topic can be found in Gottfried Michael Koenig's essay "Serielle und aleatorische Verfahren in der elektronischen Musik" (1964), Die Sonde, V/1, 1965, and Electronic Music Reports, No. 4, Utrecht, 1971.

> fitted into a pattern which [if] at all possible had to be derived from the series too.[360]

Thus, it was possible now to manipulate musical material according to arbitrarily chosen numerical series or proportions between elements, affecting both the microscopic and the macroscopic dimensions of musical representation. Consequently, every process used according to such rules would cause a distinct pattern of distribution of musical material, unique to the series and material being utilized. Since it merely represented a system of proportional restraints, serialism soon led to a

> mathematical style of reasoning, and the operation of an electronic sound apparatus induces scientific and technical interest. The composer dreams that the image of the universe as outlined in the concepts of Einstein's relativity, Heisenberg's principle of indeterminacy, Planck's quantum theory or Schrödinger's wave equations is somehow reflected and sublimated in his complex serial manipulations of musical atoms, although they do not require much beyond junior-college mathematics."[361]

However, all four scientific concepts seem like a deterministic description of non-deterministic properties. This became a disturbing realization for advocates of music serialism around the mid-1950s, when the serialist objective to ultimately control every facet of a musical work reached a limit of descriptive power: the musical material began to present itself in an unpredictable manner, i.e. it became "aleatory". Koenig remarked in retrospect that "it appeared that the trouble taken by the composer with series and their permutations has been in vain; in the end it is the

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[360]Gottfried Michael Koenig: "PROJECT 1", Electronic Music Reports, No. 2, July 1970, p. 33.

[361]Ernst Krenek: "A Composer's Influence", Perspectives of New Music, Vol. 34, No. 3-4, Fall 1964, p. 41.

statistic distribution of musical events which determines the features of a composition".[362] Seen from this perspective, serial technique appears to be only a special case of aleatory compositional technique.

How does serial technique then establish the operational networking of the musical material? As there is no single system or unified procedure to be found in the development of serial technique, we will approach this topic by specifying all the allowable possibilities that meet the criteria of this technique in the broadest sense. This includes such possibilities as the formation of the various interacting series via a common design, without any independence between them, or without inner coherence. Even more possibilities exist regarding the assignment of values: 1) Each number in a series has a value which corresponds to the identical number in the other series; (2) each component of a series is determined by a corresponding interval (between components) of another series; (3) the different elements are given a common unit of measurement; (4) a fixed[363] ordering of proportions between the components of the series is determined. This order of proportions holds for all serial-controlled elements.

a) The Creation of a Continuum

If we want to base serialism on a fundamental principle, the above measurements imply an established

[362]Gottfried Michael Koenig: "PROJECT 1", Electronic Music Reports, No. 2, July 1970, p. 33.

[363]See Karlheinz Stockhausen's idea of gradation of the time continuum in: "How Time Passes", Die Reihe, Vol. 3, Vienna, 1957, p. 13.

connection between extremes. Surprisingly, extremes are no longer opposed to each other when such a connection is made, as "they belong to the same phenomena, which are created simultaneously with the establishing of the [serial] connection".[364] Connections can be formed either continuously (like pitch-glissandi) or discontinuously (as in the case of a discrete set of values). Discrete series often employ equidistant scales (mostly for duration and pitch). Serial "values" can be assigned according to the position of the individual steps within their overall positions in the scale[365] of physical dimensions.

b) Parameters

Musical elements can be classified as constants or variables depending on their point of reference within the overall structure: the timbre of an individual part within an orchestral score can be considered constant (in comparison with the timbre of other instruments) while pitches, durations, and dynamics are variable, and vice versa. Variable elements are labelled as parameters, a term which was first introduced in serial music and which is generally accepted today as relating to physical values of frequency (pitch), duration (time), and dynamics (amplitude). These variables are then ordered in series which are subjected to serial treatment as well.

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[364]Kare Kolberg: "New Terms in the Theory of Music", Studia Musicologica Norvegica, No. 1, Olav Gurvin, Ed., Institute for Musikkvitenskap, University of Oslo, 1968, p. 137.

[365]For example, in a series of dynamic values, ff has a higher value than f.

c) The Principle of Equivalence

Hierarchical relationships within the same parameter (such as pitches in the 12-tone chromatic scale) introduce the principle of equivalence (excluding tonality in this case). Furthermore, variables of new elements could become equal (for example, new categories of parameters could be introduced). Consequently, a fundamental equality could be established between different parameters.

d) Global Serialism

If we create equality between all the aforementioned components, the serial organization of larger categories, or global parameters, becomes possible through geometric projections on a larger scale. These would comprise, for example, register, density, dynamic disposition, relationships between formal sections etc., all governed by the proportional relationships formerly imposed on the total organization of the musical material on the elementary, or micro-structural level. However, the process of projecting a serial structure on the level of macro-structure was not without drawbacks: extending the domain of serialism often resulted in elementary parameters becoming independent, as they were now also subjected to a superior organization. In other words, the introduction of serial treatment applied to global parameters frequently resulted in deviations in the treatment of elementary parameters: a gradual strengthening of the global parameters often results in a corresponding weakening of the elementary parameters.

e) Serial Automatism

As serialism was being developed, the tasks of human evaluation and decision were gradually narrowed down; the focus of creative activity was shifted to the preparatory phase, the selection of parameters, and the operational mode. A certain paradox begins to surface:

> The more we issue directives, the more indeterminate becomes the resulting overall structure, and vice versa: the more one attempts to determine the resulting structure, the less one is capable of determining elementary specifications and relationships.[366]

Considering the natural flow of its historical development since Schönberg, it is interesting to note that during the 1950s, serial technique progressed from the determination of details (elementary parameters/micro-structure) to the determination of macro-structural properties (global parameters). Conversely, this focus on global structure often resulted in a weakening of elementary serial technique to such an extent that it was eventually found inept, and often omitted, especially in later serial works. Thus, we can expect the highest degree of automatism to occur when the greatest possible balance is maintained between the determination of details on one hand, and overall structure on the other: "Deviations from the predetermined will be so small that the serial technique can be carried out in both domains with no loss of concept-determined characteristics, despite exceptions".[367]

The emancipation of serial technique is therefore most evident in a situation where automatism is most highly

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[366]György Ligeti in "Pierre Boulez - Decision and automatism in the STRUCTURE 1a", Die Reihe, No. 4, p. 38.

[367]Kolberg, op. cit., p. 140.

developed. The direct result of the above progression towards a preference for global organization is that individual musical elements (notes or small tone groups) become highly independent, resulting in a musical texture of isolated sound objects, hence termed as a "pointillistic" style. Often, single musical events will be differentiated only internally, by changing the parameters of pitch, duration, articulation, and so on: an individual gestalt is thus induced, precisely determined by a combination of various elements.

However, shifting the serial principle from elementary to global parameters resulted in the loss of the individual event's independence within the overall structure because it was governed by series affecting both the elementary and the global levels of organization. This includes the type of organization where singular musical events (notes) are replaced by multiple events ordered into "fields", "regions" etc. (In other words, an individual note can be determined with regard to tone quality and register, or the ordering of tone qualities can be replaced by an ordering within fields, resulting in a statistical technique). These principles, the pointillistic and the statistic, can be regarded as extremes in serial compositional technique. Metzger wrote in 1959:

> What is meant is a method of composition which isolates the individual elements in such a way that their relationship and proportions can be grasped; the counterpart to this is the concept of the statistical, which developed along with composition whose complexity no longer permits a point-wise hearing of each individual element, but rather provokes higher-order categories of perception, which try to refer to average density, pitch, duration, intensity of passages, to rising, falling, swelling or ebbing tendencies, and so on.[368]

[368]Heinz-Klaus Metzger: "Abortive Concepts in the Theory and Criticism of Music", Die Reihe No. 5, p. 26.

f) Groups

The concept of groups is an attempt to mediate between the individual note bearing a maximum intrinsic value, and the individual note or event that is submerged in a statistical distribution (and thus has lost its independence). A group is constituted when a modest number of individual musical elements are grouped together to form a new unit, becoming a discrete phenomenon with regard to other units, or groups. Within groups, the degree of independence of individual notes or musical events may vary from total autonomy (where the exclusion of single events will hardly be noticed), to total dependence (the exclusion of a single event results in a loss of identity for the entire group). Groups can formally affect any level within the entire spectrum of the structural hierarchy, from elementary to global proportions. The ordering within groups and of groups can be subjected to principles of traditional twelve-tone technique (representing a segment of the series and acting as a "motive"), as these are generated according to principles of serialism. In this case groups are treated as as parameters, or according to a fixed ordering of proportions, in the form of pre-determined proportional series, for example, such as Stockhausen has described in "How the Time Passes".[369] The ordering of groups can therefore be effected on the elementary or global level, resulting in individual groups with distinct qualities of <u>gestalt</u>; or it can be affected by compounding units toward the creation of formal structures, so that the ordering process becomes parametrical in principle. Structures and individual groups can then be considered as both ends of a

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[369] Karlheinz Stockhausen: "How Time Passes", <u>Die Reihe</u>, No. 3, English version, Theodore Presser, 1959, pp. 10-40; orig. "Wie die Zeit vergeht", <u>Die Reihe</u> No. 3, Vienna, 1957.

spectrum of parametrical organization, which again might be subjected to a process of normalization, where both extremes are made consistent with each other through the establishment of other organizational relationships, acting as a new parameter. In other words, a continuum can be established between former extremes, allowing a gradation of groups:

> The concept of the group mediates between structure and shape. As soon as the group approaches the stage of a structure it becomes unsynoptical and the segregation of the elements in the group is strong enough to give it a great similarity to other groups in its environment. And conversely, the more a group becomes concentrated - in other words the fewer the elements it conjoins in a simple order and the less repetitions it contains - the more it approaches the state of a unique and unrepeatable shape. Thus one can establish a series of groups.[370]

In Stockhausen's Gruppen, a composition which was created during the period of time when GESANG DER JÜNGLINGE was realized, all the above properties of groups can be found. Furthermore, the extension of serialism, along with an increased number of separate parameters, created a growing need to correlate units of measurement between parameters. The principles of serialism seemed predestined to fulfill these needs by offering a system capable of establishing a comprehensive coherence in the organization of musical material on all levels of structural organization. In order that all parameters should relate to a common unit of measurement or denominator, Stockhausen, in "How Time Passes", set out to structure musical material over the entire acoustical spectrum of human perception,

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[370]Karl H. Wörner: Stockhausen - Leben und Werk, Rodenkirchen, 1963. Transl. Bill Hopkins, Life and Work, University of California Press, Berkeley and Los Angeles, 1973, p. 96.

according to the single all-encompassing parameter of time, serially structured into "phases":

> Music consists of order-relationships in time; this presupposes that one has a conception of such time. We hear alterations in an acoustic field: silence-sound-silence, or sound-sound; and in between the alterations we can distinguish time-intervals of varying magnitude. These time-intervals may be called *phases*.[371]

g) Phases

Phases can be arranged in phase-groups, over a continuum ranging from periodic to aperiodic phase groups at either end of the spectrum. Relationships between phases (i.e., their phase durations) can be measured by means of a "unit-quantum",[372] which could be based, for example, on the time interval of one second:

> Our sense-perception divides acoustically-perceptible phases into two groups; we speak of *durations* and *pitches*. This becomes clear if we steadily shorten the length of a phase (e.g., that between two impulses) from 1" to 1/2", to 1/4", 1/8", 1/16", 1/32", 1/64", etc. Until a phase-duration of approx. 1/16" we still can hear the impulses separately; until then, we speak of 'duration', one that becomes extremely short. Shorten the phase-duration gradually to 1/32", and the impulses are no longer separately perceptible; one can no longer speak of the 'duration' of a phase. The latter process becomes perceptible, rather, in a different way: one perceives the phase-duration as a 'pitch' of the sound. 1/32" phase-duration makes us, say, 'a "low" note'.[373]

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[371]Karlheinz Stockhausen, introduction to: "How Time Passes", op. cit., p. 10.

[372]Stockhausen, "How Times Passes", op. cit., p. 10.

[373]Stockhausen, "How Times Passes", op. cit., p. 10.

In terms of the perceptual differentiation of phase-durations, phases can be classified into two groups: (1) micro-phases with durations of less than 1/16 second, and (2) macro-phases with durations of more than 1/16 second. For example, let us attempt to define a single tone as a musical event according to such criteria: this individual tone would belong in the macro-phase group. However, an individual tone could also be described in terms that allow a distinction between the duration of the tone and the corresponding phase-duration of its pitch. Furthermore, a tone may be considered to have many varying phase-durations, forming groups, and determining timbre.[374] An elementary ordering of these particular phases and phase-groups could be achieved by the simple arithmetic means of multiplying and dividing a basic unit, the fundamental phase. In fact, the **multiplication** of a fundamental phase by an arithmetic series would result in a "sub-harmonic" series of proportions, its **division** by an arithmetic series would result in a harmonic series of proportions, a phase-spectrum. Stockhausen describes such a fundamental phase and all its divisions as *formants*, and a group of formants as a *formant spectrum*.[375]

[374]I have already investigated this issue in Chapter I, in the discussion of complex sound spectra and Fourier analysis, emphasizing that every sound can be understood as a limited set of the most elementary wave forms: sine-tones. It was the proven existence of a limited set of wave-forms making up any imaginable complex wave-form which finally allowed the precise determination of the quantitative data involved in complex sound spectra by means of information theory.

[375]Stockhausen's definition is not congruent with the acoustical definition where a formant is defined as the outcome of emphasizing certain fixed bands of harmonic series of frequencies, resulting in a 'coloring' of timbre as found in all vibrating bodies. The distribution and intensities of the component frequency spectra can be described in statistical terms.

Series can now be altered by varying their structural contents (or tone/event-row) by several means. For example, the traditional twelve-tone technique used simple geometric modifications (original-inversion-retrograde, retrograde+inversion) or linear modifications such as transposing pitch and duration over the entire series. In principle, the original structural ordering of the series was not essentially affected.[376] In fact, decreasing local dependencies between serial elements was eventually brought about through geometric *permutations* of all the individual elements of a series. This was an extreme case in terms of Schönberg's original idea, which was to allow the beginning of a new rotation only after all the elements of the series had been sequentially used up. However the technique of permutation, with its profound effect on the positioning of elements within a series, represents a much more drastic modification of a structural order. The degree of recognition of a permutated series depends essentially on the degree of permutation of the series and can be based on statistical criteria.

The application of the permutation principle also involves the strategy of *rotation*, used mainly in later serial technique. Rotation causes the elements of a series to change their relative positions according to a serially conceived plan, occuring in regular phases. Other versions of the rotation technique have been discussed by Kagel[377]

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[376]Hence the understanding that Schoenberg, Berg and Webern (early in his career) still operated with series or parts thereof as "motives" in terms of traditional composition technique.

[377]Mauricio Kagel: "Transition-Rotation", Die Reihe No. 7, Vienna, 1965 (orig. publ. 1960), pp. 32-60.

and Eimert.[378] According to Eimert, the rotation technique evades the dimension of time (assuming that series had to be presented sequentially "in time"), as it produces a new spatial-geometrical fixation of a given figure any time it rotates. As with geometric figures, the degree to which a given serial figure is "rotated" can be indicated by the "rotation angle". The technique of rotation thus embraces the operational approaches of permutation, transposition, and geometric manipulation (inversion etc.). It is of fundamental importance in GESANG DER JÜNGLINGE, the first electronic piece involving spatial projection through such means.

h) Aleatory Processes

Aleatory processes, as a compositional principle, can be seen as a direct result of extreme pre-determinations of details and "totalities". We have already discussed the situation wherein the two concepts of elementary and global technique seemed to have reached a Heisenbergian dimension of uncertainty, i.e. where a gradual strengthening of the serial structuring of global parameters resulted in a corresponding weakening of the elementary parameters in order to conform with the global demands. Indeterminate procedures were thus induced on the elementary level. Xenakis, in his essay "The Crisis of Serial Music"[379](1954), described this dilemma from a **perceptual** point of view:

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[378]Herbert Eimert: Grundlagen der musikalischen Reihentechnik, Vienna, 1964.

[379]Iannis Xenakis: "The Crisis of Serial Music", Gravesaner Blätter, No. 1, July 1955, p. 3.

> Linear polyphony destroys itself by its very complexity; what one hears is in reality nothing but a mass of notes in various registers....There is consequently a contradiction between the linear polyphonic system and the heard result, which is surface or mass. This contradiction inherent in polyphony will disappear when the independence of sounds is total. In fact, when linear combinations and their polyphonic superpositions no longer operate, what will count will be the statistical mean of isolated states and of transformations of sonic components at a given moment [compositionally]. The macroscopic effect can then be controlled by the mean of the movements of elements which we select. The result is the introduction of the notion of probability, which implies, in this particular case, combinatory calculus. Here, in a few words, is the possible escape route from the "linear category" in musical thought.[380]

Both the principle of total deterministic control over the entire form and the principle of indeterminate patter ns cropping up within a strict serialist approach[381] - which were at first considered incompatible - proved to be just extreme manifestations of a compositional approach involving a whole spectrum of possibilities in between: the concepts of probability were introduced into composition through "musical necessity".[382] Contrary to popular belief, the use of aleatory processes was not due to a reaction against serialism, but was in fact a logical consequence of its development. As a matter of fact, such processes had been a

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[380] Iannis Xenakis, Formalized Music, Bloomington, 1971, p. 8.

[381] Heinz-Klaus Metzger characterizes this situation as reflecting "the dialectic preposition that greater complexity and finer organization are penalized by cruder perception", in Die Reihe No. 5, Vienna, 1955, p. 26.

[382] Iannis Xenakis: Formalized Music- Thoughts and Mathematics in Composition, Indiana University Press, Bloomington, 1971, p. 9. Orig. publ. as Musiques formelles, Paris, 1963.

part of serialism from the outset, but had not been detected as such until an impasse had been reached.[383] The development of serial electronic music as produced in Cologne played a vital role in introducing the use of such aleatory processes, as its procedures were based on an investigation of the essential nature of the acoustical, perceptual, and structural characteristics of musical material which was found to be essentially aleatory in nature.

3. Aleatory Technique

The term 'aleatory' was first used in 1955 by Meyer-Eppler in his article "Statistic and Psychological Problems of Sound" and reads as follows:

> A process is said to be aleatory (from Lat. *alea*=dice) if its course is determined in general but depends on chance in detail. Calculations of these procedures can be effected by statistical means. Musically, everything which is not 'written in the notes' is within the aleatory sphere.[384]

Meyer-Eppler's definition is quite clear in discriminating between "chance procedures" such as those just then introduced by the experimental American School under the influence of John Cage, and "aleatory procedures".

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[383]This topic has also been discussed by Monika Lichtenfeld in her article "György Ligeti oder Das Ende der seriellen Musik", wherein Ligeti expressed his opinion that the logic of serial thought had finally steered serial methods into a dead-end from where an "escape in the form of a continuous development was impossible." In: Monika Lichtenfeld, "György Ligeti oder Das Ende der seriellen Musik", Melos, 1092/2, p. 74.

[384]Werner Meyer-Eppler: "Statistic and Psychological Problems of Sound", Die Reihe, No. 1, Vienna 1955, pp. 55-61.

What does the latter expression really mean? A procedure is called aleatory when "immediate prediction is lacking due to predetermination being employed to too little or too great an extent".[385] Both cases produce a situation in which a total control of the data output is not possible, as the results are regarded as being affected by processes of chance. In fact, total chance can never occur because the existing input parameters limit the field within which possible and desirable data can be generated. Therefore the inclusion of a limited scope of chance is characteristic of aleatory procedures. Again, the limitations imposed on aleatory freedom could be placed somewhere between the extremes of total determinism on one hand and random procedures on the other.[386]

However, although both extremes can still be considered aleatory, the rules of a game of dice cannot. How can we account for this paradox? Meyer-Eppler does not provide a clear answer. It would appear that both sides of this distinction border on a continuum. Metzger called it the "forgotten definition" in his critique of the erroneous use of the term 'aleatory': "Aleatory...processes are those whose course is determined as a whole but whose individual

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[385]Kolberg, "New Terms in the Theory of Music", op. cit., p. 150.

[386]In fact, this idea is not as new as it seems: it was already commonplace in mathematical terms since Port Royal Logic in 1662, and Bernoulli in 1713, as both sources stated that there is no absolute polarity between chance and determinism, rather a continuous spectrum between both extremes. Mathematics could then be used "to describe and manipulate degrees of disorder, or the movement from order to disorder and from disorder to order". In: Christopher Butchers: "The Random Arts: Xenakis, Mathematics and Music", Tempo, No. 85, Summer 1968, p. 2.

details depend on chance".[387] Conversely, the above definition might suggest that to compose music according to the rules of a game of dice would mean allowing the whole of a work to be produced by processes of chance, while individual details might be pre-determined. Addressing Stockhausen's use of this principle, Wörner stated:

> With th s, Stockhausen first brought into play the concept of chance, of the aleatory...technique of composition for large forms. In the handling of musical elements aleatory methods were of decisive importance in GESANG DER JÜNGLINGE and also in GRUPPEN - although they are no longer recognizable in the final fixed version - as well as ZEITMASSE... It should be mentioned here that Stockhausen had already been stimulated to conduct experiments in aleatorism by Meyer-Eppler in 1953. Meanwhile the aleatory, as Stockhausen understands it, is only the contributing factor in the entity which was to be defined in the concept of the typical process, or 'process model'.[388]

It is no coincidence that the article containing Meyer-Eppler's definition was published in 1955, the year in which Xenakis' critique was issued; this subject was already obvious to every composer using serial technique. It is also no accident that Stockhausen, the co-editor of Die Reihe, had studied acoustics, phonetics, and information theory with Meyer-Eppler, one of the leading specialists in Europe in the field of communication science during the 1950s. And it is certainly no coincidence that Meyer-Eppler's article on aleatory processes in electronic music was preceded by Stockhausen's article, "Actualia", explaining the progress of his work on GESANG DER JÜNGLINGE; the aleatory compositional technique was taken seriously here by one of

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[387]Meyer-Eppler paraphrased by Heinz-Klaus Metzger in, "Abortive Concepts in the Theory and Criticism of Music", Die Reihe, No. 5, Vienna, 1959, p. 26.

[388]Karlheinz Stockhausen, as quoted in Karl Woerner, op. cit., p. 220.

the main proponents of total serialism - Stockhausen himself.

a) Indeterminate Form

Stochastic and aleatory music had been born as a direct result of using serial technique with an ultimate degree of precision: the pre-relativistic world of music, reflecting until then an 18th-century Newtonian approach of determinism with regard to musical material and structure, had been subjected to an upheaval similar that experienced by nuclear scientists at the turn of the 20th century, when they discovered that deterministic results were just a special case within the overall scope of probability theory.[389] "Serial thought...sets out to mediate between any given extremes"[390] and does, in fact, include the entire spectrum of probability. Once this idea of universal mediation is understood in its full dimension,

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[389]Christopher Butchers wrote, "In fact in some respects it is not an exaggeration to state that it is the central importance of probability which principally differentiates the science of the twentieth century from that of the past: in that we have moved from the belief that science consists of an ever more exact measurement of ever more precise entities to the belief that knowledge is valid and comprehensive when it embraces an appreciation of the general characteristics of entities on a macrocosmic plane, the precise properties of the micro-components of those entities being irrelevant. This knowledge of general properties is statistical, probabilistic knowledge: for it consists in the statement of the probable nature of the whole when given precise measurement only of a sample, and in the structure of the probable forms taken by logical assemblages of entities rather than their individual content". In: Christopher Butchers, "The Random Arts: Xenakis, Mathematics and Music", Tempo, no. 85, Summer 1968, p. 2.

[390]Karl-Heinz Wörner: op. cit., p. 82.

> ...nothing should be excluded from its scope. Its conceptual principle is a principle of organization: to establish a scale between extremes and then to construct a series having determinate proportions. These proportions are to be observed throughout a work's entirety, and will give the work its character and its structure.[391]

We notice that it is the series which has determinate proportions affecting the entirety of the work; but we have also seen that on the elementary level, the proportions are indeterminate or statistical.

b) Statistical Form

Statistical form was the issue that gradually began to extend the concept of serial technique, rapidly gaining a fundamental importance in the compositional developments of 20th century music. In fact, once music was accepted as a special form of acoustic communication - and this was certainly the case for composers working in the field of electronic music in Cologne - the development of the concept of statistical form, with its close affinity to probability calculus, required a mathematical means to control the process of statistical composition. The aleatory principle was found to be most favorable in this respect, as it allowed composers continued serial control on the macro-structural level, while micro-structural details were conveniently handled by procedures related to probability theory. The latter represents a fundamental component of information theory, and music - being explicitly communicational in nature - was suddenly perceived as having a strong affinity with certain aspects of this theory,

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[391]Karl-Heinz Wörner, op. cit., p. 83.

including a structuralist approach that served as a common ground for both disciplines.

c) An Example of Statistical Form: Stockhausen's KLAVIERSTÜCK X

How was this structuralist, serial approach finally applied in Stockhausen's work? Before we begin our discussion of GESANG DER JÜNGLINGE, let us summarize this approach through a brief example of the application of its inherent principles, especially regarding the manner in which structural order and disorder can be imposed on a musical texture which is **not** electronic in origin. In KLAVIERSTÜCK X, Stockhausen explored the traditional concept of the dialectic relationship between order and disorder; he attempted to establish serial relationships among various levels of structural organization by drawing up a scale mediating between the two extremes of organizational order. This scale was then used to compose structures in series exhibiting distinguishable degrees of organization.

> The higher degrees of organization are identifiable by their greater unequivocalness - in fact, their absence of chance - whilst lesser degrees of organization can be identified through their higher probability factor and their greater levelling-out of differences, constituting a tendency towards entropy.[392]

When organizational pressure is applied to raw, unordered musical material, there results an increased differentiation between individual musical events. At the same time, this process leads to tendencies that lower the density of individual events, promoting their dissociation from the higher entropic context from which they have been

[392]Karl-Heinz Wörner: Stockhausen, p. 94.

selected. The result is a greater necessity of a clear description of individual characteristics, within processes that increase the isolation of individual events. Ultimately these processes lead to a single, unique event, a tone. In KLAVIERSTÜCK X, we have a mediation between two extremes: one where structures will be hardly distinguishable from vast complexes involving the random distribution of individual events, the other corresponding to a maximum degree of organization, where structures might crystallize into unique, highly individualized shapes or patterns. In terms of procedure, this translates into moving from one extreme involving a perfect simulation of random-type white noise,[393] to another where, through the compositional process, structural order finds its way into this unstructured, random universe,

> out of which are expounded more and more and increasingly sizable shapes. These shapes take up more and more room. The phenomenon may be regarded as similar to a genetic process.[394]

Since the aleatory process itself can be considered only as a contributing factor in the entity to be defined as a 'process model', the final product might not disclose the process by which it was composed. The generative process itself, on the other hand, might well be considered to represent the foundation of this work, as its existence is entirely due to procedural, statistic properties. Composing with various degrees of statistical order naturally leads to a virtually infinite number of possibilities regarding the

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[393]Hiller would have termed this situation a 'black and white random white noise' situation.

[394]Wörner, op. cit., p. 95.

final 'realizations': 'virtual' music can take place without a pre-determined model orientation.[395]

> You see, in the fifties the processes that led to the new music were sometimes more important than the quality of the music itself. That's what happens in big historical changes: theoretical aspects become more important than the inherent quality of art.[396]

This is exactly what Stockhausen has described in his work regarding the development of statistical form: through the processes involved in our limited perceptual recognition, individual notes, or other sectional forms, are consciously related to the entirety of a musical work, from which they cannot be disassociated; the perceived structures are then recognized as statistical in nature. Conversely, if we attempt to compose music from a non-perceptual basis, certain statistical criteria have to be devised beforehand. Thus, musical form would not necessarily be a result of the properties of all the individual musical elements involved, but would merely proceed from the organizational principle itself. In other words, in the development of statistical form, detailed specifications concerning individual elements are considered only as an extreme possibility involving a limited degree of efficiency. Statistical form is more efficient in describing the "average" speed, geometric distribution or intensity of increasingly complex structures. Of course, individual events within a dense musical texture could still be further analyzed, but often

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[395]Stockhausen states in Jonathan Cott: "I explained the relationships between the structuring *within* the sound and the structuring *of* sounds in order to build larger entities, to construct larger musical formations that allow many solutions for a given process plan." In: Jonathan Cott, Stockhausen, p. 187.

[396]Stockhausen in Ekbert Faas: "Interview with Karlheinz Stockhausen", Interface, Vol. 6 (1977), p. 198.

they cannot be grasped perceptually apart from the overall structure of the work. For example, a score might specify that a swarm of notes travels through a register of several octaves downwards in a matter of seconds. We would hear the effect of a shooting cascade of complex sound, but we would not be able to distinguish individual elements. In fact, it would make no difference at all to our perception if the same score were defined in a completely deterministic fashion, or if it were written in statistical terms, merely indicating the performance instruction to "travel from A' to C" in a specified time interval, leaving out the notation of discrete pitches. This is exactly the advantage of statistical form in composition: textural structures formerly considered too complex become a matter of simple notational description.[397]

So far, we have seen that the statistical development of form relies increasingly on the aleatory principle, as variances in the placement of elements, or in the serial order, can no longer be recognized any more. The more complex and dense the musical texture, the more variance of aleatory freedom can be tolerated without changing the overall perception of the gestalt. Predictions regarding individual events present at a certain time and place become approximate in nature, and increasingly subject to the laws of probability: "One cannot account for the whole on the basis of the individual part, for the whole is conceived as

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[397]It will be beyond the scope of this dissertation to discuss matters of musical notation with respect to statistical formation. However, it is interesting to note that, for example, Ligeti and Xenakis still write out every single note in the score, Penderecki operates with a black-box notation system, and Cage opts to dispense with the notation of events altogether.

the probable result of many components".[398] In other words, the criteria for statistical composition ought to become the properties of certain theories that rule similar phenomena in the micro-structural and macro-structural dimensions of this universe.

4. The Influence of Meyer-Eppler on Stockhausen

How then did Stockhausen manage to control the musical material statistically, especially in the paradoxical situation where the medium is electronic music, with its rigorous demand for precise descriptions of every parameter? Was Stockhausen familiar with information theory? Had he used some of its concepts before? And which of his electronic works exhibit this influence most clearly? The first indication regarding these questions comes from Wörner, who states that:

> Stockhausen reports that the development of the forms he calls 'statistical',[399] 'variable' and 'polyvalent'

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[398] Wörner, op. cit., p. 98.

[399] Stockhausen, questioned on his concept of 'passing time' with respect to form, stated in an interview (1978) conducted by David Felder: "Maybe I have been able to contribute a lot to this movement, what I call statistical composition - to transcend completely the traditional notation that you have to compose detail so clearly that you can hear everything . . . then we have reached a completely new concept of music . . . It had a lot to do naturally with the expansion of consciousness toward atomic physics, nuclear physics and also with the expansion of the consciousness through the new astronomical discoveries. We become more fully aware of the aspects of the density of the universe; and it's still only known and felt by very few people that statistical composition has been one of the most important expansions of musical composition during its whole course, because it also has led us to the use of totally new means which allow us the condensation of sound and the micro-structuring of sound, through electronic means . . . " David Felder: "An Interview

> was germinated as early as 1953 by his research[400] with Meyer-Eppler into phonetics[401] and information theory...[402]

This is a remarkable statement, both concerning the use of information theory, and the introduction of the principle of chance procedures into music in Europe as early as 1953.

a) Dating early experiments in aleatory technique

Stockhausen was certainly interested in finding out more about experiments in electronic sound synthesis after his brief period of experimentation in Paris (1952); together with his friend Goeyvaerts, he attempted to obtain additional information from Meyer-Eppler whose experiments fascinated them considerably (Meyer-Eppler started electronic sound experiments as early as 1951).[403]

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with Karlheinz Stockhausen", Perspectives of New Music, Vol. 16, Fall-Summer 1978, p. 87.

[400]"I have studied phonetics, where I probably learned most about the statistical, microtonal nature of sound, and transposed this knowledge into the macrotonal composition; also phonology, the study of the system of language. This was a very important time in my life". Stockhausen as quoted in David Felder: "An Interview with Karlheinz Stockhausen", Perspectives of New Music, Vol. 16, Fall-Summer 1978, p. 93.

[401]Stockhausen, in an interview with Jill Purce (1978, in the journal Sound International, No. 6-8, Oct, Nov, Dec 1978), once referred to Meyer-Eppler as his teacher in linguistics. In: Karlheinz Stockhausen, Texte VI, Köln, 1989, p. 347.

[402]Wörner, op. cit., p. 237.

[403]Stockhausen: "Tomorrow we will hitch-hike to Cologne, I would like to find out what Dr. Meyer-Eppler's electronic music is up to" (letter of Stockhausen to Goeyvaerts on July

A constant discrepancy seems to persist in properly dating Stockhausen's studies with Meyer-Eppler, especially concerning aleatory experiments. Wörner dated aleatory experiments under Meyer-Eppler as early as 1953,[404] and also a 'study of phonetics and communications[405] under Professor Werner Meyer-Eppler at Bonn University from 1954-56.[406] However, we find the following remarks, explicitly written by Stockhausen himself, when the Free Berlin Network asked him for a "concentrated" biographical statement in 1973:

> In 1953, he composed the first piece of electronic music: STUDIE I for sine tones. From 1953 to 1956, he studied phonetics and communication science with Meyer-Eppler at the University of Bonn.[407]

Was it 1954 or 1953? One might think that one year or the other, or even the months in between, would not matter. However, this is not the case. In fact, we find some critical comments regarding priority claims by both Stockhausen and Herbert Eimert as to who wrote the first "electronic music", a term adopted from then on in the Cologne School. The matter was never completely settled, and entailed once again the dating of experimental research. Stockhausen claimed to have written electronic music (STUDIE II), and termed it as such, already at the end of 1953,

6, 1952), in Herman Sabbe: "Karlheinz Stockhausen...wie die Zeit verging...", Musik-Konzepte Vol. 19 Heinz-Klaus Metzger and Rainer Riehn, Eds., Munich, May 1981. See also Richard Toop, "Stockhausen and the Sine Wave", Musical Quarterly 65(3), 1979, pp. 379-391.

[404] Wörner, op. cit., p. 220.

[405] He is probably referring to communication theory.

[406] Wörner, op. cit., p. 254.

[407] Stockhausen in an interview with Gill Purce, op. cit., p. 78.

before Eimert's electronic composition. Eimert, on the other hand, insisted that Stockhausen's report of experimental details was submitted as late as 1954, providing proof in form of the official date printed on top of the published manuscript submitted by Stockhausen.

It is not important for our purposes to clarify who used the magic word 'Elektronische Musik' first in the context of the electronic experiments performed (in fact, it was Meyer-Eppler). But it is of considerable interest to discover from what date Meyer-Eppler's influence began, according to Stockhausen. Was it 1953 or 1954? Or more precisely, was it before, during, or after STUDIE I was completed; before, during, or after STUDIE II? These are important questions, from a musicological, compositional, and philosophical point of view.

b) Aleatory elements in STUDIE II

I would like to approach the matter from the angle of STUDIE II: is this piece, considered to be "the" utmost materialization of serialist thought, really completely serially structured, i.e., macro-structurally **and** micro-structurally? I would like to propose that STUDIE II must have had at least a modest outside influence beyond Stockhausen's intention of entirely structuring the acoustical material according to serial thought, because the composer had already made these decisions during the process of generating sound elements, allowing the aleatory modulation of these sound elements through the process of reverberation. In fact, it is possible that, during the conceptual phase of the piece, Stockhausen intended to realize the acoustical material in the form in which it was finally represented in the score, i.e. in its original, un-reverberated state. This is usually the material to which all the analyses by different authors refer: clean, tidy, predictable, in short, entirely determinate in structure. But **is** this really STUDIE II in its final form, presented as an electronic music work?

Stockhausen must have realized that the sonic material would sound as dull as in STUDIE I, despite his idea of using inharmonic sound spectra in STUDIE II, which offered a clearly richer and acoustically more complex quality of sound (STUDIE I used only spectra of harmonic sinus-tones). What he did was to subject this utterly precisely determined sonic material (as notated in the score, published in 1956) to the process of acoustic reverberation. It is important to note that this step was not taken as a final measure of the compositional process (for example, reverberating the entire piece after the tape editing was completed), but right at the conceptual phase of micro-structural sound generation: pure sine tones, produced by a generator, serially pre-determined in pitch, were first recorded on tape, then several sine tones were assembled into desired complexes, which were finally prepared as a tape-loop. This tape loop was then played through a loudspeaker in one of the acoustical reverberation chambers of the WDR (Westdeutscher Rundfunk) and immediately re-recorded on tape. These sound samples, now transformed in structural complexity and arrangement through processes of reverberation, i.e., largely unpredictable micro-structural aleatory modulation, were then used as the final material (with the initial sound attacks or 'heads' cut off) from which STUDIE II was literally assembled through a tape editing technique.

However, in terms of the consistency of the serial principle, these procedures broke the serial bond between the micro-structural and the macro-structural levels: on the micro-structural level, the elementary sound material presented in STUDIE II bears only a faint resemblance to the material which was originally predetermined by the serial proportioning of five formerly isolated sine-tone type frequencies (the "ideal"). Through multiple reflection within the reverberation chamber, the amplitudes of the spectrum became aleatoric. In fact, from a perceptual point of view, the elementary sonic material had become unpredictable.

Seen as a geometrical projection of the micro-structural into the macro-structural level, the credo of serial thought was, in fact, strongly modified: according to this credo, "organization and musical material are one", as Stockhausen claimed, yet in STUDIE II they are **not** one. Here, organization and material are in fact completely statistical, approximate in nature. We learn that, as early as in STUDIE II, the aleatory principle had been clearly followed; the macro-structural surface of the piece, as printed in the score, depicts a structural entity with all its proportions exactly determined. The acoustical reality of the micro-structural material is at best close to the serial specifications reflected in the overall structural makeup of the work. It becomes unpredictable, and increasingly so, as the overall structure of the piece becomes more dense.

In fact, Stockhausen does not hide these facts and acknowledges the use of 'aleatory modulation' on page 13 of the score of STUDIE II. Attached to the score is "a spectrogram of the note mixtures on page 13 of the score as obtained by the aleatory modulation of the sequence of sinus notes **after** reverberation."[408] This aleatory aspect of the work has not been mentioned in previous musicological research.

Consequently, and contrary to popular belief, I propose that STUDIE II was clearly conceptualized in terms related

[408]Karlheinz Stockhausen Nr. 3 Elektronische Studien: Studie II, Universal Edition Wien, 1956, p. ix.

to statistical form and aleatory processes. We have already seen that aleatory processes were systematically researched by Meyer-Eppler since 1951, particularly in the context of information theory. Realizing that Stockhausen was extremely articulate and precise in describing his development of compositional processes (many examples can be found in numerous letters exchanged between him and Goeyvaerts regarding this matter), I presume that he must have at least consulted Meyer-Eppler during the period of the creation of the sonic material of this work. It is not likely that a composer so vehemently adhering to the principle of serial control down to molecular proportions (and Stockhausen's writings reveal him reaching a peak of this tendency during 1953-54 as well) could accept having his sonic material manipulated beyond recognition through the process of reverberation.

Stockhausen, in order to reach this point of compositional decision, must have consciously accepted the fact that serial technique, taken to its ultimate level of control of micro-structural material, was in conflict with the overall serial structure of the piece. These points are not a critique of Stockhausen's course of development, but rather an affirmation that, during critical phases of compositional decision, he has increasingly given preference to the intuitive, artistic musician in himself, instead of the system he often helped to devise. In STUDIE II therefore, he made in fact a crucial decision to mediate between serial automation (total determination, as originally attempted) and artistic choice, as a human being ultimately concerned with the true nature of sound, which he found to be questioned by the compositional process itself.

It is quite possible that Stockhausen had originally planned to conceptualize STUDIE II according "to the books", and that he might have accepted as a fact the aleatory behavior of sonic material without the influence of Meyer-

Eppler. However, my overall impression is that concepts related to aleatory technique started to gain momentum in Stockhausen's work from as early as 1953. In fact, this perspective opens new vistas of musicological research not pursued until today as I have found no sources to this effect. Meyer-Eppler is no longer alive to provide an exact date and Cott and Wörner present only ambiguous dates.

I finally contacted Stockhausen himself on the topic of the influence of Werner Meyer-Eppler on STUDIE II. With his friendly permission I would like to reproduce the relevant section of his answering letter in my own translation: "STUDIE II: I wouldn't know what Prof. Meyer-Eppler could have contributed."[409] Stockhausen stated, however, in a personal letter to Ekbert Faas, who attempted to uncover the issue of open form and the influence of statistics, information theory and phonetics in Stockhausen's work, that he "studied with Meyer-Eppler from 1953".[410]

It would certainly be beyond the scope of this dissertation to discuss the pivotal influence of Meyer-Eppler and this particular principle on the development of electronic music composition since 1949. However, a detailed account of the importance of this scientist and musician for the development of electronic music has recently been published by Elena Ungeheuer (1989), who sighted and catalogued Meyer-Eppler's estate, almost 30 years after his death in 1960, in her Ph.D. dissertation "Wie die elektronische Musik erfunden wurde" ["How electronic music

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[409]Personal letter to the author from Stockhausen, dated Nov. 21, 1994.

[410]In: Ekbert Faas: "Interview with Karlheinz Stockhausen Held August 11, 1976", Interface, Vol. 6 (1977), pp. 187-204, esp. p. 191.

was invented"].[411] Ungeheuer's research leaves no doubt that Stockhausen's statements to the effect that Meyer-Eppler was his most important teacher in the 1950s were fully justified. Stockhausen's concepts of electronic music composition, from late 1953 to 1956, were fundamentally influenced by Meyer-Eppler's preliminary or ongoing research in acoustics and information theory.[412]

That influence, in connection with Meyer-Eppler's emphasis on the area of electronic sound analysis and synthesis (and, in particular, speech synthesis), was certainly most prominently felt in electronic works composed between 1954 and 1956. This is obvious not just as a result of historical coincidence, but structurally and conceptually as well. GESANG DER JÜNGLINGE, composed during this period (together with GRUPPEN and ZEITMASSE), reflects Stockhausen's pioneering influence on the acceptance of the aleatory principle within the existing system involving serial technique. In fact, Stockhausen's fascination with

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[411] Elena Sybil Ungeheuer: Wie die elektronische Musik erfunden wurde - Kritische Quellenstudie zu Meyer-Epplers musikalischen Entwurf zwischen 1949 and 1953, Ph.D. dissertation, University of Bonn, 1989.

[412] The use of the term 'information theory', as Meyer-Eppler understood it, has to be clarified at this point. Elena Ungeheuer points out that Meyer-Eppler (in his report of the "Kommunikations-wissenschaftliches Symposium in London, September 1952" in: Fernmeldetechnische Zeitschrift, 6, 1953 H.4, p. 189) refers to the mathematically founded information theory as a discipline within the sciences of telecommunications related to current American research in cybernetics. In Ungeheuer: Wie die elektronische Musik erfunden wurde, p. 138.

Meyer-Eppler's experiments can be traced back as early as 1952.[413]

Before we examine GESANG DER JÜNGLINGE from the standpoint of the influence of acoustical research, information theory, and speech analysis and synthesis, I believe the above considerations justify a brief summary of that part of Meyer-Eppler's research which is of critical relevance to the genesis of GESANG DER JÜNGLINGE.[414]

c) Meyer-Eppler's Research Objective Regarding Electronic Music

According to Ungeheuer, "Meyer-Eppler's objective in his electronic music experiments from 1949 to 1953 was to promote the future evolution of music so as to match current developments in the technical sciences".[415] The approach taken was that of a scientific process of invention corresponding to developments in the realm of communication

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[413]In fact, Stockhausen had been in contact with Meyer-Eppler during July 1952 and, in response to a question of his friend Goeyvaerts in a letter (dated Oct. 1952), he wrote (transl.): ". . . in general, degrees of densities of electronic sounds can be determined by means of a comparative analysis with reference - and filtered - tones. But don't forget that electronic material doesn't merely consist of (mostly) tones, but of complex sounds, and that already the process of creating different sounds carries a distinct differentiation of density within the material, the command of which is not yet perfect. Next week, I will once again confer [about this topic] with Dr. Meyer-Eppler in detail." In: Herman Sabbe, "Karlheinz Stockhausen . . . wie die Zeit vergeht", Musik-Konzepte, Vol. 19, Heinz-Klaus Metzger and Rainer Riehn, Eds., Munich, May 1981, p. 40.

[414]The author cordially acknowledges the assistance of Elena Ungeheuer in this matter.

[415]Ungeheuer, op. cit., p. 11.

sciences. In the field of acoustical research, his theoretical deductions and conclusions were often inspired by experiments in electronic sound synthesis which he had conducted himself. What differentiated Meyer-Eppler's research from that of most other acousticians of his time was not only his systematic classification of acoustical phenomena according to communicational properties beyond their acoustical characteristics, but also his intuition that these results should be available to the world of music.[416] Meyer-Eppler's research in reference to the vocoder is particularly important in this regard (see Chapter I). This device, developed by Dudley and Bell Telephone Laboratories to reduce the transfer rate of the information contained in speech transmissions (through applications related to concepts of information theory), became a fascinating research tool in the hands of Meyer-Eppler as he was investigating electronic music.[417] In treating music entirely as a form of acoustical communication, i.e. as a sequence of discrete, discernible

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[416]Michael Kurtz remarks that Meyer-Eppler maintained that "...speech, musical sounds, in fact, all acoustical phenomena were understood as sound-signals [orig. German: 'Schallsignale']. Sound processes which were not ordered in their acoustical structure [for example, sounds with solely harmonic spectra], were investigated by Meyer-Eppler by means of statistical methods, in relation to [concepts of] information theory." In: Michael Kurtz, Stockhausen: Eine Biographie, Kassel, 1988, p. 102.

[417]Ungeheuer proposes that "the fact that the Vocoder functioned as catalytic initiator of electronic music has to be regarded as music-historical novelty. In other words, it provided the means to finally bring together the mutual influences and alternations of linguistic and musicological research. Electronic music therefore, and not merely through Meyer-Eppler's scientific orientation in phonetics and communication theory, but also in technological sense, bears clear marks of the linguistic sciences." In: Ungeheuer, op. cit., p. 214.

series of acoustical signs according to information theory, the sound-modulatory capabilities of this device opened a hitherto unknown horizon of compositional mediation between music and speech,[418] which had a tremendous influence on Stockhausen.

As he was about to formulate his ideas concerning his concept of the 'unity of time' spanning the entire acoustical universe, in his ground breaking article "How Time Passes", Meyer-Eppler's lectures must have been highly significant in this respect. Furthermore, these lectures supported the idea of creating an acoustical continuum

[418]Elena Ungeheuer, in her cataloguing of electronic music tapes found in Meyer-Eppler's estate, has also investigated specific tapes which explicitly contain research material concerning speech synthesis/Vocoder, transitions between speech and music, and electronic sound synthesis, to mention a few that are relevant to our subject. The latter example (electronic sound synthesis) had been subdivided into different aspects of sound synthesis, and includes the category of 'acoustical and information theory-based experiments in perception'. (In: Ungeheuer, op. cit., p. 164-165). Demonstrations found on tape marked "synthetic speech" (for the Darmstädter Ferienkurse 1950) explore degrees of varying comprehensibility regarding spoken words or popular pieces, which are caused by varying degrees of electronic sound manipulation. Manipulations include filtering, reversal of time, changes in the speed of performance etc. (Ungeheuer, op. cit., p. 181). As a result, Ungeheuer describes a "surprising spectrum of variance of perception while maintaining a clear comprehensibility of the original sound source" (Ungeheuer, op. cit., pp. 181-182), relating to the communicational phenomenon of 'valency', which Meyer-Eppler introduced into the world of electronic music, as will be discussed later. Meyer-Eppler, on an attached information sheet, also associated variances of perception with those of expressive emotions, explicitly marked on the sheet as 'decreased (1/2:1) and increased (2:1) emotions'. Illustrating how filtering processes could bring about varying limits in the transmission of speech according to the available frequency spectrum, Meyer-Eppler was able to demonstrate that a similar limit to the emotional expressiveness and comprehensibility of the sounds of speech existed once the bandwidth of transmission would be narrowed. (Ungeheuer, op. cit., p. 182).

between speech and electronic sounds, as was done in GESANG DER JÜNGLINGE. All this was important and necessary as Stockhausen applied Meyer-Eppler's research to music. In fact, Ungeheuer's investigation provides evidence that Meyer-Eppler's research often focussed on the issue of the transitional area between the phonetic characteristics of vowels (formants) and those of consonants (random noise generators).[419] A collection of printed musical examples which were found in Meyer-Eppler's estate,[420] subjected to spectral analysis, might well cast a light on Stockhausen's notation[421] of STUDIE II, published in 1956, which included a spectrogram of a part of the work. It is unlikely that the electronic studio in Cologne had a spectrograph. So it is quite possible that these charts could have been made under Meyer-Eppler's supervision at Bonn University, where Stockhausen was a student of his from 1954 to 1956. In his lecture entitled "Die elektrischen Instrumente und neue Tendenzen der elektroakustischen Klanggestaltung ["Electronic Instruments and New Tendencies in Electro-Acoustical Sound Manipulation"], a lecture held "several times since 1954",[422] Meyer-Eppler focussed particularly on

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[419]Ungeheuer, op. cit. p. 95.

[420]Ungeheuer, op. cit., pp. 191, 194, 197, 198, 199, 201, 202-208.

[421]Richard Toop, in his article "Stockhausen's Electronic Works: Sketches and Work-Sheets from 1952-1967", remarks that "the score of STUDIE II is, once again, a retro-perspective concoction. As with its predecessor [STUDIE I], the realization was made from a combination of tables and montage charts." Richard Toop, in his article "Stockhausen's Electronic Works: Sketches and Work-Sheets from 1952-1967", Interface, 10 (1981), p. 169.

[422]Ungeheuer, op. cit., p. 202.

the subject of perceptual changes related to standard performance variants when playing a recorded tape 'forward' and 'backward' (Meyer-Eppler called this the 'exact retrograde'), at half or double speed. The retrograde version would not only change the temporal succession of musical events, but also the perception of certain spectral components as soon as the speed of the tape was changed.[423]

However, as he examined the 'time-frequency-spectrum of music in terms related to quantitative information theory analysis, Meyer-Eppler advised[424] composers (and especially those working in the electronic realm) to use a Gabor[425] matrix (see Chapter I). Such a matrix would allow the conversion of continuous wave-form acoustical messages into a finite-set matrix of limited perceptual 'quanta', which could also be used in quantifying acoustical messages by means of information theory.' Composers would be able to use this matrix to determine perceptual boundaries while devising their musical textures as a limited, finite-set of acoustical quanta, or 'cells', which could be distinctly comprehended by a human perceiver. This was a perfect model of information theory to convert, in this manner, a continuous acoustical phenomenon into a finite-set matrix of discrete sonic particles.[426] This was exactly the process

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[423]Meyer-Eppler (lecture in Basel, 1955) in: Ungeheuer, op. cit., p. 202.

[424]Meyer-Eppler: "Metamorphose der Klangelemente", lecture held at the Symposium of Electronic Music, Basel, May 1955, quoted in: Ungeheuer, op. cit., p. 231.

[425]See Chapter I, under Gabor and information theory.

[426]This concept is of considerable relevance to GESANG DER JÜNGLINGE, especially those portions involving speech analysis and synthesis by means of serial or statistical procedures.

desired; the amount of information to be sent through a communication channel could be significantly reduced. Meyer-Eppler made the following remark:

> [trans:] Claude Shannon, the American mathematician, developed a general communication theory which can be applied to electronic music as well as to all other acoustical phenomena; it can also be used to make accurate predictions about sound structures. An essential theorem of Shannon's communication theory suggests the conclusion that only a limited number of distinguishable sonic events of limited duration exist. Therefore a discontinuous, discrete matrix provides the most appropriate means of description, rather than the continuous wave form created by an oscillograph.[427]

It appears that, in 1955, Meyer-Eppler's research and experiments approached an asymptote of amalgamation between the areas of electro-acoustics, electronic music, and information theory. Ungeheuer remarks that, at one point in his manuscript for a lecture held in Gravesano in 1955, he proposed to implement the procedure of 'coding' a limited set of sonic elements as a way to increase the efficiency of the compositional processes:[428] by means of information theory, the composer "would be able to access details regarding how the 'cells' of the perceptual field were being filled with sonic elements, providing the sonic realization is supposed to possess a certain degree of comprehensibility."[429]

A state of development had been reached wherein the traditional music-aesthetic distinction between 'musical' and 'non-musical' sound could be replaced with notions such as 'comprehensible' and 'non-comprehensible', as used in

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[427]Meyer-Eppler: "Metamorphose der Klangelemente", as quoted in Ungeheuer, op. cit., p. 231.

[428]Ungeheuer, op. cit., p. 232.

[429]Ungeheuer, op. cit., p. 232.

communication sciences and linguistics. In fact, the detection of certain degrees of comprehensibility does involve the establishment of a communicational chain between the transmitter and the receiver of acoustical messages. Consequently, in order to devise a scale of clearly distinguishable, discrete numbers of perceptual 'cells', one must determine their classification according to their common or disparate properties. The degree of relative comprehensibility between perceptual cells could be indicated by their 'valency',[430] i.e., a value representing their communicational properties. In other words, within the acoustical universe, characterized by the physical properties required to define a singular sonic event (frequency, duration, amplitude etc.), a communicational universe exists, embedded into the acoustical universe by functions of a communicational nature in the form of a cellular structure, a "metric field of valencies".[431] However, while the sonic composition of a selected acoustical event might change through the manipulation of physical parameters, it might still maintain its former degree of comprehensibility, or valency; changing the spectral properties of spoken words does not affect the comprehensibility of the original message at first. A loss or gain in comprehensibility will become apparent only if their acoustical structure continues to be manipulated to an ever greater degree. At some point then, the valency of the original message will be lost, as other possibilities of interpretation will become increasingly likely. Finally, a

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[430]Meyer-Eppler: "With reference to the terminology customary used in physiological optics, we will call this quality the valency of the stimulus". In: Die Reihe, Vol. 1, Vienna 1955, p. 58.

[431]Meyer-Eppler in Die Reihe, Vol. 1, p. 58.

perceptual switch into other valency fields will be unavoidable because of newly developed similarities either with a bordering or a more remote perceptual cell: thus a discrete step in perception has been made as additional information has been acquired. The concept of valency,[432] in this case addressing only the communicational status of acoustical material, is therefore of utmost importance, especially in the field of speech recognition and music.[433] GESANG DER JÜNGLINGE was conceptually structured to establish a mediation between the two extremes of phonetic speech and electronic sounds within the acoustical universe. Evidently, certain issues related to the communicational universe embedded within it are also addressed in this work.

It seems that GESANG DER JÜNGLINGE was also a pivotal work in the mutual exchange of ideas and concepts between Stockhausen and Meyer-Eppler: Stockhausen, who initially transferred the latter's ideas to the field of compositional design, had a growing influence on Meyer-Eppler's definition of electronic music from 1955 onward. Stockhausen's GESANG DER JÜNGLINGE embodies Meyer-Eppler's ideas as learned in

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[432]Stockhausen formulates his concept of valency as follows, in his article "Music and Speech", relating to GESANG DER JÜNGLINGE and addressing the establishment of a timbre-continuum between speech and electronic sounds: "...in a selected scale of electronically-produced sounds, single steps are **occupied** by sung speech-sounds". The English translation uses the word 'replaced' by speech-sounds, but this is entirely misleading; Stockhausen explicitly means the occupation of a certain place. In fact, this is the correct description of the concept of valency as used in quantum physics, denoting the (spontaneous statistically occurring) relocation of a charged sub-atomic particle (for example, an electron) within the given hierarchical sub-atomic structure.

[433]Stockhausen, on defining 'comprehensibility', remarks that this term is differentiated semantically as well as acoustically-phonetically. In Karlheinz Stockhausen Texte II, DuMont, Köln, 1963, p. 61.

the seminars[434] from 1954 to 1956, but it also foreshadows the procedural formalization of a compositional approach which, as in the instance of developing a terminology of 'valence', was crystallized into a system by Meyer-Eppler as late as 1959. In other words, in terms of procedure, both Meyer-Eppler's and Stockhausen's research show an interesting phase shift of influence: from 1955 onward, Stockhausen, the former student, begins to notably surpass Meyer-Eppler's experiments in electronic music and speech, while the ideas of the teacher find their way into the compositional processes involved in GESANG DER JÜNGLINGE.

Stockhausen's Use of Information Theory

Stockhausen sketched the influence of statistics, information theory[435] and phonetics on music as follows:

> When I was studying music, the highest ideal of a good interpreter was to be faithful to the score. Then, one by one, scores were written in which statistical processes became very important. I started doing this

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[434]Georg Heike attended the same seminars with Stockhausen. He described Stockhausen's participation as follows: "[transl.] Stockhausen was always all ears when he assumed he could use something [from the seminars] in his music: he followed the course of seminars from the perspective of the composer. Meyer-Eppler was proud of Stockhausen and declared him, in the presence of others, as his [own] student." In: Michael Kurtz Stockhausen: Eine Biographie, Kassel, 1988, p. 104.

[435]Jonathan Harvey considers Meyer-Eppler's influence as far reaching: "He started his studies with Professor Meyer-Eppler in 1954, and it seems likely that this gentleman was the main catalyst of these radical developments of Stockhausen's increasing preoccupation with information theory". In: Jonathan Harvey, The Music of Stockhausen, University of California Press, Berkeley and Los Angeles, 1975, p. 30.

> in 1954, highly influenced by my teacher, Meyer-Eppler, who was teaching communication science at the University of Bonn, where aleatory statistical processes, primarily in mathematics but also in sociology and physics, played a key role. In the seminars conducted at that time, we were making artificial texts by cutting up newspaper articles into one-, two-, three-syllable units, sometimes going to the extreme of cutting up individual letters. We'd shuffle them like cards, make new artificial texts, and then study the degree of redundancy obtained. Naturally, the more we cut down a given text, the less redundant would be the result of the new chance-produced text...We worked with micro-theories in communication science: Shannon was a major influence as a mathematician - so was Markoff. Then I simply transposed everything I learned into the field of music and, for the first time, composed sounds which have statistical characteristics, with definite limits, in this given field.[436]

With regard to carrying out experiments with time while working with aleatory processes, Stockhausen makes a point concerning time, transformation, and chance in the processes he used in electronic music composition:

> Actually, the big change in statistics resulted from speeding up processes in electronic instruments. They'd speed up rhythms to such an extent that the rhythms would turn into something like aleatory textures or masses. For when you speed something up to this extent you find that your senses can no longer analyze or even register its order.[437]

Stockhausen even maintained that the phenomenon of chance can be considered as merely a case of relative structural perception:

> Take a fir tree like the one out there, for instance. It has a very distinctive gestalt when you look at it from a distance. Because there is an average statistical distribution of elements which is different

[436]Karlheinz Stockhausen, in: Ekbert Faas, "Interview with Karlheinz Stockhausen", Interface, Vol. 6 (1977), p. 195.

[437]Faas: "Interview", p. 201.

> from that of, say, a birch tree. Then, as you move closer this Gestalt becomes blurred as you watch a random confusion of branches and leaves. But when you look at a single leaf or branch you again discover a distinctive Gestalt. The final proof of this infinite oscillation between the statistical, aleatory randomness and individual Gestalten or forms is provided by the microscope. If you have one that is strong enough, you discover that the molecule, for instance, at first seems random. But as you approach one particular element closely enough, it becomes precise again. It's what you do in...music: go into the deepest possible layers of the individual sound by penetrating these various layers of individual forms and random multiplicity.[438]

The vehicle used is the serial principle, driven alternately by deterministic and non-deterministic, i.e. aleatory-compositional procedures. Xenakis expresses this phenomenon in the following way:

> ...First of all, natural events such as the collision of hail or rain with hard surfaces, or the song of cicadas in a summer field. These sonic events are made out of thousands of isolated sounds; this multitude of sounds, seen as totality, is a new sonic event. This mass event is articulated and forms a plastic mold of time, which itself follows aleatory and stochastic laws.[439]

Thus we have completed a full circle back to the beginning of this chapter, where we were explaining serial and statistical procedures. Xenakis' critique of serial music in 1954 pointed in the right direction. However, Stockhausen had already moved on, recognizing these facts in STUDIE II, and realizing their full compositional consequences, in terms of aleatory detail, in GESANG DER JÜNGLINGE.

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[438]Faas: "Interview...", op. cit., p. 203.

[439]Iannis Xenakis: Formalized Music, Indiana University Press, Bloomington, 1971, p. 9.

5. GESANG DER JÜNGLINGE

Meyer-Eppler's research centered on language perception, as Stockhausen recalled:

> [Meyer-Eppler] was a teacher who had come from phonetics, had given up analyzing the different sounds of language in order to devote himself to studying statistics, because he wanted to know more precisely what all the different noises were, and analyzing the wave structure of noises and consonants in language led him to use statistical methods of description and analysis. He would give us exercises demonstrating the principles of Markoff series; in one we were given cut-outs of individual letters from newspaper articles, and we had to put them in sequence by a chance operation, and see what sort of a text came out.[440]

These exploratory experiments, regarding the limits of perception between chaos and order, are at the heart of the organization of GESANG DER JÜNGLINGE; "they symbolize, to a religious disposition, the divine act of creation itself and the work of human imagination".[441] Stockhausen has summarized this particular work in the following terms: "Music is destined to become speech and speech to become music". GESANG DER JÜNGLINGE was not a reaction against 'pure electronic music', or a belated tribute[442] to *musique*

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[440]Karlheinz Stockhausen and Robin Maconie: Stockhausen on Music, London, 1989, p. 50.

[441]Robin Maconi, regarding GESANG DER JÜNGLINGE. In The Works of Karlheinz Stockhausen, Oxford, first published 1976, 2nd Edition, 1990, p. 58.

[442]Simon Emmerson, in his article "The Relation of Language to Material", concludes similarly that "it is a gross simplification to imply that Stockhausen's GESANG DER JÜNGLINGE, in using the recording of a boy's voice as part of the material, broke the barriers between the two groups [Elektronische Musik and musique concrete]. The difference between the two approaches were fundamentally between the abstract and abstracted approach to syntax". In: Simon Emmerson The Language of Electroacoustic Music, MacMillan

concrete after years of abstinence, but simply a natural outcome of Stockhausen's development of a compositional method which was still serial in overall character, but statistical in detail. Meyer-Eppler's research[443] focused on the fact that a close relationship between music and the organization of speech sounds could be found by means of statistic and probability analysis applied to the distribution and degree of modification of units of spoken language; subsequently Stockhausen set out to mediate a structure between the extremes of purely electronic sounds (sine tones) on one hand, and of a live recording of a boy's voice on the other, according to statistical concepts.

a) Historical Background

GESANG DER JÜNGLINGE was conceptualized starting in late 1954 or the beginning of 1955, and was performed in May 1956, in Cologne.[444] Several versions of the work exist; it

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Press, London, 1986, p. 39.

[443]Maconi mentions that "as part of his investigations Meyer-Eppler dissected individual speech sounds from tape recordings, and reassembled them to form synthetic words and phrases". Robin Maconi, in: The Works of Stockhausen, op. cit., p. 46.

[444]Without going into too much detail, GESANG DER JÜNGLINGE was never finished according to the original plans of the composer. In fact, Michael Kurtz writes that at the end of March 1956, two months before the projected concert premiere of the piece, Stockhausen had completed only the first seven minutes of the work which was projected to have a duration of approximately twenty minutes according to the compositional plan. As a consequence of the impending deadline of the performance, Stockhausen had to abandon his original plans, and the unfinished work was presented to the public as GESANG DER JÜNGLINGE *(Part I)* [italics supplied], with a duration of 13 minutes (the fact that it was marked 'Part I'

is available as a five-channel tape,[445] a two-track stereo version, and in a monophonic version. Despite a considerable effort on the part of the composer, and a number of attempts by other musicologists, no score has yet been published.[446]

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has almost entirely vanished from all sources consulted, including Stockhausen's). Kurtz continues : "[transl.] For the second part, which has not been realized until today, Gottfried Michael Koenig remembers that Stockhausen planned to add the names of his personal friends into the permutations of the text." (In: Michael Kurtz, Stockhausen: Eine Biographie, Kassel, 1988, p. 119). A similar situation came up with KONTAKTE: for the second time, a major electronic work (two years in the works, together with Stockhausen's assistant Koenig) had to be abandoned before it could be completed (Michael Kurtz, op. cit., p. 140).

[445]Referring to the state of affairs regarding the original performance tapes of GESANG DER JÜNGLINGE, Stockhausen remarks: "...that the original five-channel master tape (4-track tape plus one mono-tape) of GESANG DER JÜNGLINGE cannot be used since 1956, as the particular tape machine [it was made on] does not exist any more; that the first four-track copy of 1956, on tape material from which copies could be made with today's tape recorders, possesses glaring technical inaccuracies; that the original master tapes of STUDIE II and the two-track version of GESANG DER JÜNGLINGE were completely destroyed (orig. Stockhausen: 'burst into a multitude of pieces') during a process of copying and do not exist any more; and that the remaining first-generation copies of STUDIE I, STUDIE II and GESANG DER JÜNGLINGE are already very noisy". In: Karlheinz Stockhausen, Texte V, Köln, 1989, p. 111.

[446]Ashley: "It's literally impossible for me to score. You must have come to situations where it's impossible for you to score?" Stockhausen: "I have. Every day, working in the electronic music studio, the worst problem I have is to describe what I have done. All you can use are words and numbers... Recently I worked four days in our studio. At the end, I had to spend another four or five days analyzing what I had done in order to write it down. It is an awful thing for me. But without what I describe there will be no culture whatsoever in the new dimension. If I make a thing, I'm not interested in the result; I'm interested in the learning; I'm interested in the initial culture. Let's say we have no score, but we do have a tape. The tape alone doesn't help enough for

Stockhausen himself has published comments on GESANG DER JÜNGLINGE on three occasions: (1) a program commentary for the first performance; (2) an article entitled "Actualia", explaining the general principles of composition used in GESANG DER JÜNGLINGE as they were rationalized during the period of realizing the work in the studio;[447] and (3) his article entitled "Music and Speech", written after the work was completed.[448] Both of the latter articles appear in Stockhausen's "Texte"[449] as well, which also contains his article entitled "Music and Space"[450] in revised form, including information not found in the original version as publicized in "Die Reihe 5". These are the direct sources which will be mainly consulted during our investigation. We will proceed from an examination of the musical material selected by Stockhausen, especially from the viewpoint of how he handled the organizational challenge involved in integrating both the purely phonetic and the electronic material within the total structure of the entire

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study. We can listen, yes; we can get a kind of idea;... but one is really not able to go further in that direction. In: "Robert Ashley-Larry Austin-Karlheinz Stockhausen: Conversation ", Source, No. 2, p. 105. Panel discussion dated: Nov. 9, 1966, Davis, California.

[447]Karlheinz Stockhausen: "Actualia" in Die Reihe, Vol. 1, Vienna, 1955, pp. 45-52.

[448]Karlheinz Stockhausen: "Music and Speech", Die Reihe, Vol. 6, pp. 40-64.

[449]Karlheinz Stockhausen: Texte zu eigenen Werken und zur Kunst Anderer - Aktuelles, Vol. 2, pp. 50-69. Also referred to as Texte II.

[450]Originally published in Die Reihe, Vol. 5, Vienna, 1959, pp. 67-82.

composition. We will thus highlight the fact that Stockhausen's decision to allow non-electronic elements to enter his formerly hermetic compositional design had induced novel, far-reaching consequences in terms of the compositional process, i.e. a clear shift towards statistical form and aleatory technique. Regarding the influence of certain concepts of information theory, I believe it will become evident, simply in the structural approach taken, that "GESANG DER JÜNGLINGE is an eloquent and convincing proof that Stockhausen's studies in information theory, acoustics and phonetics (under the direction of Werner Meyer-Eppler) were necessary, for without them the creation of this composition would have been impossible."[451]

b) Stockhausen's Use of Speech

Sketching the initial phase of the project, Stockhausen wrote in a personal letter to his friend Goeyvaerts, dated February 1955:

> [transl.] I am now determined to compose the GESANG DER JÜNGLINGE IM FEUEROFEN (Benedictine). I do feel the urge to immerse myself in such a joyful and timeless text to the praise of God - and to unite the most indeterminate element, the voice of the human being, with the most determinate, the electrical medium, despite all the difficulties arising from the [musical] material and the [compositional] craft. If ever one looks into this in depth, one will find that it is only the attitude of the composer which creates a distinction between what is 'chaotic' and what is 'strictly ordered'. However, if you add ordering criteria and methods of defining perceptual qualities,

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[451]Seppo Heikinheimo: "The Electronic Music of Karlheinz Stockhausen - Studies on the Esthetical and Formal Problems of its First Phase", <u>Acta Musicologica Fennica</u>, Vol. 6, Helsinki, 1972, p. 66.

> this dichotomy will cease to exist: this requires that one has rigorously researched the fact that a non-intellectual perception of music can exist, without taking into account all the properties of the human ear along with all their consequences...[452]

One senses that at the end of the project (as printed in the program for the premiere in 1956), Stockhausen's initial enthusiasm had finally reached a somewhat more realistic, seasoned perspective:

> The work on the electronic composition GESANG DER JÜNGLINGE proceeded from the idea of bringing vocal tones in harmony with electronically produced ones: they ought to be exactly as fast, long, loud, quiet, dense and interwoven, audible in as small and large intervals, and as differentiated in timbre variations as prescribed by the imagination.[453]

Continuing in detail, Stockhausen states the problems he faced in establishing a serially ordered continuum of sound material between the human voice and the purely electronic medium:

> Accordingly, a number of electronic sounds, much more differentiated than before, had to be composed,[454] the most complex sound structure being speech sounds sung along the extensive scale between the vowels (sounds) and the consonants (noises). Thus an amalgamation of all the colors being used in a sound family can be experienced only if the vocal sounds can appear like electronic sounds and the electronic sounds like vocal ones.[455]

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[452]Stockhausen in a personal letter to Goeyvaerts, dated February 1955. In: Herman Sabbe, "Die Einheit der Stockhausen-Zeit...", <u>Musik-Konzepte</u>, Vol. 19, Heinz-Klaus Metzger and Rainer Riehn, Eds., Munich, May 1981, p. 52.

[453]Stockhausen, <u>Texte II</u>, op. cit., p. 49.

[454]Stockhausen mentions the gradation of the scale of an octave in up to 42 different discrete steps of pitch.

[455]Stockhausen, <u>Texte II</u>, op. cit., p. 49.

But how could this amalgamation be achieved? He had demonstrated, in both his electronic studies from 1953 and 1954, that purely electronic sound could be entirely parametrically controlled by serial means. But his experiments in preparation for GESANG DER JÜNGLINGE had also revealed that the task of achieving ultimate control over instrumental (non-electronic) timbre presented insurmountable difficulties in terms of parametrical description; in his numerous additional attempts to both analyze and synthesize speech, he had to resort to procedures ruled by chance, i.e. by aleatory manipulation. As he attempted to compose the entire work according to a unified serial principle, the composer faced the difficult problem of integrating structurally disparate material (some could be serially controlled, some not), as well as devising a common procedural foundation in order to create the proposed continuum between extremes. It appeared that a mediation based solely on acoustical properties was simply not possible using corresponding serial strategies alone.

Realizing that a solution was not possible within the limitations of a Newtonian system solely dependent on determinate control, Stockhausen adopted the relativist attitude of 20th century sciences (aleatory principle; inclusion of a probability system), while focussing on the communicational and semantic nature of speech. In other words, he took advantage of the fact that the singing voice could carry a text with a significant semantic content beyond the limits of mere physiological perception determined by acoustical properties. Thus, the sound of the human voice, by nature belonging to an entirely probabilistic system, changed his perspective on including the parameter of 'comprehensibility' as a **determining factor** in the compositional procedure, and allowed him to access the world of communicational processes and information control, while also maintaining control serially by statistical means and by the application of some concepts of information theory. What had happened? Suddenly, a mediation between electronic sounds and speech could be established through the common parameter of the comprehensibility of an acoustical message. If this was accepted as a condition, this continuum could then be equally divided into regions of valency[456] or defined locations within which perceptual cells could take form, which would denote certain degrees of comprehensibility regarding the biblical text, and would encompass the two extremes of pure electronic sound (without any resemblance to phonetic text) and of the spoken words themselves (with a limited resemblance to electronic sound). With two problems solved at once (aleatory procedures versus deterministic control), and serial control of the area of semantics covers the approaches and the types of material still available, Stockhausen was now in a position to maintain with confidence his belief in adhering to an overall serial control of the entire work.[457]

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[456]Meyer-Eppler defines this situation systematically as follows: "Music and speech can be meaningfully dealt with only by means of a valency-oriented terminology, not by merely defining the properties of the signal-carrying vehicles [the acoustical phenomena] of the valencies alone, as they might contain perceptually irrelevant properties...The inclusion of such properties [i.e., acoustical properties] in compositional design will certainly be completely ineffective. Only valency-bearing parameters can be considered here regarding the assessment of the degree of potential comprehensibility of [sonic events in] speech and music. The upper limit of the number of possible states can be approximated by means of information theory." In: Meyer-Eppler "Zur Systematik der elektrischen Klangtransformationen", Darmstädter Beiträge zur Neuen Musik, Mainz 1960, p. 76.

[457]Stockhausen, as quoted before: ". . . however, if you add ordering criteria and methods including perceptual qualities, this dichotomy will cease to exist....One has to rigorously research the fact that no intellectual perception of music can exist without taking into account all the properties of the human ear with all its consequences". In:

Having clarified this issue, Stockhausen now subdivided this continuum of comprehensibility into **seven** different degrees of understanding[458] which, in practice, did not have fixed boundaries within the continuum, according to the concept of semantic/perceptual valency. In fact, Stockhausen's intention to praise God by means of text, which would be structurally embedded in a highly complex 'polyphonic' musical texture, was not merely the result of chance, but of compositional determination, personal faith,[459] and conviction.[460]

Herman Sabbe, "Die Einheit der Stockhausen-Zeit . . . ", Musik-Konzepte, Vol. 19, Heinz-Klaus Metzger and Rainer Riehn, Eds., Munich, May 1981, p. 52.

[458]In Stockhausen's Texte II, we find a clearer description of these seven degrees and their associated perceptual characterization: (1) "no comprehension at all"; (2) 'quantified' by Stockhausen as "not comprehensible"; (3) "barely comprehensible"; (4) "a little bit comprehensible"; (5) "more comprehensible"; (6) "almost comprehensible"; (7) quantified as "comprehensible". Stockhausen maintains that the above scale of degrees has not been determined by a scientific measurement of some sort, but solely through empiric experimentation: "That these degrees of comprehensibility cannot be measured but only determined by means of multiple judgements, discussions, and testing on the part of the composer, is obvious. Numerous listeners have to be asked for their feedback, and only through their feedback can such a qualitative scale of comprehensibility emerge." In: Stockhausen, Texte II, p. 62. It has to be noted that Stockhausen used the term 'quantified' in the determination of the degrees of comprehensibility.

[459]"Wherever the sound events of the music for a moment become language, it praises God". In: Stockhausen Texte II, op. cit., p. 49.

[460]Clearly referring to the traditional practice of polyphonic writing which includes the treatment of text, similar effects of constant variance in the degree of comprehensibility of text can be found in many musical works, especially in music composed for use in church services. In

c) Structure of the Musical Material

i) Microstructural Elements

The only unstructured part of the entire composition is the raw electronic musical material (sine tones, noise, impulses) at the micro-structural level. From this electronic material and the recordings of the boy's voice singing the German text of the *Benedictine,*[461] Stockhausen devised three scales, proportioned according to the serial method. For the electronic material, the three scales attempt to mediate between the contrasts of (1) dark and bright timbre; (2) random noise bands and purely harmonic spectra; (3) a spectrum between darkest and brightest noise. Similarly, for the text to be sung by the boy's voice, the three scales span contrasts between (1) dark and light vowels; (2) vowels and consonants; (3) dark and light consonants. No other elementary material is used in GESANG DER JÜNGLINGE.

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fact, Stockhausen envisioned using the *Benedictine* to write a mass for the Altenberg Cathedral. However, "investigations by Herbert Eimert, Stockhausen's friend and mentor at the electronic studio in Cologne, revealed that this would not have been favorably received by the cardinal: loudspeakers don't belong in the Church". Last quote paraphrased and translated from: Michael Kurtz, Stockhausen: Eine Biographie, Kassel, 1988, p. 117.

[461]The text of the *Benedictine* was chosen from the third chapter of the book of Daniel, the prayer to be found in the Apocryphe. However, only nine of the twenty verses are used, all containing variations of the same basic theme: "Preiset den Herrn, ihr Werke alle des Herrn" ('Praise the Lord, all ye creations of the Lord').

ii) Degrees of Comprehensibility

Varying degrees of comprehensibility were achieved by Stockhausen through the following procedures: (1) masking certain effects with similar textural material occurring at the same time with varying degrees of intensity, frequency and pitch. For example, rapidly changing clouds or aggregations of impulses often partially mask certain frequency bands of timbre, which are already sonically occupied by the phonetic material of the vocal text. This creates a perceptual situation similar to that of a partially perforated cover through which the semantic meaning of the words can be detected with a varying degree of comprehension. (Aggregates of impulses can only be statistically determined as their sound texture is subjected to a constant flux of parametrical variation). (2) Another way of decreasing the comprehensibility of text is through changes in relative amplitude compared to the rest of the acoustical content, creating a perceptual field ranging from total prominence (loudest source) to extreme elimination (silence). (3) Varying degrees of articulation can play an important role as well, as attacks represent the most important part of sound recognition in human perception.

iii) Reverberation

Stockhausen also uses artificial reverberation to varying degrees in GESANG DER JÜNGLINGE, which affects changes in its spatial representation for the audience (the work was devised for five channel projection), and also alters the comprehensibility of the text through aleatory modulations on the elementary level of sound[462]. When levels of reverberation are raised, the valency of the semantic meaning of a chosen segment of the text is increasingly challenged by a growing number of micro-structural inconsistencies with the original phonetic material. Structural order is systematically lowered toward random-type noise textures, resulting in the destruction of semantic meaning on the micro-structural level, i.e., an increase in the amount of entropy.

iv) Semantics

This technique was also used by Stockhausen on the next higher level of structural organization: that of linguistics. With the aleatory technique of permutation, modulatory processes on the micro-structural level were allowed to be geometrically projected into the next higher level in the hierarchy of the perceptual field, affecting the order of positioning of linguistic elements in various ways. The placement of words would be changed in sentences, syllables could be changed in a word, phonemes in a syllable, micro-structural segments in a phoneme. In other words, a mediation between the two extremes of musical material was achieved through two simultaneous compositional processes: using the aleatory technique, Stockhausen introduced disorder in the original structure of the vocal text, moving it perceptually and structurally towards electronic sounds (and complete incomprehensibility), while he imposed order on the original sounds of electronic music through filtering processes which resulted, in structural

[462]As demonstrated in STUDIE II.

terms, in a clear move towards the creation of sonic entities within the valency fields of phonetic sounds.

In a manner reminiscent of the East-Asian Yin-Yang philosophy, even in situations reaching an extreme end of the scale, the opposite principle cannot be entirely excluded; it is as much an inherent part of the process as the contrary principle, and can never be separated from it because there is no real opposite. This represents a closed system, accessed through the limited approach of an observer who determines the perspective of interpretation. However, while it is much more difficult to bring about a change of perspective in the field of instrumental music, this can readily be achieved by a composer using the technical means of electronic music composition: tape cutting and splicing, and manipulations affecting the interpretation of perceptual fields.[463] Stockhausen knew from experiments in spectral analysis under Meyer-Eppler that vowels resembled musical sounds, and consonants resembled noise. Taking this additional acoustical proof into account, Stockhausen was now in a position to create, with confidence, a marriage of speech and electronic sounds.

d) Description of the Musical Material

i) Electronic Material

The elementary electronic material used in GESANG DER JÜNGLINGE consists of the following eleven forms which "are considered as non-identical in their basis and are used like

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[463]Stockhausen: "They'd speed up rhythms to such an extent that the rhythms would turn into something like aleatory textures or masses. For when you speed something up to this extent you find that your senses can no longer analyze or even register its order". In: Ekbert Faas: "Interview", op. cit., p. 201.

sinus tones which had previously been our only element. A basic element is one which cannot be reduced to further varied spectral components...":[464]

> (1) Sinus tones; (2) Sinus tones in which the *frequency* modulates 'periodically' or (3) 'statistically; (4) Sinus tones in which the amplitude modulates 'periodically' or (5) 'statistically; (6) 'periodic' or (7) 'statistical combinations of both sinus tone combinations; (8) Colored noise with constant density of (9) 'statistically' varied density; (10) Periodic' or (11) 'statistical sequences' of filtered sequences of impulses.[465]

Stockhausen uses seven different types of sine tone modulation, including pure sine waves, corresponding to the previously mentioned seven degrees of comprehensibility affecting text. The remaining four groups of eleven are subdivided into two types of coloured (in this case filtered) noise variants and impulses. Impulse-based composition refers strongly to new issues related to Stockhausen's proposed continuum between time and perception, and foreshadows the development of KONTAKTE, which was entirely created using the impulse technique. All of the electronically devised material of GESANG DER JÜNGLINGE is of this nature.

ii) Phonetic Material

Stockhausen describes the process of realization involved in the vocal musical material as follows:

> All individual phones or permutations of phones which are required, among them the words of the original

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[464]Karlheinz Stockhausen: "Actualia", in Die Reihe, Vol. 1, English version, p. 46.

[465]Karlheinz Stockhausen: "Actualia", in Die Reihe, Vol. 1, English version, p. 46.

> text, are executed by a boy's voice. Similar to the electronic sounds, they are recorded on tape for later use. Where possible the pitch level, duration and dynamic intensity desired for the singing of the phones or sequences of them are executed by the boy at the recording. Otherwise, the sung sounds are transposed to their final pitch levels, durations and dynamics during the montage. The timbre is, as far as possible, determined during the recording.[466]

Stockhausen does not provide any additional, more detailed information about the structure of the material, and no score has yet been published despite several attempts to condense the four large document folders[467] into a consistent score format.[468] Stockhausen still possesses the original sketches, while the only authorized direct copies of the entire volume of Stockhausen's sketches are in the hands of Rudolf Friesius.[469] Further information regarding the formal structure of the piece has not been provided, so far, by the composer, and an aural analysis seems futile considering the textural density of the piece.

> Some preliminary drafts of the composition do exist, but according to Stockhausen they are so difficult to understand, so badly smudged, crossed out and rewritten, that no one [other] than the composer can get anything out of them.[470]

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[466] Karlheinz Stockhausen: "Actualia", Die Reihe, Vol. 1, English Edition, Theodore Presser, p. 46.

[467] Telephone conversation of the author with Elena Ungeheuer, November 1994.

[468] The last attempt was conducted by Hugh Davies in 1982.

[469] Letter by Stockhausen to the author, dated November 1994.

[470] Seppo Heikinheimo: "The Electronic Music of Karlheinz Stockhausen", Acta Musicologica, Vol. 6, Helsinki, 1972, p.72.

Regarding its overall form, Stockhausen claims that:

> GESANG DER JÜNGLINGE is composed in six totally coherent textures. This formal arrangement can only be perceived from the fact that 'preiset' or 'jubelt' can be heard fully understandably in connection with the words 'den Herrn' in all of these lengthy textures. This creates coherence and spans large periods of time.[471]

The structural organization of the overall form, divided by Stockhausen into "Textures", has been given by the composer himself:

- During the first Texture, one hears a remote (after 10,5") and unclear 'jubelt'.
- In the second Texture (from 1'02") one hears, at first as a chorus 'dem Herrn jubelt', and soon after (after 1'8.5" and after 1'58,5") very closely, with a solo voice, 'preiset den Herrn'.
- In the third Texture (from 2'52"), with a solo voice, 'preiset den Herrn'.
- In the fourth Texture (from 5'15,5") many voices sing in chords 'den Herrn preiset' (once again at 5'46,5").
- In the fifth Texture (from 6'22"), with many voices, and from a wide distance (at 6'52,5") 'Herrn preiset' is heard, then 'preiset den Herrn' (at 7'20,5" and at 7'51").
- In the sixth Texture (from 6'22") a solo voice sings, in large melodic lines (at 8'42") 'jubelt dem Herrn' and (at 8'51") 'preiset', then (at 10'50"0) 'ju-----belt'.[472]

6. Investigating the Compositional Method: The genesis of Speech

Although a detailed description of the entire formal structure (Textures I-VI) of GESANG DER JÜNGLINGE does not

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[471] Stockhausen: Texte II, op. cit., p. 59.

[472] Stockhausen: Texte II, op. cit., p. 59.

yet exist, Stockhausen provides a structural diagram of the last Texture, i.e. the sixth, in which twelve different elements are used, arranged in the form of a matrix so that, statistically, an equiprobable distribution, or one of minimum redundancy/maximum entropy, is achieved. These twelve elements are classified by Stockhausen as follows (see Tab. 12. in the appendix).

a) Using determinate procedures

Stockhausen describes the procedures used as follows:

> Methods of analytic phonetics (vowels-sinus sounds; consonants-band of noise; plosives-impulses; various hybrid forms) were made use of for the system of the scale of sound-elements (arrangement of the sounds in the synthetic sound-family).[473]

These elements are arranged in the form of the following matrix, from which elements are selected in sequential order.[474] It is obvious that the above matrix represents a gradual move through the formerly specified continuum between speech and electronic sounds, with element "x" serving as a synchronizing device attached to the overall structure of GESANG DER JÜNGLINGE. As such, it could also be considered to be arranged in a cyclical form, connecting both ends of the scale of the continuum, similarly to Stockhausen's concept of overall form in ZYKLUS.[475]

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[473]Stockhausen in Die Reihe, Vol. 5, "Music and Speech", English Version, Theodore Presser, 1964, p. 60.

[474]See Table. 13. in the appendix. In Stockhausen: Texte II, op. cit., pp. 64-65.

[475]See Table. 14. in the appendix.

This process of continuously changing elements is divided into four rows in which numerous geometric and simple arithmetic tendencies appear. Here, first, are the rows, as provided by Stockhausen:

	A	E	I	M	Q	U	-->
-->	B	F	J	P	T	(X)	-->
-->	C	G	K	O	S	W	-->
-->	D	H	L	N	R	V	

Each of the above rows can now be assumed to be capable of structurally representing a group within which permutations of sequences of selected elements can take place, within the 'time-field' of the entire composition.[476] The permutational possibilities include a change of order and a change of the number of elements as well: this is a model of aleatory modulation according to the serial principle. Stockhausen mentions four different types of group formations:[477] (1) groups which are uniformly different (for example, containing two 'SV', 4-R, 1 SK etc.); (2) groups that are all uniform, but their different elements indicate where each group ends (for example, 2-SV,GA or 4-SV,R etc.); (3) groups which are varied internally while maintaining their endings; (4) groups that are singularly uniform while a fixed element consistently indicates their ending. This shows clearly that no opposites between phonetic and electronic sounds can be generated as all permutational combinations take place within the serially established scale between speech and electronic sounds. To

[476]This is a similar approach to the one already used in STUDIE II, wherein the sonic elements of 'sound-mixes' (consisting of five sinus tones) are grouped together in aggregates, which can be considered to represent 'groups'. See especially in: Elmar Bozzetti: "Analyze der STUDIE II von Karlheinz Stockhausen", Zeitschrift für Musiktheorie, No. 4, 1973, pp. 37-47

[477]Stockhausen: Texte II, op. cit., p. 65.

establish a compositional principle governing the formation of comprehensible speech segments, Stockhausen used the following device, already contained in the overall serial structure of the matrix:

> A group of 2 and more LS provides the opportunity to form syllables and words which can be used according to the degree of comprehensibility (which depends on their respective structure-duration).[473]

The desired mediation between syllables and elementary sounds was obtained by applying the following principle:

> The acoustic use of LS (besides the previously fixed pitch, duration and intensity) conforms to varying degrees of a series of internally structured distributions affecting the dark-bright-vowel aspect or the voice-unvoiced-consonant aspect; this always takes into consideration, however, the fact that such degrees are to be checked with the selected elements of speech.[479]

The following example is provided to illustrate Stockhausen's use of the serial technique in the assembly of words from syllables, based on phonetic elements which are "**discretely** determined in their parameters by means of the composition":[480]

> It is best to show a sequence of phonemes which were produced for a partial structure; the phonetic transcription symbols in parentheses indicate the attitude adopted in selecting the syllables. In these examples, either the pitch was to be sustained on the phonemes...(and half or full consonant phonemes before or after the vowel in the syllable were treated as extremely short attacks or decays), or the articulation used the longest part of the duration of the voiced

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[478]Stockhausen: Texte II, op. cit., pp. 65-66.

[479]Stockhausen: Texte II, op. cit., pp. 65-66.

[480]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 62, orig. "Musik und Sprache", Vienna, 1960.

> consonant (w-erk, [tu] j-), or the unvoiced consonant was emphasized by means of the duration (Sch-a, [Rei] f-), or the accentuation (wer<u>k</u>); various forms also changed as a result; or the same vowels were used, with various attacking phonemes, etc.[481]

Stockhausen provides the following phonetic table, listed in four groups of six phonemes each.[482] And regarding the assembly of syllables into words, Stockhausen continues:

> The forms employed in the text were especially exploited in structures with the same vowel: [ai] diphthong in *Reif, preist, Eis, -keit;* or [ ] in *Werk, Herrn, Näch-, gen, -ren, des, -set, -kel, -len, -ken;* such groups were completed, if necessary, with meaningless syllables (see above example, *ult, jeb, tuj*).[483]

Another example provides an illustration of an LS-structure consisting mainly of an accentuated consonant structure ('noise'), in this case the [s] and [t] phonemes. Here,

> the prescribed pitch, having first been sung as briefly as possible, proceeds to the consonant and fills the prescribed duration, thus also differentiating the frequency register of each consonant: high *s*, middle *s*, low *s* etc.[484]

Using this material to proceed towards the assembly of entire words, larger formal units could be achieved by the following means:

> By means of various non-simultaneous attacks and articulation endings, arranged in simultaneous layers, one could structure formal complexes consisting of larger time-units using the phonetic technique with consonants...This LS-complex lasts about 6 seconds; it

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[481]Stockhausen <u>Texte II</u>, p. 66, English transl. in <u>Die Reihe</u>, Vol. 5, p. 61.

[482]See Table. 15 in the appendix. In Stockhausen: <u>Texte II</u>, op. cit., p. 66.

[483]Stockhausen <u>Texte II</u>, op. cit., p. 66.

[484]Stockhausen <u>Texte II</u>, op. cit., p. 66.

is simultaneously connected with R-groups and I-groups and proceeds imperceptibly towards a complex of coloured noise, [s] and [t] consonants. A structure consisting mainly of [ ], [f], [s] and [c] consonants is completed with sounds from Sch(nee), (Rei)f, (prei)st, (Nä)ch-(te). Here then is an example for *s, t*.[485]

b) Using Indeterminate, Statistical Procedures

Whereas the above examples were based on the assembly of groups, structures, and complexes through determinate, serially controlled micro-structural procedures, Stockhausen also used a second technique of achieving statistical structure in the treatment of speech which was "based on and referred directly to statistical structural ideas."[486]

In a particular complex, A IV for example, the following [parameters] were serially defined: the number of groups of six layers, the number of syllables per layer (5-10), the total duration of the individual layers (in cm. at a tape-speed of 76.2 cm/sec). Also the relative distribution of time and the direction of pitch in the syllable sequences, the width of the frequency band and the direction of the total movement of the complex (933:767 Hz to 508:400 Hz), as well as the average dominant phonetic structure ([u], [ ], [ ], [e:]). Diagrams and models prepared on tape (with approximate pitch and duration data) were **then** used to aid the boy in singing the various layers, and the best results were superimposed. The 6 diagrams with which the boy sang look like this[487] (one must imagine them

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[485]See Fig. 33. in the appendix. In Stockhausen Texte II, op. cit., p. 67.

[486]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 62.

[487]See Fig. 34. in the appendix. In Stockhausen Texte II, op. cit., p. 68.

> simultaneously intermingled in the 'synchronisation' which followed later):[488]

Referring to the statistical aspects involved in forming the above sound complex, Stockhausen describes the electronic procedures as follows:

> Such complexes were again dynamically regulated, reverberated, synchronized with others, etc. They could now be distinguished according to their **average** density (as the product of the number of layers, **average** number of syllables per layer and **average** length of the layers), according to the **average** intensity and type of spatial presentation - spatial depth, from far to near or vice versa; and they can be regulated also according to the spatial location of the source of sound in the auditorium and the direction of its movement in space...as well as in the degree of comprehensibility of speech.[489]

7. GESANG DER JÜNGLINGE: Overall Organization

Finally, the organization of the overall form of GESANG DER JÜNGLINGE was achieved by using a series of seven discrete values similar to those employed in the determination of 'comprehensibility'. Examining the original sketches of GESANG DER JÜNGLINGE, Richard Toop[490] found that it was especially the serial proportions of the

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[488]At first all the layers were produced with equal average volume intensity.

[489]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 63.

[490]Richard Toop: "Stockhausen's Electronic Works: Sketches and Work sheets from 1952-1967", Interface 10 (1981), pp. 149-197.

following 7-square which had the most considerable impact on both the overall form and the details of the work:[491]

3	**7**	**1**	**6**	**5**	**2**	**4**
7	**4**	**5**	**3**	**2**	**6**	**1**
1	**5**	**6**	**4**	**3**	**7**	**2**
6	**3**	**4**	**2**	**1**	**5**	**7**
5	**2**	**3**	**1**	**7**	**4**	**6**
2	**6**	**7**	**5**	**4**	**1**	**3**
4	**1**	**2**	**7**	**6**	**3**	**5**

Toop supplies an illustration of an unfinished 'study score' which we have reproduced below. In fact, an investigation of the first 62 seconds of the composition revealed that the proportional duration[492] of the parts, subdivided into two sub-sections, with each consisting of 7 parts, is approximately **7 4 5 3 2 6 1** (the second row above).[493] I have compared the serial values with the actual ones found in Toop's score and obtained the following values:

Row:	**7**	**4**	**5**	**3**	**2**	**6**	**1**
Math:	**533.4**	**304.8**	**381.0**	**228.6**	**152.4**	**457.2**	**76.2**
Tape:	**512.0**	**282.6**	**380.4**	**210.0**	**157.0**	**463.7**	**86.1**

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[491]Richard Toop, op. cit., p. 177.

[492]In fact, Richard Toop complies with Stockhausen's remark that "the methods by which we differentiate and select elements lead us to the following conclusion: our point of departure is always *the structure of the duration* [italics supplied]; all other functions of sound are derived from it." In: Karlheinz Stockhausen, "Actualia", Die Reihe, Vol. 1, Vienna 1955, English transl. Theodore Presser, 1958, p. 46.

[493]'Math' denotes a calculated length according to the product of tape speed and row factor; 'tape' denotes the actual tape length at 76.2 cm/sec.

However, the second part, theoretically reflected in the third row above, reveals already considerable modifications: the original series **1 5 6 4 3 7 2** is now presented as **1 6 5 3 4 7 2**, a modification in the order of 57%. The correspondence of serial values and actual tape length is similar to that found in the first section:

Row:	**1**	**6**	**5**	**3**	**4**	**7**	**2**
Math:	76.2	457.2	381.0	228.6	304.8	533.4	152.4
Tape:	78.0	463.0	380.0	210.0	284.0	512.0	172.3

In other words, as suspected, the overall form of GESANG DER JÜNGLINGE has been primarily developed on the global, macroscopic level first. This level is entirely serially controlled, with the progressive inclusion of indeterminate procedures as it moves towards the microstructural level of the work. Having investigated the sketches, Toop comments that besides the above row, which applies to the overall durations of the work, many other serial sequences seem to have been 'modified' or, should we say, subjected to the aleatory procedure of permutation. One might ask then why Stockhausen needed such a totally determined organizational plan, when, in the end, he decided not to follow its directive. The following comment by Ligeti casts a light on this situation:

> There is a question that can hardly be avoided when discussing this 'freer' phase of serial composition: if the serial determinants have been removed to the global categories of form, and only lay vague claim to the control of the individual moments, why then must we have serial manipulations at all? Wouldn't it be possible to leave the form completely to the discretion of an unrestricted imagination, both in its general flow and in all its details?[494]

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[494]György Ligeti, "Wandlungen der musikalischen Form", Die Reihe, Vol. 7, Vienna, 1960, p. 12.

Stockhausen has not provided us with any details in this respect, but seen from the angle of the development of open form (while composing GESANG DER JÜNGLINGE, he also worked on ZEITMASSE and GRUPPEN), his decisions to alter some serial successions might well have been due to his artistic instincts[495] rather than to the strict principles of serial automatism.

Taking into account this element of unpredictability due to human influence, Stockhausen has in fact demonstrated that the creation of aleatory or statistical structures can often yield superior and faster results through human manipulators rather than through a determinate process simulating statistical form. As a final step before concluding our investigations into GESANG DER JÜNGLINGE, we shall examine the production process involved in three selected impulse complexes. They have been selected mainly in order to give a clear account of how Stockhausen devised statistical structures, in which we are interested mostly with regard to information theory. All three impulse-complexes can be found also in the first section of the score provided further below (marked as I).[496]

Considering the complexity of such sketches which, of course, represent only a minimal selection within the entire

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[495]In an interview, Stockhausen mentioned also that he had sometimes deviated from strict formal concepts in the final version of a composition as a result of personal impulse: for example, while composing STUDIE I, which is supposedly entirely serially determined, he inserted a booming noise into the work, on the day of the birth of his daughter Suja (the sound was selected from scrap tape found on the floor of the studio on that particular day). Karlheinz Stockhausen, "Wille zur Form und Wille zum Abenteuer". Interview with Rudolf Friesius, published in Neuland, Vol. 2, 1981/82, quoted by Stockhausen in: Texte VI, Koln 1989, p. 324

[496]Fig. 35. and Fig. 36. in the appendix. In Richard Toop, score from "Sketches", op. cit., pp. 178-179.

work, it becomes apparent why all attempts to score GESANG DER JÜNGLINGE have failed once a certain point had been reached in the notational transfer of the sketched data into the piece. Any attempt to include a representation of the spatial aspects[497] (the work includes a serial structuring of the spatial parameters for five channels as well) seems to clearly overtax any effort to reduce the entire multi-dimensional structure into a two-dimensional system of graphical notation. What we finally have to relate to is the sonic entity of the actual tape. In brief, concerning GESANG DER JÜNGLINGE, Stockhausen makes an important statement regarding the overall leading principle of his compositional approach:

> The basic conception may have become clear: first of all, to arrange everything separate into as smooth a continuum as possible, and then to extricate the diversities from this continuum and compose with them[498]...The selection and composition of material is one indivisible process[499]...The structure of a work and its material are one and the same thing[500]... According to the 'colour'-continuum, the composition was based on the idea of a 'speech-continuum[501]...The intention, therefore, is, by selecting individual steps

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[497]Heikinheimo has investigated this aspect in detail in his article "The Electronic Music of Karlheinz Stockhausen", op. cit., pp.83-92.

[498]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 64.

[499]Stockhausen, "Actualia", Die Reihe, Vol. 1, op. cit., p. 47.

[500]Stockhausen, "Actualia", Die Reihe, Vol. 1, English version, op. cit., p. 51.

[501]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 58.

> from a sound-word continuum, to let 'speech' proceed from the composition [502]...The will of the selected musical arrangement determines how fast, how long, how loud, how soft, how dense, how intricate the tones must be, how great and small the proportions of pitch and timbre must be in which the tones are audible[503]...

8. A New Definition of Form

a) Statistical Form

Stockhausen considers that GESANG DER JÜNGLINGE belongs in the category of statistical form, stating his definition of form as follows:

> In the genesis of the statistical form I tried to mediate between groups and points on one hand, and between collectives organized according to the **law of large numbers**,[504] on the other. The problem is to perceive the same elements which appear as collectives (statistically determined - in crowds - complex) under certain circumstances as groups and points in other circumstances.[505]

In electronic music, this mediation can be easily attained by the simple method of manipulating the speed of the original formation of sound, directly triggering a transposition of musical material into a different perceptual realm. In terms of its morphology, GESANG DER JÜNGLINGE (statistical) is therefore situated somewhere

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[502]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 59.

[503]Stockhausen "Music and Speech", Die Reihe, Vol. 5, English Version, Theodore Presser, 1964, p. 58.

[504]This term likely refers to statistical methods.

[505]Stockhausen, Texte I, Dumont, Köln, 1963, p. 235.

between STUDIE II (determinate/statistical) and GRUPPEN (statistical/group form).

b) Form as a Process

Questioned on the issue of form, Stockhausen replied that:

> In one of the first versions of the text I used the word 'Formentwicklung' (development of the form), and in connection with it, 'pointillistic', 'group-like' etc. Yet I never meant specific forms but always the processes which led to an undefinable multitude of isomorphic forms, i.e., the genesis of form through a 'pointillistic', 'group-like' etc. formal process.[506]

In other words, Stockhausen did not relate to the term 'form' in the traditional sense, as a static entity. In fact, his definition is entirely dynamic, describing 'form' in terms of processes leading to the genesis of structural forms.[507] If we regard form as the final crystallization resulting from the process of formation, a clear distinction between **formation** and **form** is implied: 'form', in this definition, represents a compositional process in the most immediate sense. I would like to conclude our investigations with an example of how this genesis of a statistical form, in this case the creation of impulse textures[508] as

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[506]Stockhausen, Texte I, op. cit., p. 222.

[507]"As a matter of fact, I have *learned* [italics supplied] these genetic principles of music generation in the electronic studio while composing and realizing **GESANG DER JÜNGLINGE**, and while realizing KLAVIERSTÜCK XI, ZEITMASSE, KONTAKTE, and so on". Stockhausen in Texte VI, Koln, 1989, p. 311.

[508]Stockhausen, regarding compositional processes used in GRUPPEN: "This is...what I'd done in earlier pieces like GESANG DER JÜNGLINGE, for example, making sound bands, also with aleatory transpositions, with generators." In: Jonathan Cott, Stockhausen, op. cit., p. 71.

described earlier, took place during the realization of GESANG DER JÜNGLINGE. Stockhausen describes it as follows:

> Together with my former assistant Koenig, [I] worked on a single sound for six weeks; it consisted of thousands of microscopic fragments, particles, which were glued together in the form of mosaic patterns, and then synchronized by a special process. Entire 'time-spectra' were devised this way. (In fact, it was the time of detection embedded in the term 'time-spectrum': layers of time would be subdivided in a similar manner as harmonics subdivide a fundamental tone - 1:2:3, 4:5:6, until 1:27, or even more periodic subdivisions of a 'fundamental' time value as I recall it. This is exactly the way we built complex sounds in which time layers contained an incredible number of fragments - particular noise components with vocal components, single tones mixed with chords). As a matter of fact, we worked six weeks on a sound which finally lasted only 4.5 seconds! At this point I said: "This can't go on like this! Otherwise, in ten years, I still won't be able the finish this piece which lasts only a few minutes..." I then invented completely different processes, in which all three of us - two assistants and myself - were operating a different device: one [person] an impulse generator, the other a resonance filter which allowed a continuous variation of envelopes, and the third operating the control of loudness. I was then drawing sketches of **process-forms**. In such a [sketched] form, which, for example, would last 20 seconds, one would vary the speed of impulses, say, from 3 to 14 impulses per second according to the provided zig-zag graph; the second [person] modified, according to another graphical pattern, the pitch envelope of the resonance filter, and the third - again according to another graphical notation - the envelope of loudness... Realizing such a **process-form**, we got together and one was counting: 3-2-1-0. Then the [process] started: the stopwatch was activated, and at 20 seconds everybody had to be done. "Shall we do it again?" - "Yes, I made two mistakes. I have been moving twice up instead of down". Ergo, the whole procedure would be repeated until we achieved the best possible realization. Every **process-form** consisted of different multiple layers. These would then be copied over each other, which finally resulted in a form which was a direct result of the interaction of three performers. In other words: the commitment that all of us would meet after a certain time period at a

> certain point, although everyone was proceeding his own way (because of that, what happens in the interim time can only be notated *statistically* [italics supplied]), leads ultimately to the genesis of a formal layer by means of a *process - 'aleatory'*, as my teacher Meyer-Eppler called it in *information theory*... The results were new, homogeneous, organic constructs, characterized by sonic properties exhibiting certain tendencies and behavior; these have then later led to a compositional method[509] with entirely new procedural charactestics.[510]

On the question of how he would then describe this statistical, aleatory structure, i.e., the final result of the compositional process, he answered as follows:

> It's a random distribution of elements within given limits. Only statistics can measure it. A noise is nothing but a statistical distribution of waves which, within limits, are non-periodic. Unlike a vowel, which has a periodic wave, a voiceless consonant's waves have a statistical, chance distribution which is irregular within given limits; there's a higher and a lower frequency limit, and inside, like air molecules, there's an entropic situation - an almost even distribution. If there's a tendency, then it's a directional statistical one - going upward or downward, becoming thinner, thicker, brighter, or darker... Parameters, which I had previously used only for the description of individual sounds, I now introduced for whole complexes of sounds, or masses of sounds. A mass has a certain density, it has certain tendencies, it has shape; and we must make a clear differentiation

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[509] Karlheinz Stockhausen, "Wille zur Form und Wille zum Abenteuer", in: Texte VI, op. cit., pp. 337-339.

[510] In another instance, Stockhausen characterizes this composition process as follows: "At that time I very often used the image of a *swarm* [italics Cott] of bees to describe such a process. You can't say how many bees are in the swarm, but you can see how big or how dense the swarm is, and which envelope it has. Or when birds migrate in the autumn, the wild geese sometimes break formation, flying in non-periodic patterns. Or think of the distribution of leaves on a tree; you could change the position of all the leaves and it wouldn't change the tree at all." In: Jonathan Cott, Stockhausen, op. cit., p. 72.

> between the gestalt and the texture... What is characteristic of statistical compositions, as of aleatory compositions in general, is that you can exchange the position of the elements within given limits at random and it doesn't change the characteristics... My personal approach to these problems has been a scientific one. A contemporary physicist couldn't do any important work without taking these new discoveries into account, and it's natural that the music reflects this. As the word says, a musical "composition" means *putting sounds together* [italics Stockhausen].[511]

The composition processes used in GESANG DER JÜNGLINGE reflect all these approaches, including general concepts of information theory, as we will briefly summarize in the following, last section of this chapter.

9. Summary

It was Warren Weaver who suggested that music be analyzed as a continuous signal rather than a series of discrete events. He proposed to make an analysis of cross-sections of the sound-waves in relation to the bandwidth of the composition. This principle had in fact been subsequently followed, and extended to the synthesis of acoustical messages, by technicians at Bell Laboratories, leading to the development of digital telecommunication devices and the Vocoder. This device was a key component in Meyer-Eppler's information theory-based research in sound and speech analysis and synthesis, which he presented in his seminars attended by Stockhausen. However, not only did Stockhausen thoroughly investigate the analysis of continuous waveforms in speech and music in Meyer-Eppler's seminars according to their acoustical properties from the

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[511]Stockhausen in Jonathan Cott: Stockhausen, op. cit., pp. 73-74.

point of view of information theory from 1954 to 1956, but he then immediately set out to realize these new discoveries as a musical work within the medium of electronic music.

In fact, the compositional approach taken in GESANG promotes not just the incorporation, but the full integration of both the discrete and continuous wave-type speech and electronic music material, implementing aleatory procedures into the framework of serial technique: statistical procedures involving probability theory became the determining factor for compositional control. Although Stockhausen has later characterized the overal compositional principles used in GESANG merely as 'statistical', it is clear that he found the formal concept of communication theory, which addresses music as a valid form of communication, to be the preferred method of handling certain principles of probability required by aleatory technique, especially regarding speech synthesis.

Having been a student of Meyer-Eppler, Stockhausen clearly understood the basic concepts of information theory, Markov processes, chance, and probability theory. GESANG can be seen as representing a condensation of all these principles: chance procedures are used in applying aleatory permutations of musical events on all levels of the compositional design through the permutation of formal sections, textures, or sonic elements, including aleatoric modulations of continuous waveforms on the micro-structural level of sound by means of reverberation.

As in linguistics, there were some general principles of Markov chain processes which became important in governing the creation or destruction of speech to varying degrees of comprehensibility. For every composer facing these challenges, a clear awareness of the basic principles of probability theory was simply a necessity in order to successfully govern all aspects of the statistical formation of musical material, from the creation of groups of impulses, electronic sounds, and phonemes to that of entire words, sentences, and ultimately the whole work as a cohesive entity. However, while for example, general concepts of information content, redundancy, and entropy have clearly served as guidelines for the implementation of aleatory procedures, Stockhausen has hardly addressed these issues in terms of information theory. Why is this so?

Having consulted a great number of available sources relating to Stockhausen's general approach or specifically to the work in question, including some sparse remarks by the composer about information theory, it seems to me that he was genuinely aware of the working concepts of information theory underlying the compositional processes which accompanied his aleatory design. In fact, a clear picture of the influence of information theory on Stockhausen's compositional design in the 1950s can only be gained by taking **both** the written evidence of sources quoted, **and** the overall composition principles of GESANG into full account. Seen from this more inclusive perspective, a letter by Stockhausen to the author, received in 1994, seems to clarify this issue. In this letter, he writes:

> GESANG DER JÜNGLINGE: not the theory [information theory], but the *transcription exercises in phonetics* with Meyer-Eppler as well as his seminars about *aleatoric operations* (including practical exercises regarding probability distributions of speech particles) which became of significant importance regarding the composition processes involved in GESANG DER JÜNGLINGE. I learned the term *aleatoric* from him and it was I who transferred it into music. A later use of this term (for example in an article by the Frenchman Boulez ["Alea"], as well as in American music as "chance operations" or "indeterminacy" (Cage), has been <u>directly</u> mediated by me from information theory

> through personal interviews or indirectly through publications.[512]

Contrasting our findings in our survey of Stockhausen's compositional procedures, as well as in the sources we consulted, with the contents of his letter, it appears that he probably did not use information theory in its strict mathematical sense according to Shannon. And he never claimed to have used it in this manner. However, in a general sense, certain concepts of information theory seem to have served him well in achieving his compositional objective, which was to integrate serial technique, aleatory processes and linguistic design within a unified conceptual framework based on communication theory. With all the basic concepts of information theory clearly spelled out in Meyer-Eppler's seminars as well as in several articles published in "Die Reihe", there can be no doubt that Stockhausen's application of the course material contained in the seminars was, in fact, very selective and utilitarian: he attempted to carry into the field of music what he considered to be important. Ultimately, it was the treatment of speech which necessitated the integration of the principles of redundancy, entropy and information content into the serial design of the entire work on all structural levels. Without these principles, any attempt to exert any control over communicational elements by means of the compositional procedure would have been doomed to failure. Seen from this perspective, these features, which reflect some very general aspects of information theory, can actually be found in Stockhausen's principles concerning the genesis of statistical form, absorbed under the heading of 'aleatory

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[512] Quoted from a personal letter from Stockhausen to the author, dated Nov. 21, 1994. Published with the explicit permission of the composer.

technique', the latter being the cornerstone of his technique of statistical composition.

For example, two opposite approaches of aleatory technique are generally found in GESANG: one involves single musical particles painstakingly mounted into aggregates of statistically determined groups or clouds of material, the other entails 'limited chance' approximations by means of live-electronic experiments, used to assemble aggregates of impulses. Both procedures achieve the objective of creating indeterminate material within set limits of probabilistic variance. Stockhausen's formation of global structures, on the other hand, follows the approach of traditional serial design: the proportions of lower-level structures are geometrically projected and enlarged to provide the overall shape of the entire composition. As severe limitations would result from the flawless serial synchronization between the microstructural and the macrostructural level, it was ultimately the adoption of the general compositional principle of statistical form which allowed Stockhausen to establish a procedural framework of compositional design which could encompass and master these opposite extremes of structural organization (hence the paradigm shift from model to process-based compositional design). This provided the composer with the elegant solution of maintaining an overall organizational scheme based on serial technique while conflicting issues regarding the formal alignment between the macrostructural and the microstructural proportioning of musical events could be mediated statistically. In other words, whatever compositional control was lost due to the nature of a strictly serialist technique could be reclaimed through the application of indeterminate procedures. Stockhausen realized the great artistic potential of this obviously paradoxical situation and used it to a great extent in GESANG: the combinatory freedom brought about by permutations of phonetic fragments ultimately afforded him a compositional control over the added dimension of speech communication, far beyond the compositional capabilities inherent in serial technique: a gestalt could emerge wherever the composer desired a certain degree of comprehensibility regarding text.

As demonstrated in Meyer-Eppler's seminars, the compositional results in terms of speech synthesis would probably have been similar if the mathematical part of information theory had been applied in a linguistic sense. However, Stockhausen simply decided to summarize his compositional efforts to introduce limited chance procedures into serial design under the heading of 'aleatory technique'. In retrospect, it can safely be said that the particular development which led from the genesis of serial technique to that of aleatory form design has to be seen in connection with the work of Werner Meyer-Eppler, one of Europe's most distinguished scientists in the field of information theory and phonetic research, who represented also one of the most formative influences during the development of electronic music in Cologne. To bring it to the point: it was not John Cage's lecture in Darmstadt, in 1956, which finally introduced the concept of chance[513] into the current European serial movement in composition, as assumed by most of today's textbooks and current musicological research. The news from the States might have come as a shock to many contemporary composers adhering to the principles of integral serialism. However, Stockhausen had been dealing with chance procedures since 1954, in Meyer-Eppler's seminars.

In fact, it was through Meyer-Eppler, as early as 1953, that the composers in the electronic music studio in Cologne gained informationwere informed about the newest trends

[513]In fact, both Stockhausen and Cage maintained that they have a radical different understanding of this term.

involving the use of chance procedures in the visual arts and music on the North-American continent, as other sources of information were quite limited at that time. And it was through Meyer-Eppler that the 'new theory from America', Shannon's and Weaver's information theory, found its way first into Stockhausen's early electronic works, as the electronic medium commanded a previously unimaginable knowledge concerning the molecular structure of musical material, especially when coupled with speech synthesis. It is particularly evident in GESANG, where a multitude of chance procedures were explored in the form of a compositional process.

Considering Meyer-Eppler's influence on the birth of electronic music composition in Cologne, it is certainly beyond any doubt that GESANG would never have been conceptualized in the form we know today if it hadn't been for Stockhausen's studies with Meyer-Eppler from 1954 to 1956. This, in fact, leads to an entirely new understanding of the history of the development of serialism in the 1950s, including electronic music composition. The scope of this dissertation could not extend beyond creating new perspectives which may now serve as a launching pad for substantial future research. The doors for a new musicological understanding of this vital segment of the history of serial music have been opened.

CONCLUSION - SUMMARY AND CRITIQUE: THE SEMINAL ROLE OF INFORMATION THEORY ON THE DEVELOPMENT OF CONCEPTS OF MUSIC COMPOSITION IN THE 1950s

What ultimately emerges from these investigations is that the 1950s spawned a paradigm shift in the definition of musical form as a process rather than as a model. From this new perspective, the compositional process in its most immediate sense defines the final form of a musical work, blending the final product and its generative evolution in a constant dynamic flow. This is the crucial paradigm shift to which Laske refers, and which Hiller brought about in his first computer music experiments leading to the Illiac Suite, one of several possible manifestations of a predetermined compositional blueprint. Envisioning the genesis of virtual music, both Hiller and Stockhausen did not relate to "form" in the traditional sense, as a static goal to be reached through the discipline of composition. In fact, the latter's definition is entirely dynamic, describing 'form' as follows:

> I call the form the finally crystallized object which is the result of the process or formation. As in an organic process you always have a certain form at a certain instant. But it changes the next second and is no longer the same. The [compositional] matrix remains constant, and the composer concentrates on the matrix ... We have to compose the composition. We are no longer facing an object which is outside somewhere but the compositional process itself.[514]

This approach represents a quantum leap in the development of a musical work. It is no coincidence that the major players in this crucial period of musical evolution

[514]Stockhausen in: "Robert Ashley - Larry Austin - Karlheinz Stockhausen: Conversation", Source, No. 2, p. 107, Panel dicussion dates Nov. 9, 1966 , Davis, California.

found themselves challenged to address the full spectrum of implications brought about by their discoveries: Stockhausen, for example, created a work with the vision that it would encompass the entire acoustical universe, from raw electronic sounds all the way to human speech. Such an ambitious endeavour would not have been possible without the advent of a scientific theory addressing issues of communication on a mathematical basis for a first time. Information theory, with its focus on statistical processes involving the measurement of information, redundancy, and entropy, led to the development of concepts and applications in musical composition which became essential tools for the realization of such a far flung objective. In Hiller's case, we find that this theory was the main contributing factor which gave his experiments their justification as well as their scientific foundation, governing the course of their development and shaping their final outcome.

1. Extracting Order from Chaos

The use of the computer, with its immense data processing capability, made it possible for the composer to concentrate on establishing selection criteria, rather than on pursuing a preconceived model; here, process begets form, and the two constantly interact in a dynamic flow of evolution. Thus, at any given moment, the composition process resembles an act of creation in that it extracts order from chaos, from the microstructural to the macrostructural, global level of the entire work. The emphasis of this dissertation has been to illustrate how information theory assisted this process of extracting order from chaos. Also, how exactly this was achieved by both Hiller and Stockhausen, the types of automated procedures which they used to this effect, and ultimately how concepts of information theory served as the guiding principle without which none of this would have been possible.

2. The Use of Automated Procedures

In terms of procedure, Hiller and Stockhausen seem to have started from opposite poles: Hiller left the selection of elements entirely up to an automated process, using a computer to simulate a model universe of random events from which to choose his basic musical material. The selection of the elements was influenced by rules of restraint imposed on the raw musical material. In the ILLIAC SUITE, the composer made his presence felt by affecting these rules of restraint through coding procedures representing musical rules. As he progressed through the compositional process towards the macrostructural, global level, he was compelled to rely more and more on arbitrarily chosen traditional forms, because the Markov processes he used were confined by their very nature to local relationships between musical events. It was only later, in 1963, that Hiller tried to circumvent this problem by designing MUSICOMP, one of the first serious attempts to write computer software for musical composition, thus realizing an automated mechanism capable of writing virtual music.

Stockhausen, on the other hand, made deliberate artistic choices regarding the musical material he intended to use from the very beginning of the compositional process. The automated procedures here are simulated by means of serial technique, which the composer, in this case, assigned in such a manner as to be weakest at the microstructural level. At this level, aleatory principles were given the greatest impact by the composer, as they broadened his influence due to perceptual limitations which he brought into the compositional process. As the latter moved more and more towards the macrostructural, global level, the influence of aleatory principles grew weaker until they almost entirely disappeared along with the emergence of statistical form. The final organisation of the work was taken over more and more by serial automatism as it reached the final stage of assembly. The degree of automated composition procedure was directly influenced by balancing rules of serial restraint and aleatory freedom, the latter being the contributing factor in defining the entity as a 'process model'.

3. The Role of Linguistic Design.

Shannon's work, which gave information theory its contemporary mathematical foundation, was the product of a whole history of developments in the field of linguistics within communication theory (e.g. the work of F. Bacon, A. Morse, R. Heartley, H. Nyquist, N. Wiener, to name a few). Shannon's use of Markoff processes in the simulation of linguistic design was later put into compositional practice by Hiller, starting out with *ILLIAC SUITE*, and perfecting it in COMPUTER CANTATA. Stockhausen did not use Markov processes in his approach to linguistic design: instead, he relied on maintaining the compositional balance between serial and aleatory processes.

To compensate for the forces of serial restraint, the introduction of aleatory freedom allowed the composer to influence the communicational capability of the musical material to a greater or lesser degree. These principles were derived from Meyer-Eppler's research involving the use of a Vocoder to analyze and synthesize speech by means of statistical methods, which were a direct offshoot of information theory. Thus a link between linguistic design and electronic sound synthesis was established. While he did not resort to such technical means, Stockhausen's approach to speech synthesis was similar in that music was treated as a form of communication where linguistic principles governed the compositional procedures (though without the strict mathematical tools devised by Shannon). In all these cases we find individual variations on a basic theme: information theory acted as a common influence, a catalyst propelling compositional developments in electronic music into the mainstream of twentieth century scientific evolution.

4. The Influence of Information Theory.

Among the many scientific theories that led to paradigm shifts in many fields of scientific development towards the middle of the twentieth century, information theory stands out because of the scope of its applications, and because of the new vistas it opened regarding the communicational nature of phenomena encountered in the sciences and the arts. Musical composition can be considered as such a phenomenon, and information theory made it possible for some composers to envision at least the possibility of designing works of art which would actually address musical communication in its broadest sense. A new aesthetic point of view emerged, where sound structures could be created which were no longer oriented by notions of beauty, but instead were optimally aligned with the evolutionary leap which was taking place in the field of communications.

The seeds of research which were planted by this theory resulted in different strands which had a remarkable impact on electronic and computer music composition in the United States and Europe. Hiller's experiments, which marked the beginning of computer music composition, served as a model for the development of computer music software. In Europe, the influence of information theory on electronic music composition was first imported through the person of Meyer-Eppler. It was through him that Stockhausen became acquainted not only with the general concept of information theory, but also with its inherent principles of probability, chance, and applications of speech analysis and synthesis. Consequently, I suggest that one cannot legitimately presume to comprehend Stockhausen's early electronic works, and in particular GESANG DER JÜNGLINGE, without taking these historical facts into account. This implies a new perception of a pivotal period in terms of music history. It also means that certain commonly held notions concerning the development of electronic music composition in the 1950s will have to be reassessed.

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APPENDIX

MORSE CODE	NUMBER OF CHARACTERS FOUND	
-	E :	12.000
—	T :	9.000
- —	A :	8.000
- -	I :	8.000
— -	N :	8.000
— — —	O :	8.000
- - -	S :	8.000
- - - -	H :	6.400
- - -	R :	6.200
— - -	D :	4.400
———	L :	4.000
- - —	U :	3.400
- - -	C :	3.000
— —	M :	3.000
- — -	F :	2.500
- — —	W :	2.000
- - - -	Y :	2.000
— — -	G :	1.700
- - - - -	P :	1.700
— - - -	B :	1.600
- - - —	V :	1.200
— - —	K :	800
- - — -	Q :	500
- - - -	J :	400
- — - -	X :	400
- - - -	Z :	200

Table 1. Morse's original code, showing the relation to quantities of type found by him in a printer's office.

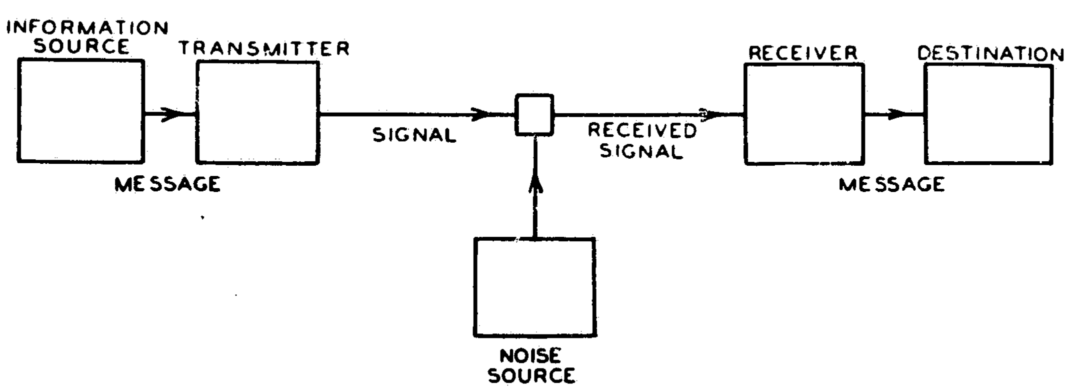
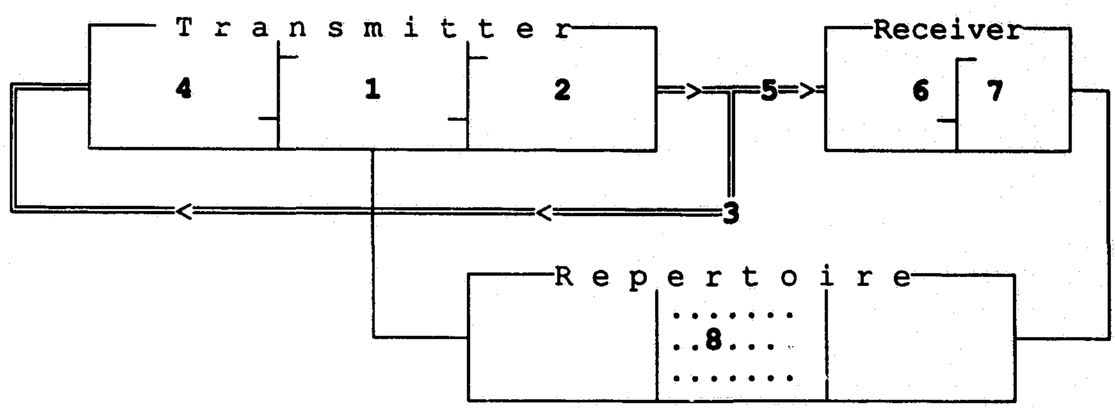


Fig. 1. Shannon's canonical block diagram of the one-way communication system. In Claude Shannon: "A Mathematical Theory of Communication," C. E. Shannon, Bell System Technical Journal, Oct. 1948, p. 379.



Disturbances on the side of the transmitter:

1) Central disturbance
2) Peripheral disturbance of production
3) Physical disturbance of exterior feedback mechanism
4) Peripheral perception disturbance of exterior feedback mechanism

Disturbances within the physical transmission line

5) Distortion of a signal

Disturbances on the side of the receiver

6) Peripheral disturbance
7) Central disturbance

Disturbances within the domain of sign repertoire between transmitter and perceiver

8) Disturbances between signs

Fig. 2. Noise interference scheme of a linguistic communication chain.

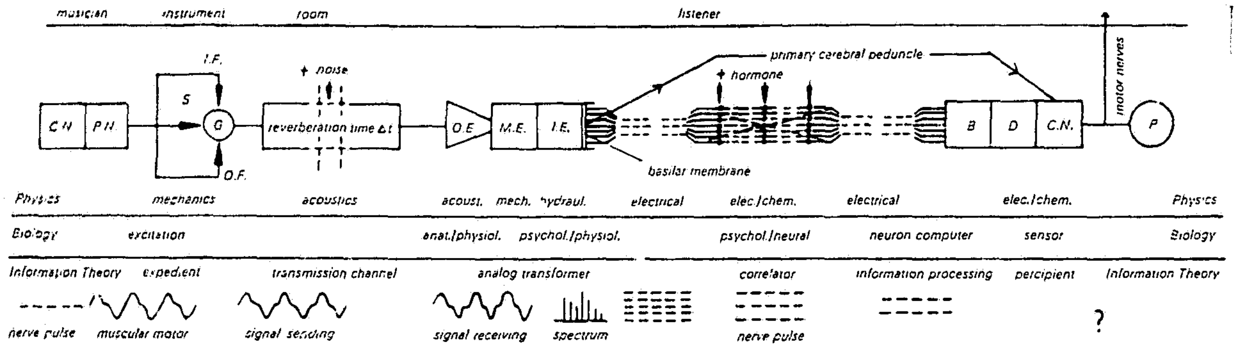


FIG. 56. Diagram of the transmission of acoustic information to the perception center in terms of physics, biology and information theory.

C.N. = central nervous system; P.N. = peripheral nervous system; G = generator (instrumentalists); I.F. = inner feedback; O.F. = outer feedback; S = stimulation; O.E. = outer ear; M.E. = middle ear; I.E. = inner ear; B = bulbar system; D = diencephalon; P = perception.

Fig. 3. Diagram of the transmission of acoustic information to the perception center in terms of physics, biology, and information theory. In: F. Winckel "Music, Sound, and Sensation".

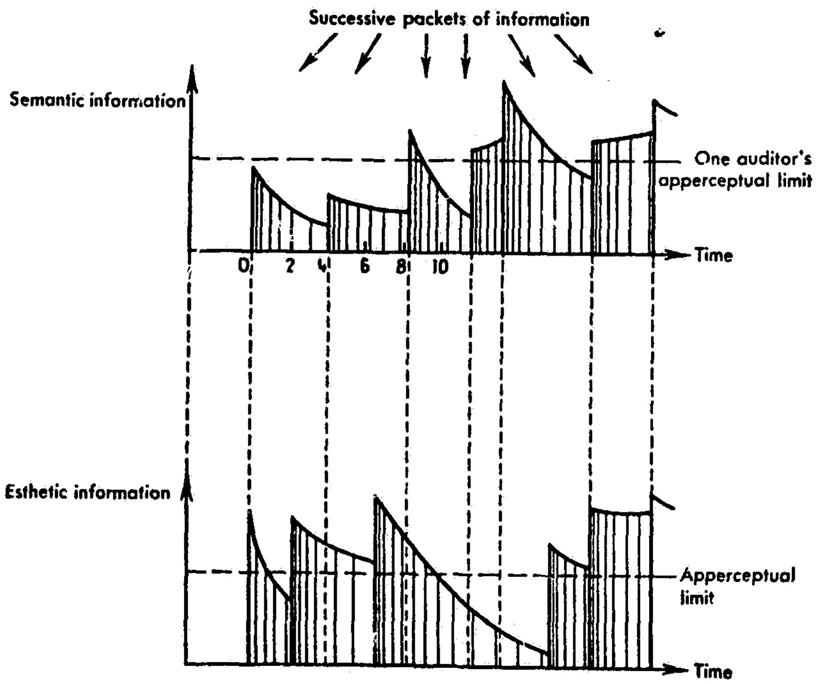
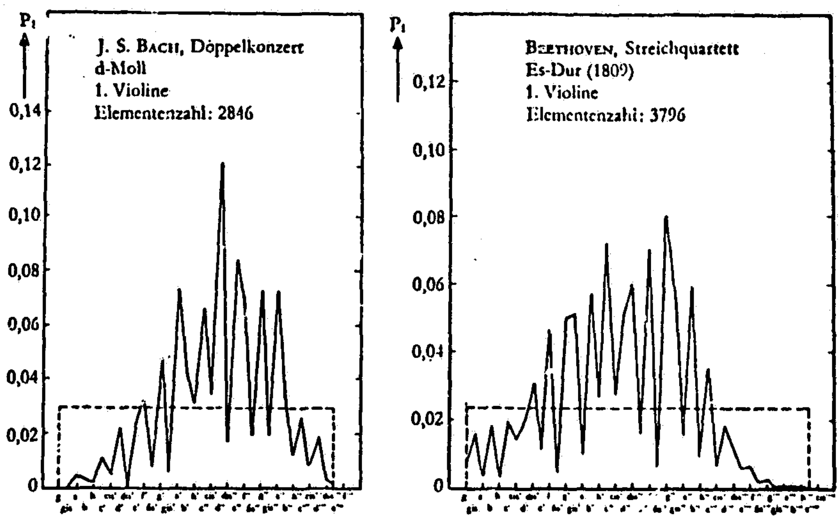
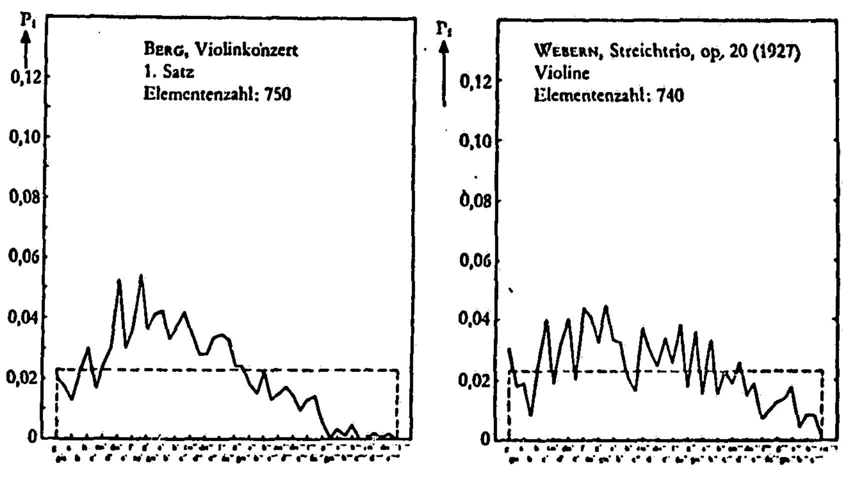


Fig. 4. The successive packets of information presented to the auditor, either semantic (above) or aesthetic (below), must be judged in comparison with his perceptual limit (dotted line). Figure taken from Hiller on this topic. In: Moles "Information Theory and Esthetic Perception", p. 156.



Verteilungen der Tonhöhen in einem Werk von a) Bach und b) Beethoven



Verteilungen der Tonhöhen in einem Werk von a) Berg und b) Webern

Fig. 5. Distribution of pitches in selected works of J. S. Bach, L. v. Beethoven, A. Berg, and A. v. Webern. According to Fucks.

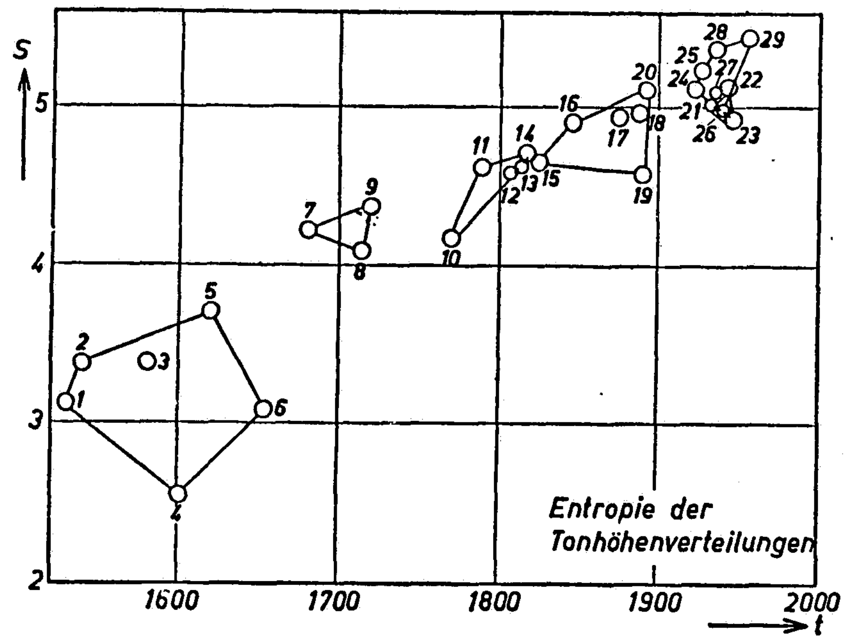


Fig. 6. Entropy of the mean variation in pitch distribution (S) as a function of historical origin (t). According to Fucks. Used by permission.

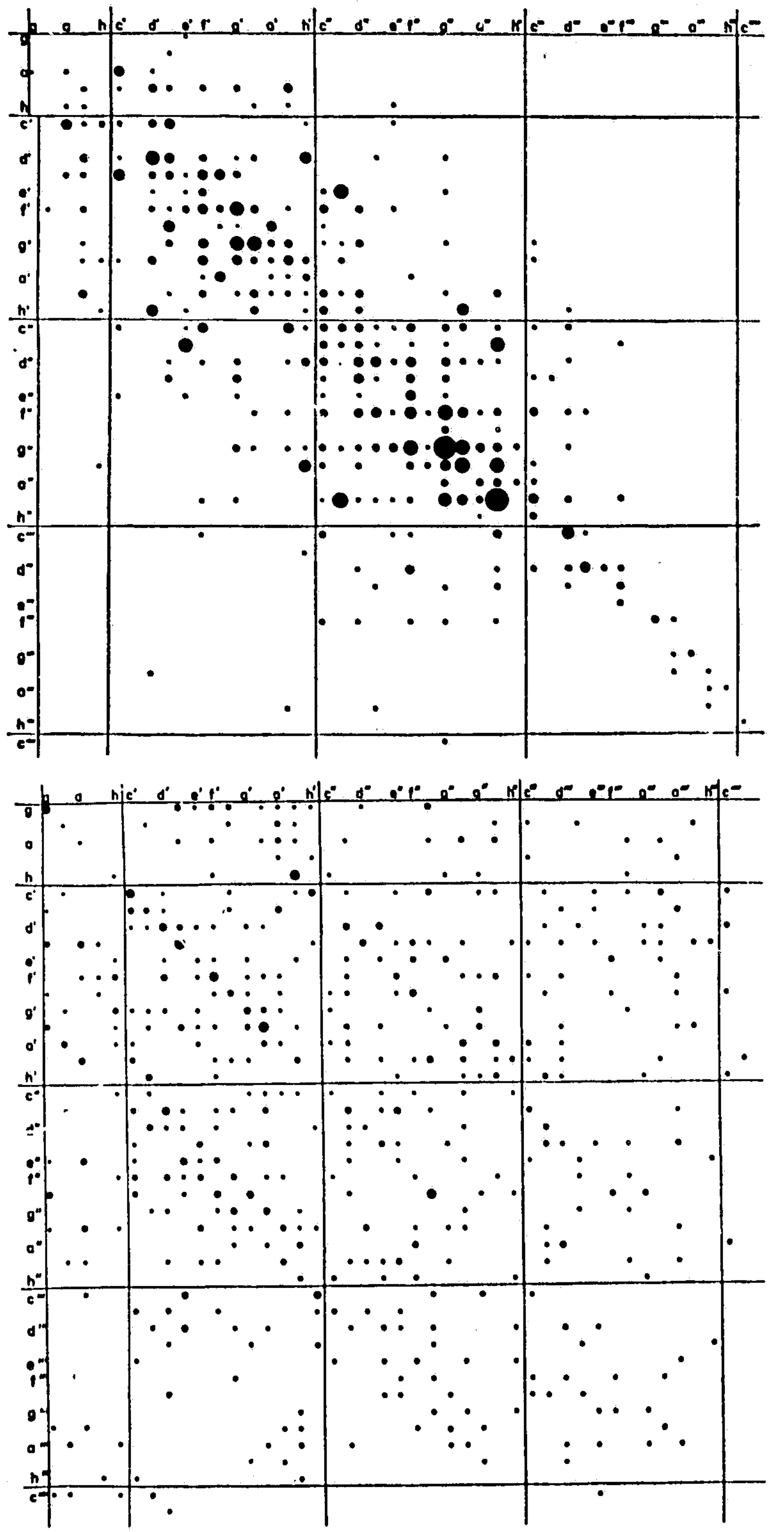


Fig. 7. Transition probabilities between pitches, (1) Beethoven, String Quartet op. 74; (2) V. Webern, String Trio op. 20. According to Fucks. Used by permission.

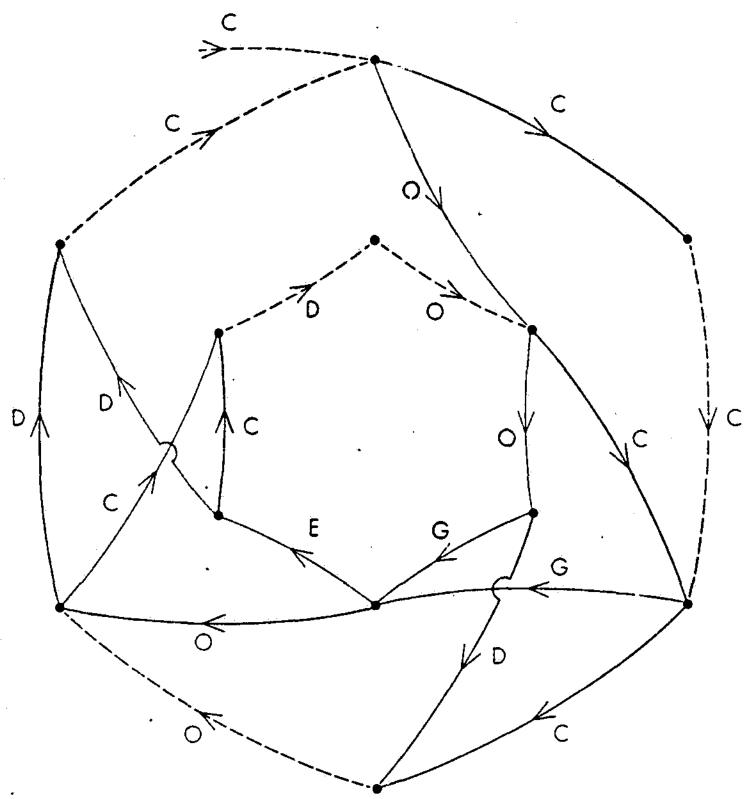


Fig. 8. BANAL TUNE MAKER produces simple, redundant melodies that sound like nursery tunes. A sequence of notes is obtained by following the path through the network, starting at the top, and writing down the note (or rest) attached to each segment traversed. Where there is a choice of paths, a coin is flipped. If it comes up heads, the black path is taken; if tails, the colored path. Broken lines show the path from a junction where there is no choice.[515] According to Pinkerton.

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[515]Richard C. Pinkerton: "Information Theory and Melody", Scientific American, Vol. 194, Feb. 1956, p. 78.

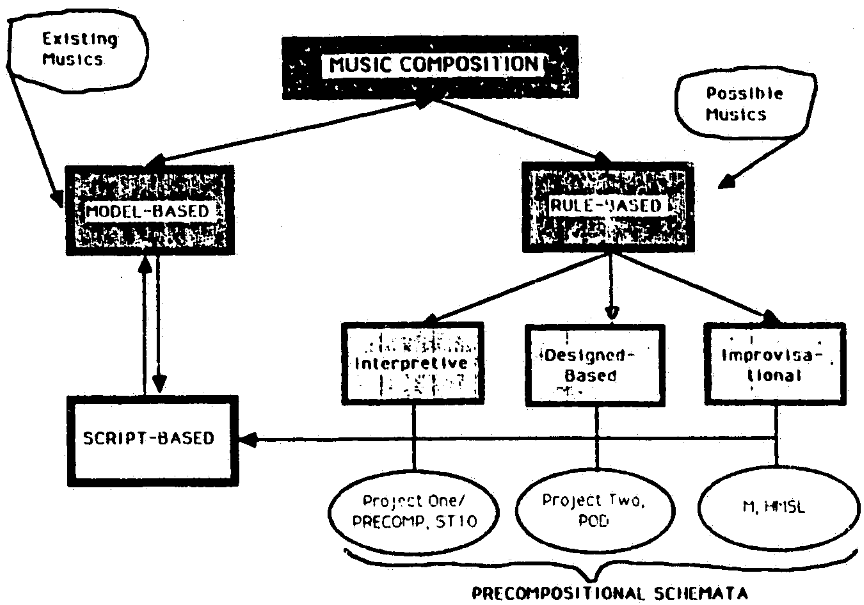


Fig. 9. Compositional paradigms. According to Otto Laske.

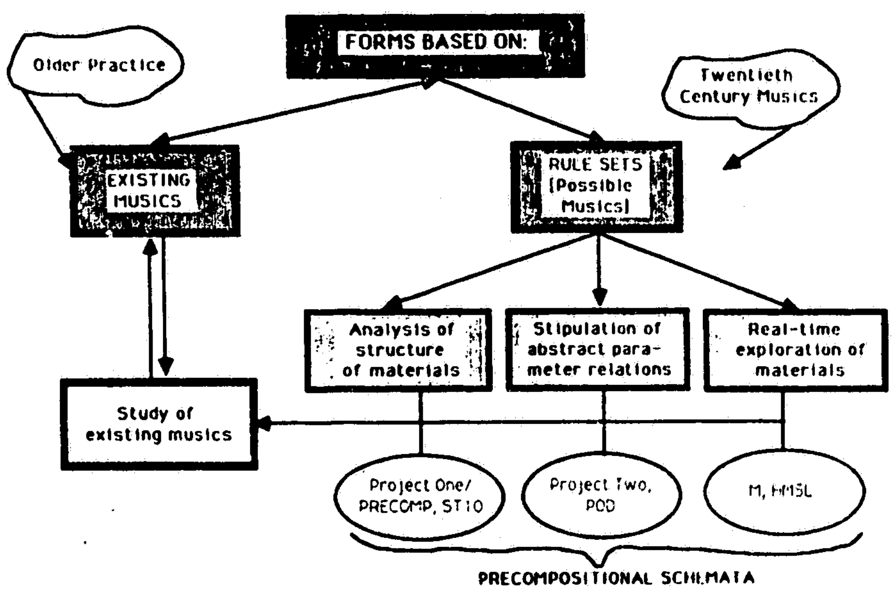


Fig. 10. Development of musical form. According to Otto Laske.

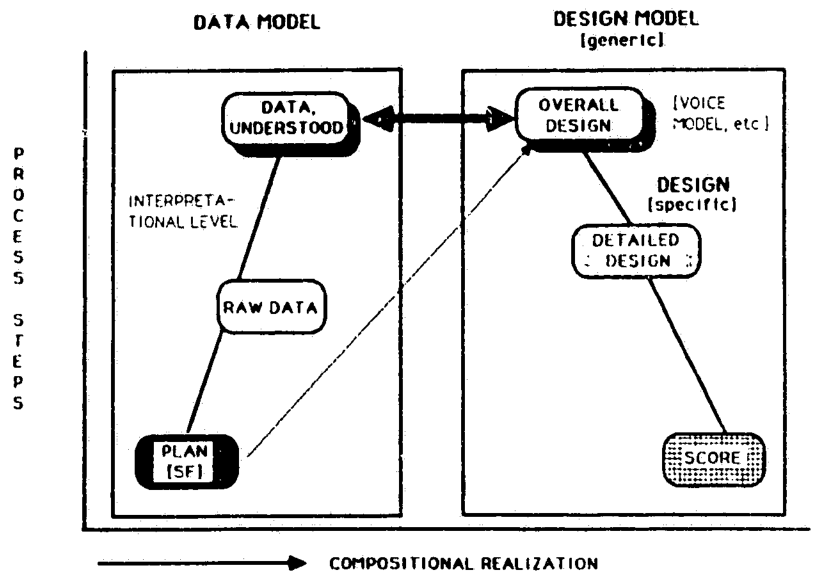


Fig. 11. Life cycle, interpretative composition. According to Otto Laske.

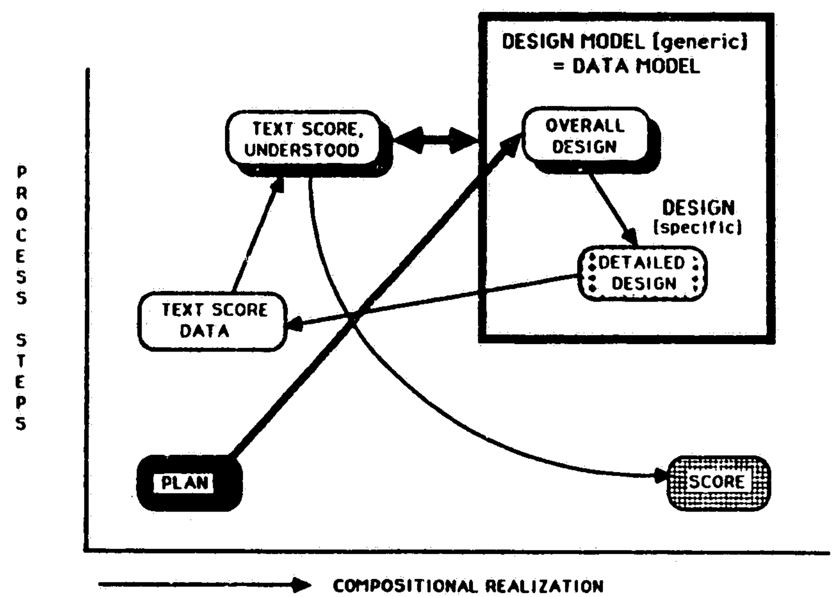


Fig. 12. Otto Laske: Life cycle, design-based composition.

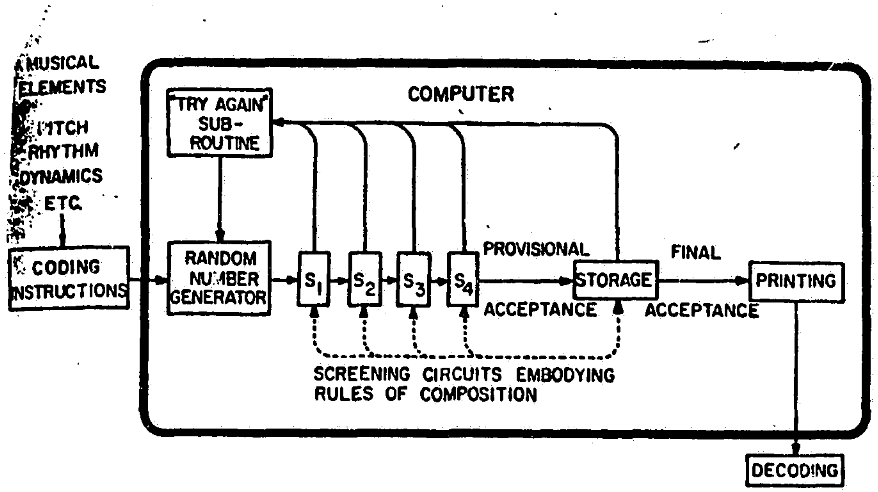


Fig. 13. A block diagram showing the general scheme for computer composition as used in the composition of the ILLIAC SUITE. In Hiller: "The Electrons go around and come out Music", p. 43.

ILLIAC SUITE Experiments summarized

Experiment One: Monody, two-part, and four-part writing

A limited selection of first-species counterpoint rules used for controlling the musical output

(*a*) Monody: *cantus firmi* 3 to 12 notes in length
(*b*) Two-part *cantus firmus* settings 3 to 12 notes in length
(*c*) Four-part *cantus firmus* settings 3 to 12 notes in length

Experiment Two: Four-part first-species counterpoint

Counterpoint rules were added successively to random white-note music as follows:

(*a*) Random white-note music
(*b*) Skip-stepwise rule; no more than one successive repeat
(*c*) Opening C chord; *cantus firmus* begins and ends on C; cadence on C; B–F tritone only in VII_6 chord; tritone resolves to C–E
(*d*) Octave-range rule
(*e*) Consonant harmonics only except for $\frac{6}{4}$ chords
(*f*) Dissonant melodic intervals (seconds, sevenths, tritones) forbidden
(*g*) No parallel unisons, octaves, fifths
(*h*) No parallel fourths, no $\frac{6}{4}$ chords, no repeat of climax in highest voice

Experiment Three: Experimental music

Rhythm, dynamics, playing instructions, and simple chromatic writing

(*a*) Basic rhythm, dynamics, and playing-instructions code
(*b*) Random chromatic music
(*c*) Random chromatic music combined with modified rhythm, dynamics, and playing-instructions code
(*d*) Chromatic music controlled by an octave-range rule, a tritone-resolution rule, and a skip-stepwise rule
(*e*) Controlled chromatic music combined with modified rhythm, dynamics, and playing-instructions code
(*f*) Interval rows, tone rows, and restricted tone rows

Experiment Four: Markoff chain music

(*a*) Variation of zeroth-order harmonic probability function from complete tonal restriction to "average" distribution
(*b*) Variation of zeroth-order harmonic probability function from random to "average" distribution
(*c*) Zeroth-order harmonic and proximity probability functions and functions combined additively
(*d*) First-order harmonic and proximity probability functions and functions combined additively
(*e*) Zeroth-order harmonic and proximity functions on strong and weak beats, respectively, and vice-versa
(*f*) First-order harmonic and proximity functions on strong and weak beats, respectively, and vice-versa
(*g*) *i*th-order harmonic function on strong beats, first-order proximity function on weak beats; extended cadence; simple closed form

Table. 2. ILLIAC SUITE Experiments Summarized. According to Lejaren Hiller, in "Experimental Music", p. 83.

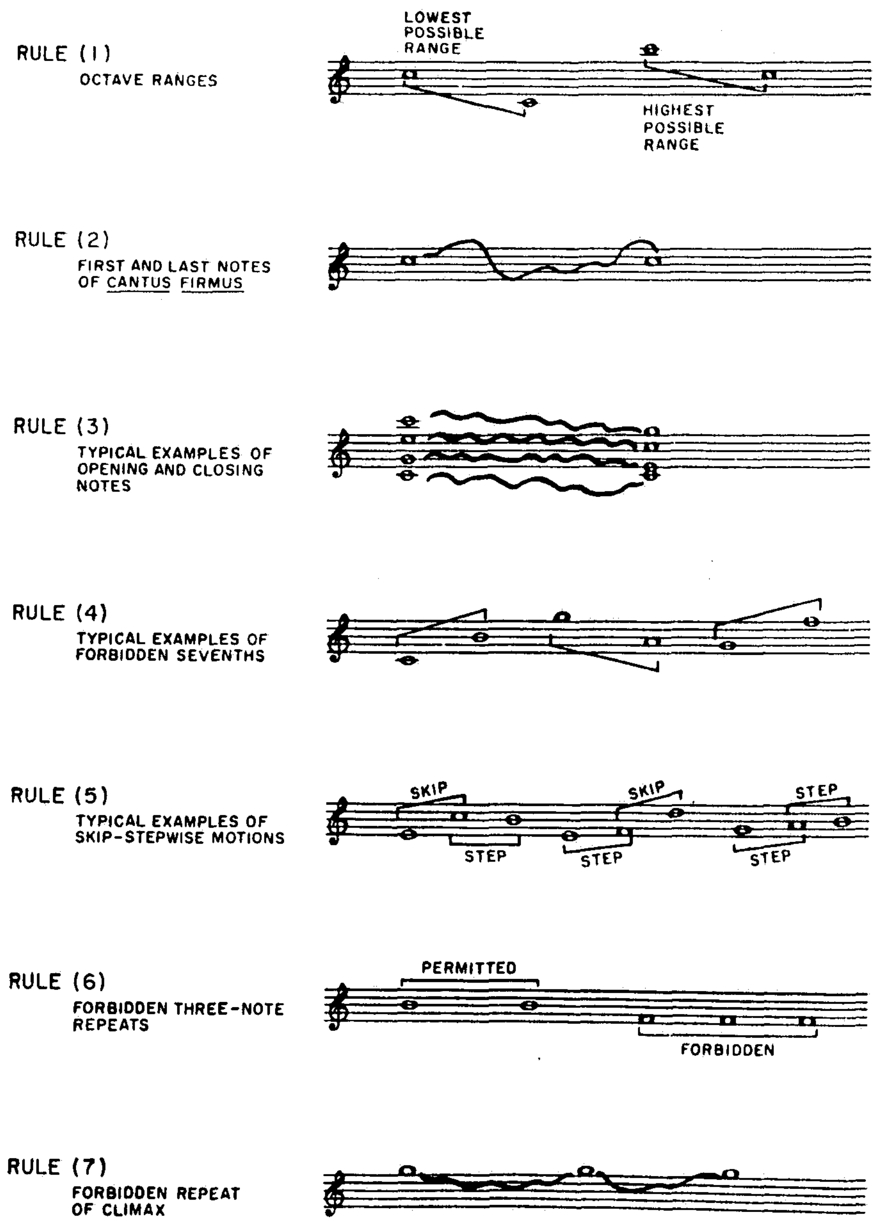


Figure 14. The rules of first-species counterpoint illustrated by means of typical musical examples, According to Hiller. Used by permission of the publisher.

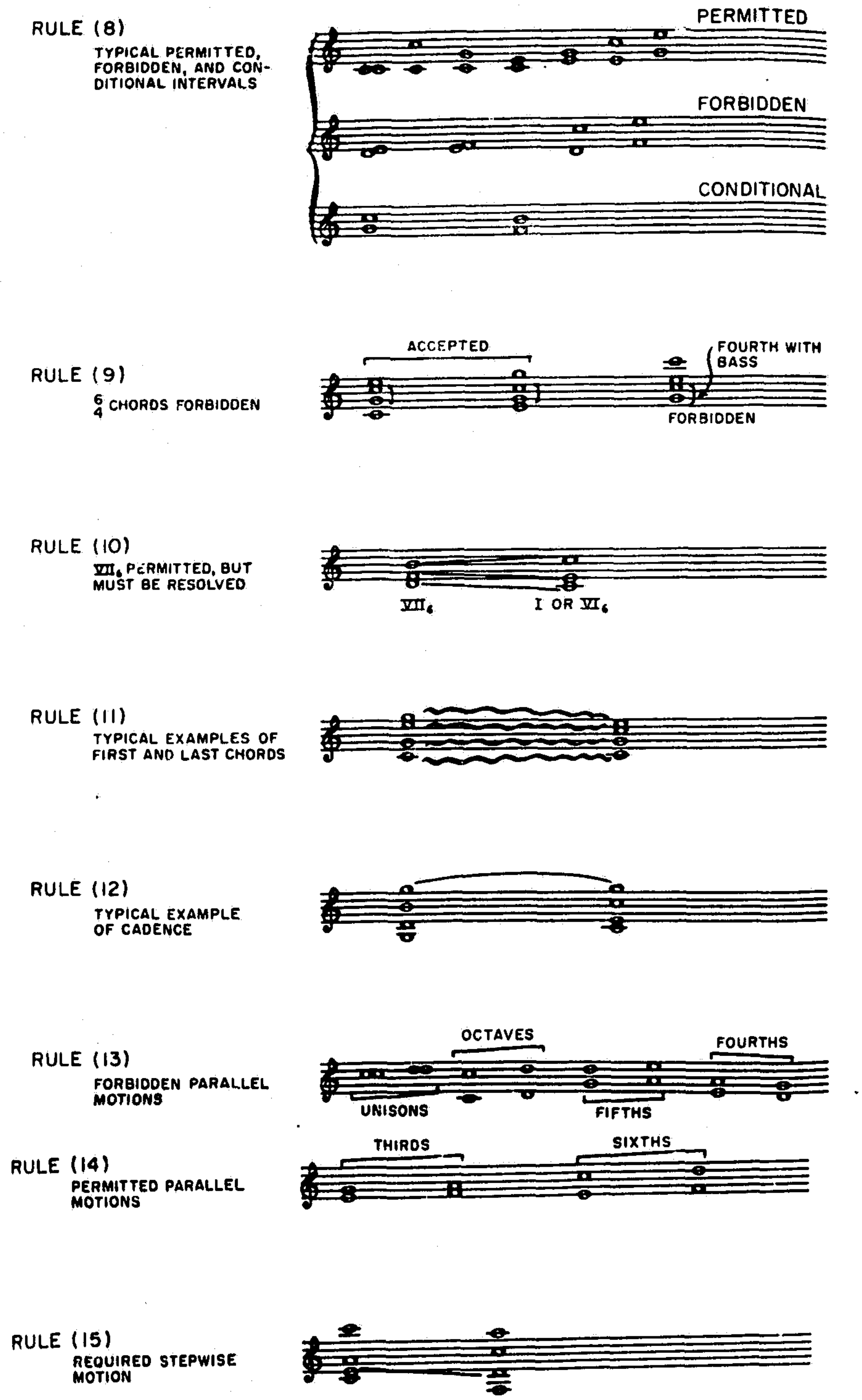


Figure 15. The rules of first-species counterpoint illustrated by means of typical musical examples. According to Hiller. Used by permission of the publisher.

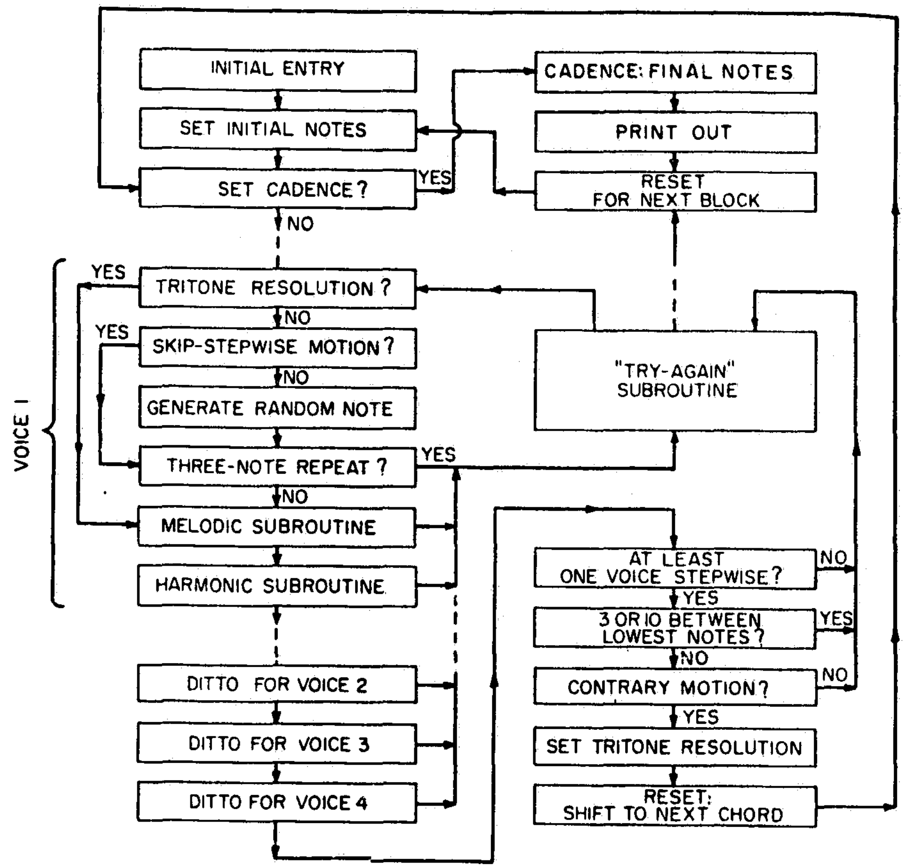


Fig. 16. Experiment TWO: Block diagram of the main routine. Used by permission of the publisher.

Last chord formed	Index plus counter		Effect on conditional transfer order to cadence	
...	$-(n-2)$	$= -(n-2)+0$	$= -(n-2)$	
Initial chord	$-(n-2)+1$	$= -(n-2)+1$	$= -(n-3)$	
Second chord	$-(n-3)+1$	$= -(n-2)+2$	$= -(n-4)$	*Negative numbers*
Third chord	$-(n-4)+1$	$= -(n-2)+3$	$= -(n-5)$	Do not set cadence
.	.	.	.	Do not transfer
.	.	.	.	Continue with main routine
.	.	.	.	
.	.	.	.	
$(n-3)$rd chord	$-(n-n+2)+1$	$= -(n-2)+(n-3)$	$= -1$	
$(n-2)$nd chord	$-(n-n+1)+1$	$= -(n-2)+(n-2)$	$= 0$	*Positive number*
				Transfer to cadence routine

Table 3. Experiment TWO: Counting Operation for Activating the Cadence Routine. Hiller: "Experimental Music", p. 96. Used by permission of the publisher.

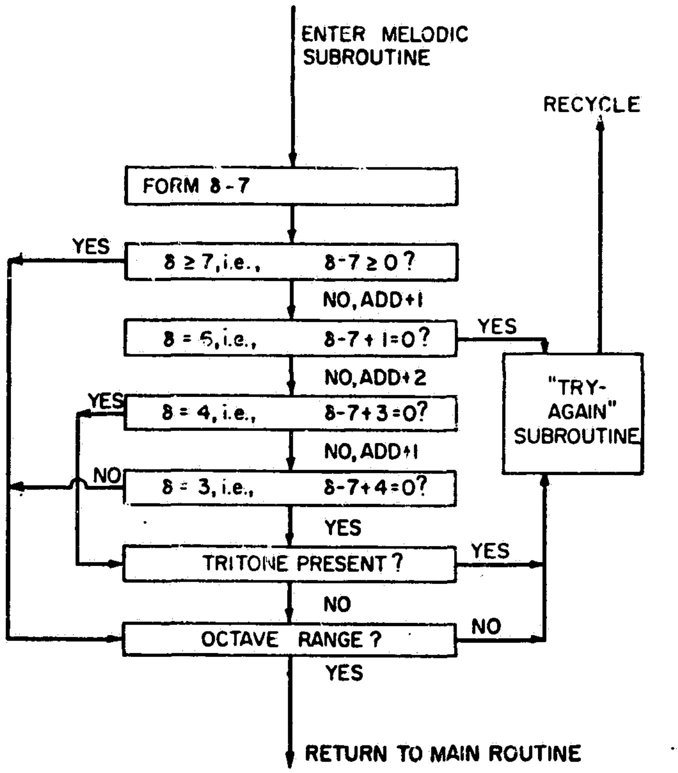


Fig. 17. Experiment TWO: Block diagram for the melodic subroutine. In: Hiller "Experimental Music", p. 100. Used by permission of the publisher.

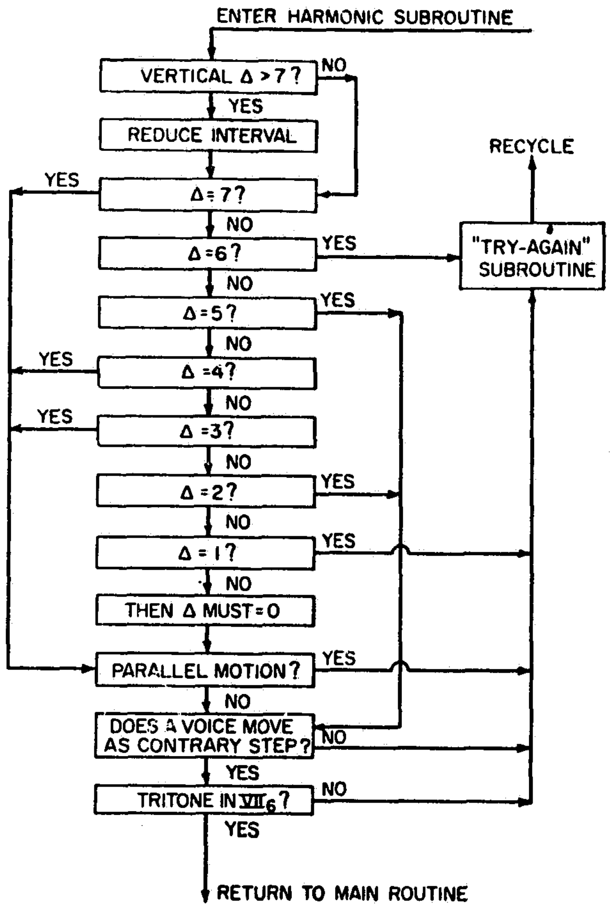


Fig. 18. Experiment TWO: Block diagram for the harmonic subroutine. In: Hiller, "Experimental Music", p. 102. Used by permission of the publisher.

DECIMAL NUMBER	BINARY NUMBER
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

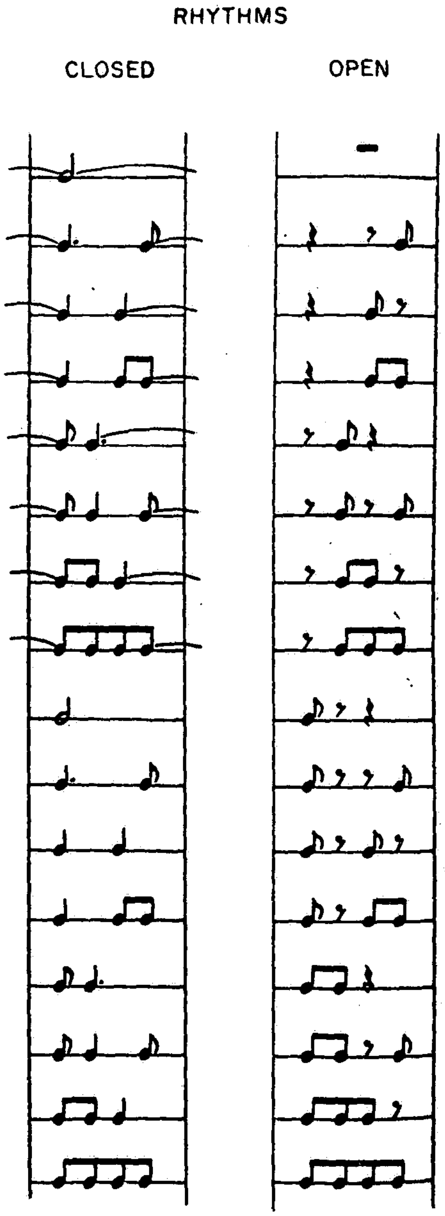


Table 4. Basic Rhythmic Scheme for 4/8 Meter. According to Hiller. Used by permission of the publisher.

Random sexidecimal integer	Playing instructions	If playing instructions are impossible, revert to
0	Bowed *legato*, held through rests	F
1	Bowed *detaché*, rests observed	F
2	Bowed *tremolo*, hold through rests	0
3	Bowed *sul ponticello*, rests observed	1
4	Bowed, artificial harmonics, hold through rests	0
5	Bowed *col legno*, rests observed	1
6	Bowed *sul tasto*, hold through rests	0
7	Bowed *martellato*, rests observed	1
8	Bowed *legato* with mutes, hold through rests	0
9	Bowed, whole tone shake, rests observed	1
K	Bowed, *glissando* octave, hold through rests	0
S	Bowed ⊓ rests observed	1
N	Bowed V rests observed	1
J	Snap *pizzicato*	F
F	Ordinary *pizzicato*	1
L	Rap on wooden body of instrument with knuckles	F

Tab. 5. Experiment THREE, Articulation.[516] According to Hiller, Used by permission of the publisher.

[516]Hiller refers to this as "Orchestration".

0101	0101	0101	0101	0101	0101
6 FF=	6 FF=	6 FF=	6 FF=	6 FF=	6 FF=
0111	0111	0111	0111	0111	0111
S PP(	S MF(	S MF(	L MF(	7 MF(	L MF(
1010	1010	1010	1010	1010	1010
9 FF)	9 FF)	9 FF)	N F=	N F=	5 F=
1101	1101	1101	0111	0111	0111
J F)	8 F)	8 F)	8 P(	8 P(	8 P(

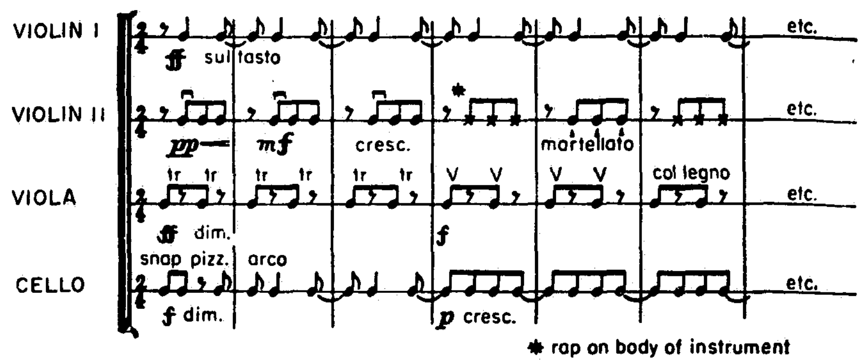


Fig. 19. Experiment THREE: Sample of computer output from the simplest program for rhythm, dynamics, and playing instructions [articulation]. Used by permission of the publisher.

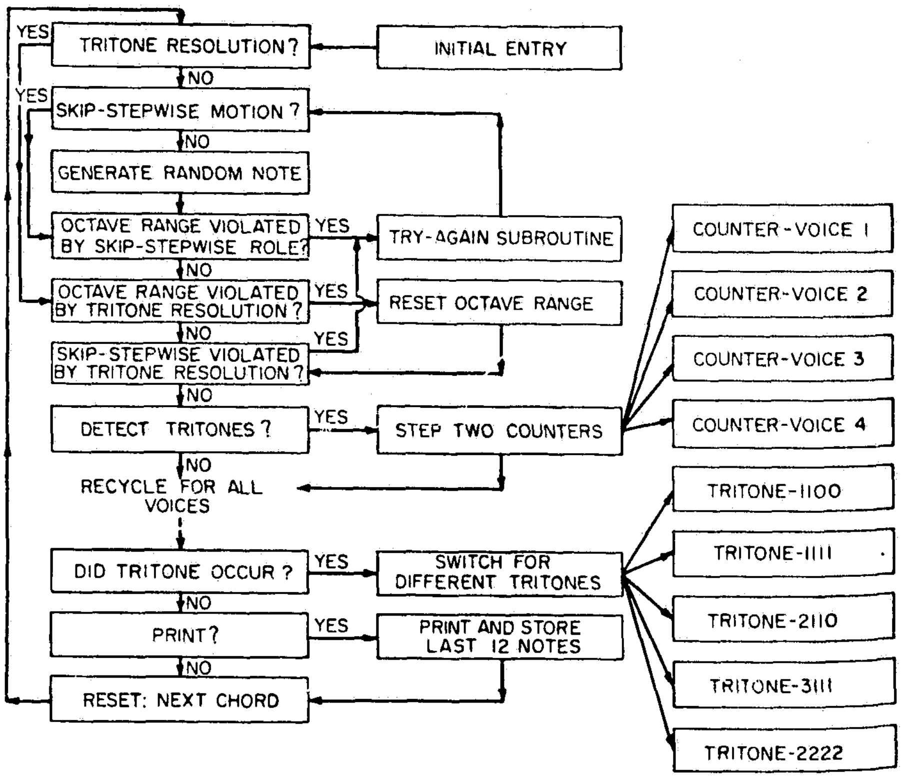


Fig. 20. Experiment THREE: Block diagram for chromatic writing. According to Hiller. Used by permission of the publisher.

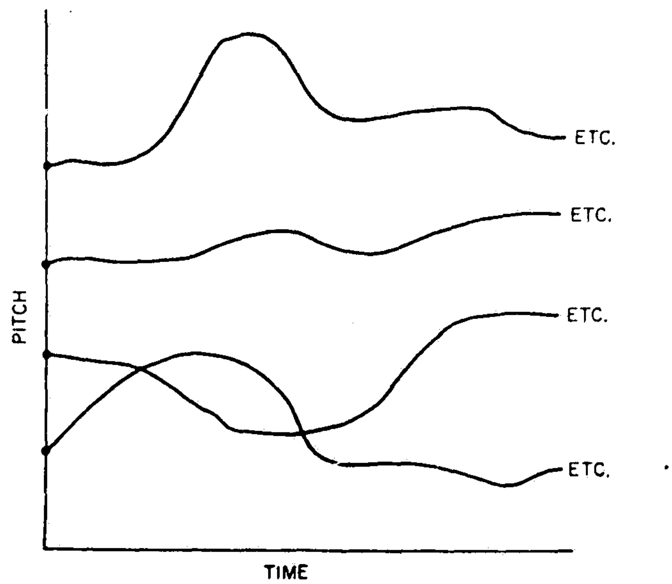


Fig. 21. Experiment FOUR: A four-voiced musical texture pictured as a random flight problem. According to Hiller. Used by permission of the publisher.

Interval	Stochastic variable v_j	Harmonic function x_j	Proximity function y_j	Combined function $z_j = x_j + y_j$
Unison	0	13	13	26
Octave	12	12	1	13
Fifth	7	11	6	17
Fourth	5	10	8	18
Major third	4	9	9	18
Minor sixth	8	8	5	13
Minor third	3	7	10	17
Major sixth	9	6	4	10
Major second	2	5	11	16
Minor seventh	10	4	3	7
Minor second	1	3	12	15
Major seventh	11	2	2	4
Tritone	6	1	7	8
	$\sum_{j=0}^{12} x_j = 91$ $[x_j = x(v_j)]$	$\sum_{j=0}^{12} y_j = 91$ $[y_j = y(v_j)]$	$\sum_{j=0}^{12} z_j = 182 = 2 \times 91$	

Table 6. Table of Functions for the Generation of Markov Chain Music in Experiment FOUR. According toIn: Hiller, Experimental Music. Used by permission.

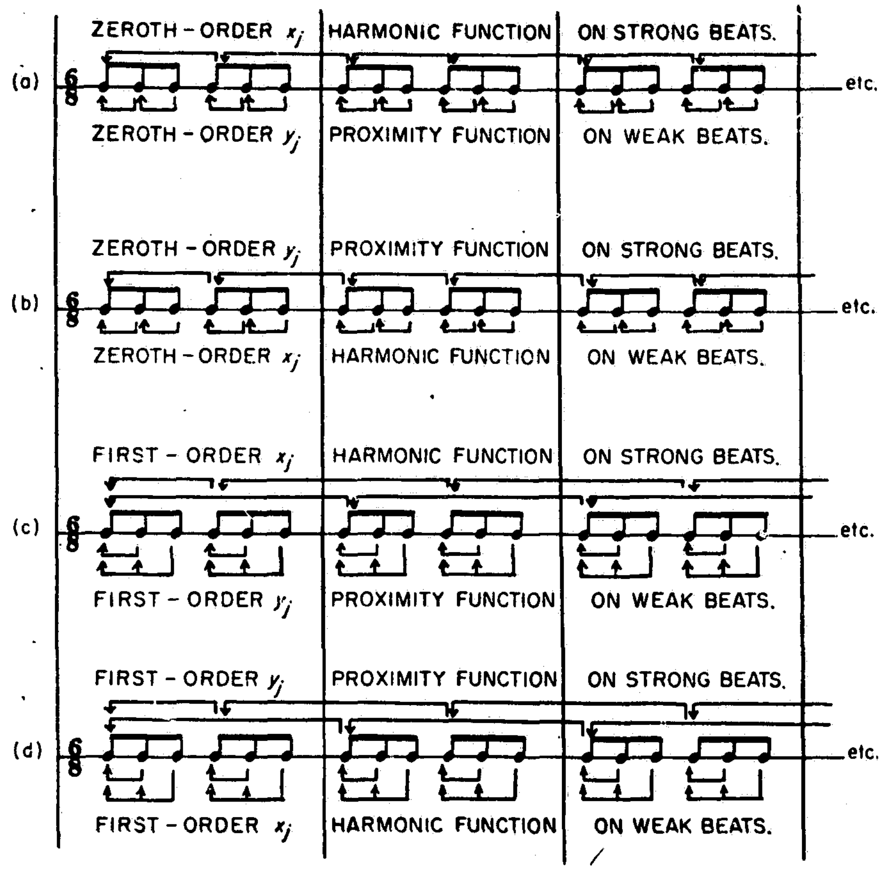


Fig. 22. Experiment FOUR: Illustration of strong-beat and weak-beat structures utilized to generate various species of Markov chain music. According to Hiller. Used by permission of the publisher.

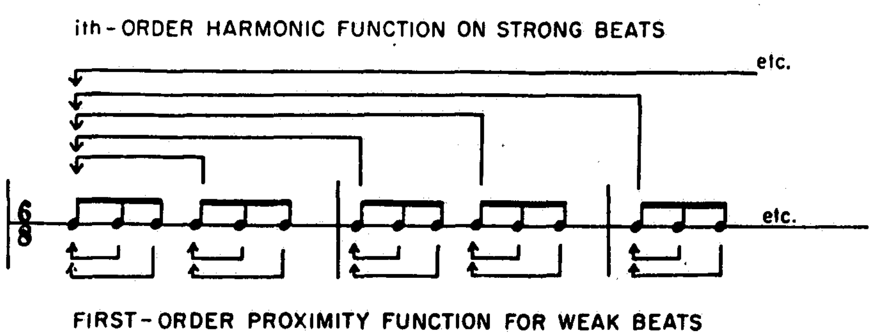


Fig. 23. Experiment Four: Musical organization of the last example of Markov chain music in Experiment Four. According to Hiller. Used by permission of the publisher.

Experiment One

Monody; 5 samples each of *cantus firmi* 3 to 12 notes long.	Two-part *cantus firmus* settings.	Four-part *cantus firmus* settings.
Presto	*Andante*	*Allegro*

Experiment Two

Four-part counterpoint, from random white-note music to strict counterpoint with rules added successively. Two samples of each type setting.	*CODA* Extra samples of cadences.
Adagio, ma non troppo lento	

Experiment Three

Basic rhythm, dynamics, and instrumentation code. A	Random chromatic music. B	Modified rhythm, dynamics, and instrumentation code plus random chromatic music. A′	Controlled chromatic music. B′	Revised rhythm, dynamics, and instrumentation code plus random chromatic music. A″	*CODA* Interval row	Tone row	Modified tone row
Allegro vivace	*Adagio*	*Allegro vivace*	*Adagio*	*Allegro vivace*	*Adagio* and *Allegro vivace* alternatingly.		

Experiment Four

Alterations of harmonic-function transition probabilities.	Zeroth-order Markoff chain music.	First-order Markoff chain music.	Separation of strong and weak beats.	*CODA* *i*th-order Markoff chain music; modulation and simple closed structure.
Tanto presto che possible				

Figure 24. [Formal] Structure of the ILLIAC SUITE. According to Hiller. Used by permission of the publisher.

Section	***Added Rules***
[A]	Random Music; no rules
[B]	Skip-stepwise rule; no more than one repeated note
[C]	*Cantus firmus* starts on C with C chord for opening; cadence on C with leading tone in one of the four voices; resolution of tritone in VII_6
[D]	Octave-range rule
[E]	Only consonant chords permitted except for 6/4 chords; i.e., harmonic subroutine added
[F]	Parallel unisons, octaves, fifths, and fourths still permitted; melodic subroutine added
[G]	Parallel fourths; 6/4 chords containing tenths still permitted
[H]	Best counterpoint

Table 7. Sequence in which strict counterpoint rules were successively added to random white-noise music. Used by permission of the publisher.

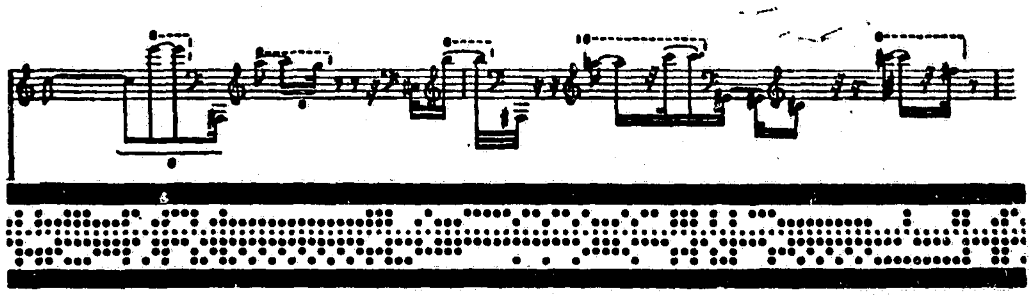


Fig. 25. A sample of music prepared and typed on the machine shown [a photograph of an electrical musical typewriter and tape unit which Hiller used at the University of Illinois]. This music is stored on punched paper tape like that shown in the bottom part of the illustration. When this tape is fed into the reader, the typewriter is activated to produce the musical score shown. In Hiller: "The electrons...", p. 44. Used by Permission.

Chronology of Computer Music Compositions

Hiller and Baker:	COMPUTER CANTATA	1963
Tenney:	STOCHASTIC COMPOSITION NO. 1	1963
Xenakis:	ST/10 - 1080 262	1962
Hiller and Baker:	ELECTRONIC STUDY NO. 4	1961-62
Champerowne:	MUSIC FROM THE EDSAC	1961
Barbaud and Blanshard:	MUSIQUE ALGORITHMIQUE	1959
Hiller and Isaacson:	ILLIAC SUITE	1956-57
Klein and Bolitho:	PUSH-BUTTON BERTHA	1956

Table 8. Chronology of computer music compositions.

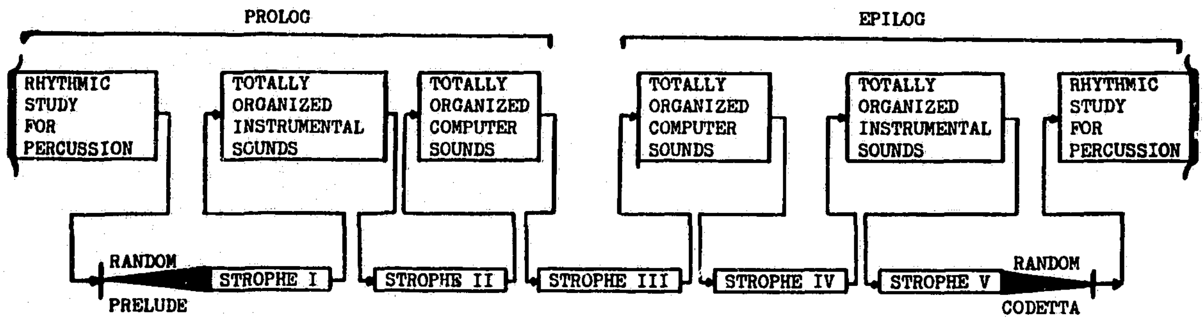


Fig. 26. COMPUTER CANTATA, Structural plan. In Hiller: "Programming a Computer for Music Composition. Used by Permission.

(I)
Prologue to Strophe I (Rhythm Study for Percussion)
Random Prelude to Strophe I
Strophe I (Zeroth-order Stochastic Approximation)

(II)
Prologue to Strophe II (Totally Organized Instrumental Music)
Strophe II (First-Order Stochastic Approximation)

(III)
Prologue to Strophe III (Polytempered Computer Sounds)
Strophe III (Second-order Stochastic Approximation)
Epilogue to Strophe III (Polytempered Computer Sounds)

(IV)
Strophe IV (Third-order Stochastic Approximation)
Epilogue to Strophe IV (Totally Organized Instrumental Music)

(V)
Strophe V (Fourth-order Stochastic Approximation)
Epilogue to Strophe V (Rhythm Study for Percussion)

Fig. 27. Overall form of COMPUTER CANTATA. According to Hiller. In "Computer Cantata...", op. cit., p. 64.

	Left Channel	Both Channels	Right Channel
CUE1	Coloured Noise:	White Noise:	Coloured Noise
	CLICK		CLACK
	SISS		CRACKLE
	SNAP		POP
	BANG		BOOM
	Square wave	Sine wave	Sawtooth wave
CUE2	Square wave	Sine wave	Sawtooth wave
CUE3	CSX-1 Sound:		CSX-1 Sound:
	3 Voices		3 Voices
CUE4	CSX-1 Sound:		CSX-1 Sound:
	3 Voices		3 Voices
CUE5		Sine wave	

Table 9. Contents of tape cues in Hiller's COMPUTER CANTATA. According to Hiller.

STROPHE I (Zeroth-order Approximation)

shhlkăchg # #mlthâlnôĕ #ēŭdȧôăōshĭsnĭ #ĭôzhvmpăthyĭĕfăôshōshĕē-ōăpkăāōōzsăăngēpĭshzōăŭgȧôĭēaōssrôdkēfngthȧngfnglkbt #

STROPHE II (First-order Approximation)

hlŭtrmkythm #twēyēh #yȧwă #nĕĭtbr #ŭŭnhfnw #dô #lr # #rĭ # # #ô #tntwō # #r #ĭ #l #zŭmhgĭ #ŭlŭdwôdōōōthyrsyr #rĭw # #ĭăvyĭōĭ āhĭwdĭ #

STROPHE III (Second-order Approximation)

ĕnŭbrôh #sōōkōhăm #kăhwŭ #ylăft #ȧy #ĭtŭbĭtȧw #gȧnĕt #y #jhĭn #dĭr #t #n #ĭykĕrȧw #w #fēn #hēynd #ch #hr #tŭrŭmēnēl #bȧyzth-imäy #ēpĭn #tȧhōnĕhȧy #ĭngk #mȧy #thĕl #fŭ #dōwnt #kēnäy #mŭ-bȧräy #m #w #hl #m #sĭt #th #ȧr #thŭ #nd #ănȧntŭrkăngtĭhlȧy #pŭ #

STROPHE IV (Third-order Approximation)

ĭn #kŭmĕnsŭprēn #bȧwstĕyĭ #krȧwr #wĭy #hăv #yōōw #yōhr #ôf #yōōwn #ăn #pēbd #wān #dōhr #ĭnthŭrz #ōwn #jhĕnĭts #hwēzĭn #yēhrd #ŭblōwm #ĭtŭ #pănt #lēng #ȧn #ĭntȧp #thŭ #jhȧn #ĭts #tȧym #ōwk #ĭt #gōwzŭ #shōōd #ŭbȧywŭr #ēyk #ĭzhĭ #ȧyn #thăt #bŭt #ĭt #fŭr #

STROPHE V (Fourth-order Approximation)

skōhr #fĕyvd #ĭzhĭr #pērpŭs #ēndŭr #gōntŭ #hȧt #wēyl #skōōwl #tŭ #sēy #sēy #nĕyt #thrĕtĭnĭtlĭy #ăn #lȧyk #ănäy #kēvŭr #ôhlŭvyĭ #äy # lōwnlĭy # hēhr # thäy # dōōw # hwĕhr # wĕyt # fōwkōw # bŭt # mēnĭtlĭy # hăpĭn # thōwz # thrēy # sĕd # kwēyndĭm # ȧy # jhĭst yōhrŭ #

Tab. 10. The stochastic text of the COMPUTER CANTATA with pronunciation scheme. In: Hiller "Computer Cantata", p. 69. Used by Permission.

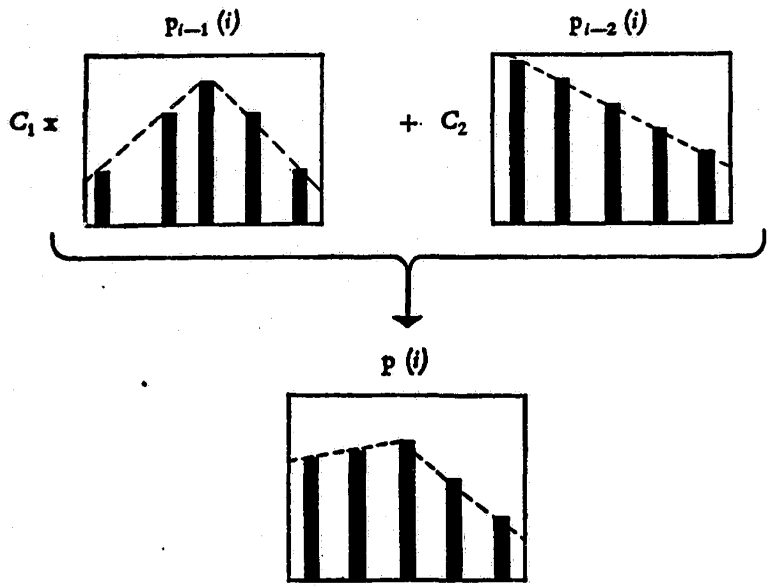


Fig. 28. COMPUTER CANTATA: matrix system for conditional stochastic probabilities. In Hiller: "Informationstheorie und Computermusik", p. 56. Used by permission.

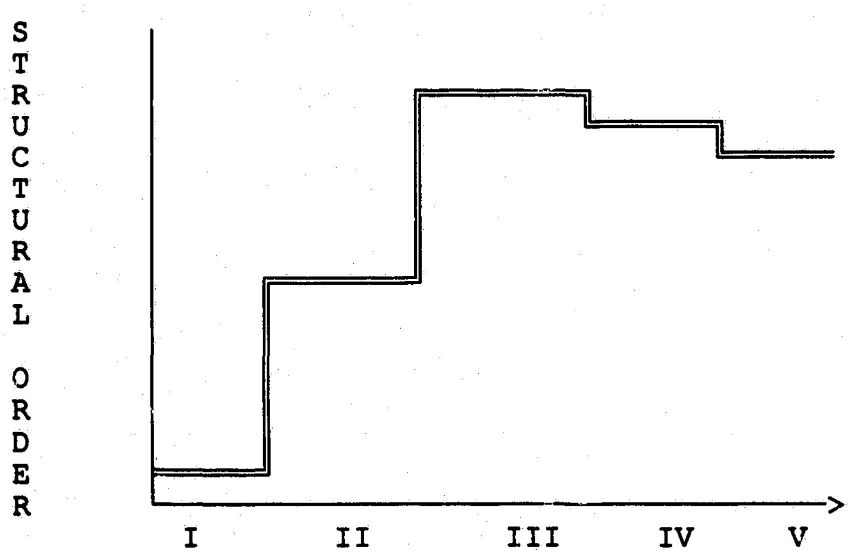
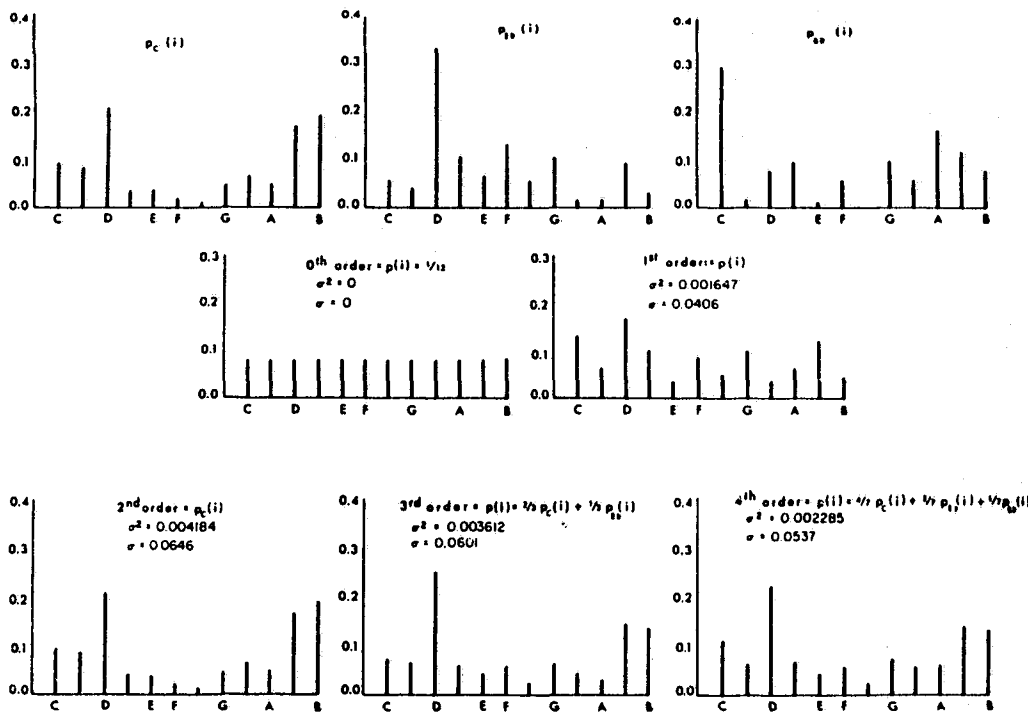


Fig. 29. Graph of approximate amount of structural order in COMPUTER CANTATA. According to Hiller.



Tab. 11. Resultant distributions, zeroth-order through fourth-order, following the sequence, B_b-E_b-C. In Hiller, Computer Cantata. Used by Permission.

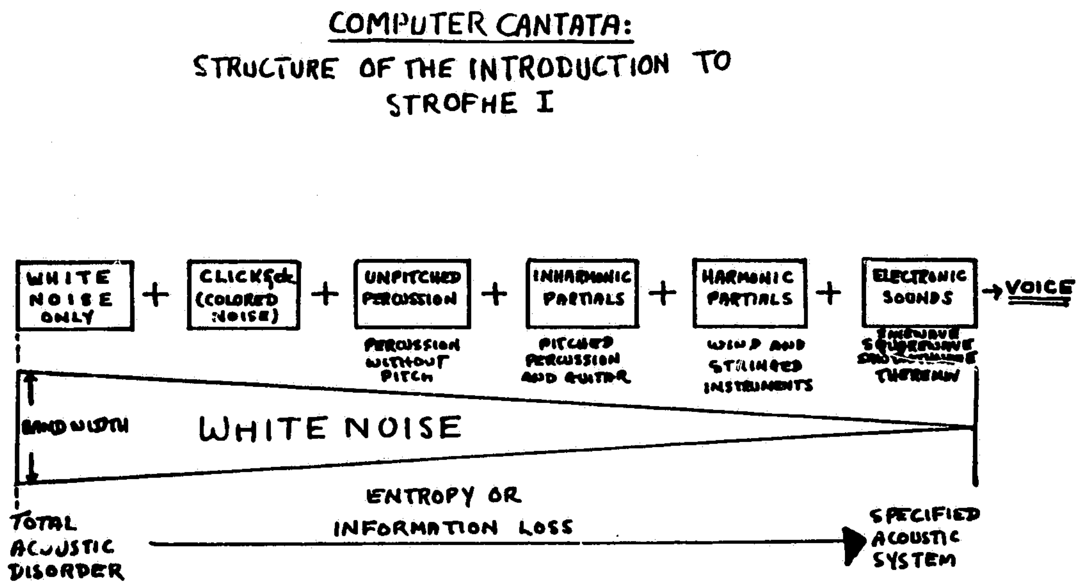


Fig. 30. Computer Cantata:[517] Structure of the Introduction to Strophe I. In, Hiller "Programming a Computer for Music Composition". Used by Permission.

[517]Lejaren Hiller: "Programming a Computer for Music Composition", in: Papers from the West Virginia University Conference on Computer Applications in Music, Gerald Lefkoff, Ed., Morgantown, 1967, p. 75.

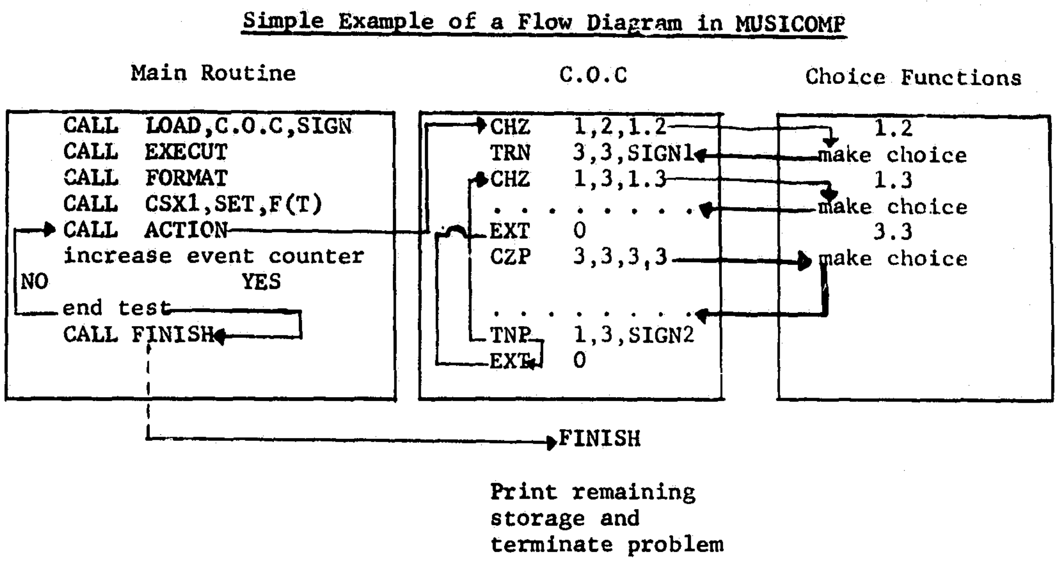


Fig. 31. Simple Example of a Flow Diagram in MUSICOMP. In Hiller: "Programming a Computer for Music Composition", p. 69. Used by Permission.

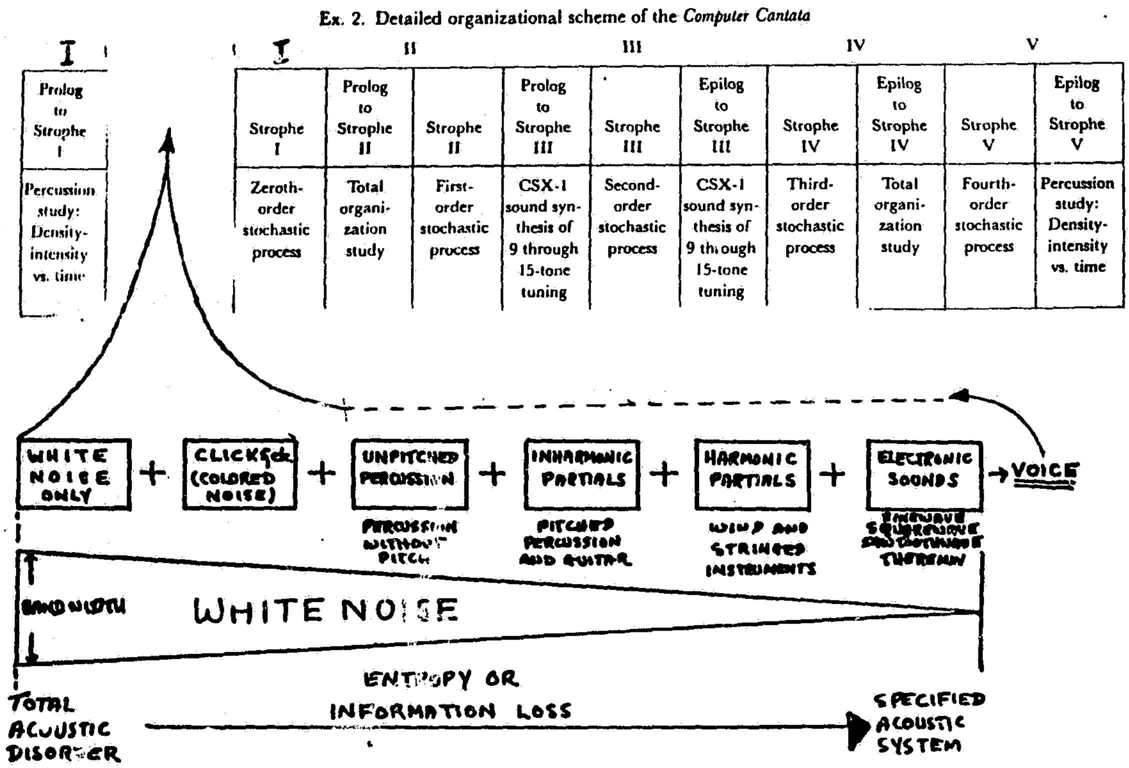


Fig. 32. Prologue to Strophe I in relation to the COMPUTER CANTATA in terms of information theory. Used by Permission.

SK = Sine complexes (showers of sine tones with defined frequency, duration and intensity in a very complex rhythmic micro-structure);

IK = impulse complexes (showers of impulses as SK);

LS = sounds and syllables;

R = noise filtered to about 2% wide (in Hz);

I = single impulses;

SV = synthetic vowel sounds (spectra, rich in overtones in various formant-combinations);

RO = noise filtered 1-6 octaves wide;

IO = showers of impulses of statistically fixed density, filtered 1-6 octaves wide;

IA = single impulses in chords (in each case, pitches of used scales);

RA = chords from 2% (Hz) wide noise bands (middle pitches according to the scale);

SA = sinus tone chords (or mixtures in unharmonic types of scales, sounds as boundary case in harmonic scales);

GA = sung chords (combined vocal sounds).

Table. 12. Stockhausen's table of sonic elements, ordered according to methods of analytical phonetics. In Stockhausen: "Texte II", pp. 64-65.

A	–	SK											
B	–	"	IK										
C	–	"	"	LS									
D	–	"	"	"	R								
E	–	"	"	"	"	I							
F	–	"	"	"	"	"	SV						
G	–	"	"	"	"	"	"	RO					
H	–	"	"	"	"	"	"	"	IO				
I	–	"	"	"	"	"	"	"	"	IA			
J	–	"	"	"	"	"	"	"	"	"	RA		
K	–	"	"	"	"	"	"	"	"	"	"	SA	
L	–	"	"	"	"	"	"	"	"	"	"	"	GA
M	–		"	"	"	"	"	"	"	"	"	"	"
N	–			"	"	"	"	"	"	"	"	"	"
O	–				"	"	"	"	"	"	"	"	"
P	–					"	"	"	"	"	"	"	"
Q	–						"	"	"	"	"	"	"
R	–							"	"	"	"	"	"
S	–								"	"	"	"	"
T	–									"	"	"	"
U	–										"	"	"
V	–											"	"
W	–												"
X[518]	–												

Table. 13. Ordering of sonic elements, serial scheme. In Stockhausen: "Texte II", pp. 64-65.

[518]Stockhausen writes that "X" receives a structure with a special definition resulting from the total plan of the work. In Stockhausen, Texte II, op. cit., p. 65.

The sequence of the matrix below could be folded over to create an endless cycle (as Stockhausen has done in ZYKLUS):

A	–	SK											
B	–	"	IK										
C	–	"	"	LS									
D	–	"	"	"	R								
E	–	"	"	"	"	I							
F	–	"	"	"	"	"	SV						
G	–	"	"	"	"	"	"	RO					
H	–	"	"	"	"	"	"	"	IO				
I	–	"	"	"	"	"	"	"	"	IA			
J	–	"	"	"	"	"	"	"	"	"	RA		
K	–	"	"	"	"	"	"	"	"	"	"	SA	
L	–	"	"	"	"	"	"	"	"	"	"	"	GA
M	–		"	"	"	"	"	"	"	"	"	"	"
N	–			"	"	"	"	"	"	"	"	"	"
O	–				"	"	"	"	"	"	"	"	"
P	–					"	"	"	"	"	"	"	"
Q	–						"	"	"	"	"	"	"
R	–							"	"	"	"	"	"
S	–								"	"	"	"	"
T	–									"	"	"	"
U	–										"	"	"
V	–											"	"
W	–												"
X	–	------------------------------------											
A	–	SK											
B	–	"	IK										
C	–	"	"	LS									
D	–	"	"	"	R								
E	–	"	"	"	"	I							
F	–	"	"	"	"	"	SV						
G	–	"	"	"	"	"	"	RO					
H	–	"	"	"	"	"	"	"	IO				
I	–	"	"	"	"	"	"	"	"	IA			
J	–	"	"	"	"	"	"	"	"	"	RA		
K	–	"	"	"	"	"	"	"	"	"	"	SA	
L	–	"	"	"	"	"	"	"	"	"	"	"	GA
M	–		"	"	"	"	"	"	"	"	"	"	"
N	–			"	"	"	"	"	"	"	"	"	"
O	–				"	"	"	"	"	"	"	"	"
P	–					"	"	"	"	"	"	"	"
Q	–						"	"	"	"	"	"	"
R	–							"	"	"	"	"	"
S	–								"	"	"	"	"
T	–									"	"	"	"
U	–										"	"	"
V	–											"	"
W	–												"

Table. 14. Possible arrangement, ordering of sonic elements.

VOWELS		VOICED CONSONANTS		UNVOICED CONSONANTS		FINAL SOUNDS (HARD-SOFT)	
ju-	[u]	tuj	[j:]	-wig	[ ]	jep	[p]
belt	[ ]	ult	[l:]	Preis	[s]	Lob	[b]
dem	[e]	-ren, dem	[n,m:]	Reif	[f]	Werk	[k]
Herrn	[ ]	Her-	[r:]	-belt	[t]	Tag	[g]
all	[a]	Wer-	[v:]	-ze	[ts]	preist	[t]
ihr	[i]	-set	[z:]	Scha-	[ ]	Wind	[d]

Table 15. Example of phonetic tabulation in Stockhausen's GESANG DER JUNGLINGE. Used by permission.

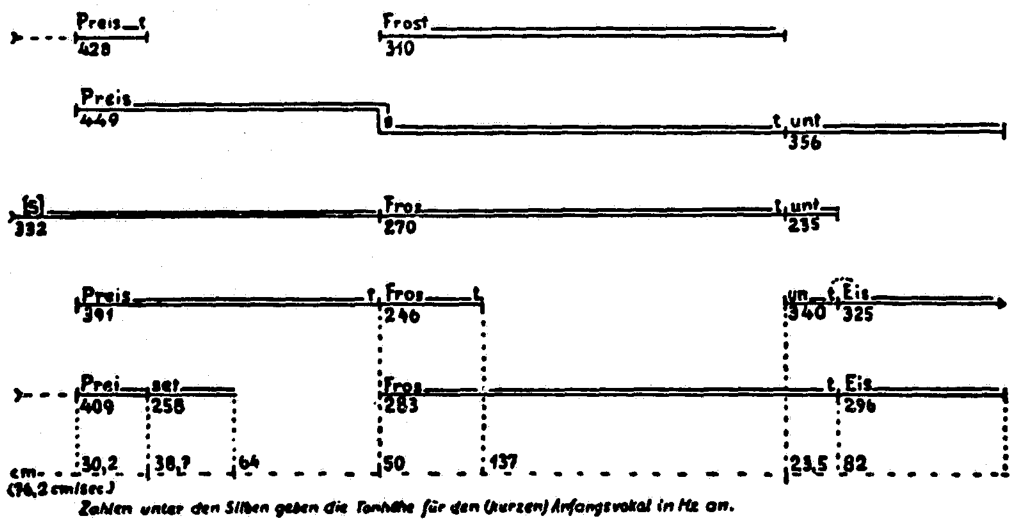


Fig. 33. Structural texture of LS-complex-I, Stockhausen: GESANG DER JÜNGLINGE. Used by permission.

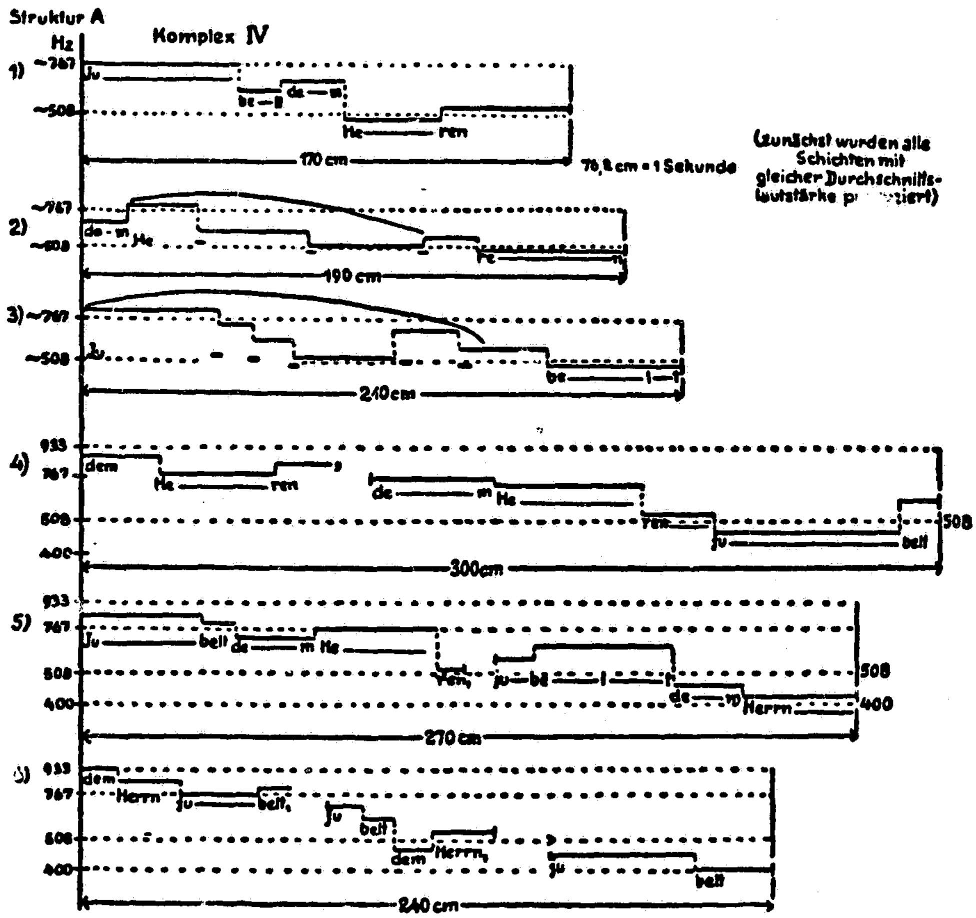
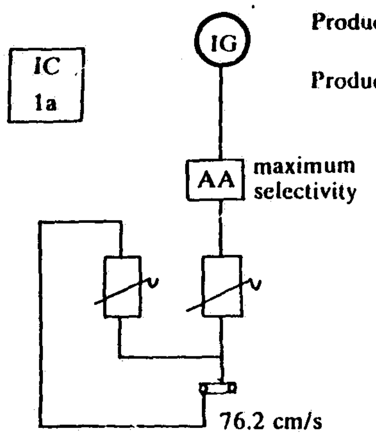


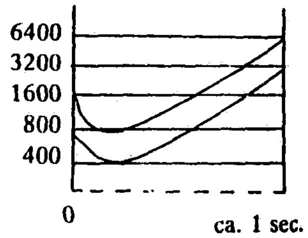
Fig. 34. Structural texture of LS-complex-II, Stockhausen: GESANG DER JÜNGLINGE.[519] Used by permission.

[519]Stockhausen Texte II, op. cit., p. 68.

Produce nine impulse-complexes (IC - 9)

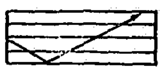
Produce 6 layers of impulses



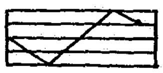


Vary impulse frequency irregularly between 6 and 12 impulses per second. Within the indicated AA frequency [illegible]ge, regulate the following AA filtercurves manually, and successively synchronise the 6 layers, each about 1 second in length, with a copy head.

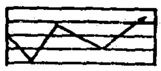
α) 2 layers 6400 Hz – 400



β) 2 layers 6400 Hz – 400



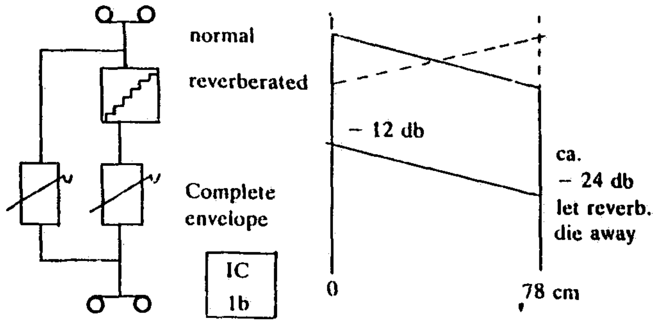
γ) 2 layers 6400 Hz – 400



These curves begin at various points between 800 and 1600 Hz, and similarly end at different points between 3200 and 6400 Hz; they cross over as often as possible.[1])

Fig. 35a. Production process used in three impulse-complexes (IC-1a,b,c) according to R. Toop. Used by permission.

The result, lasting approx. 1 second, is cut after 78.0 cm.
The result is produced in normal and reverberated form:



Produce and synchronise 5 impulse-layers as IC 1a.
AA-frequency range unaltered
Impulse frequency between 4/8 imp./sec. Duration ca. 5 sec.

• AA filter-curves over ca. 5 secs.

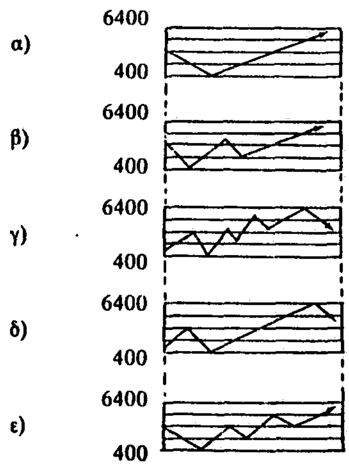
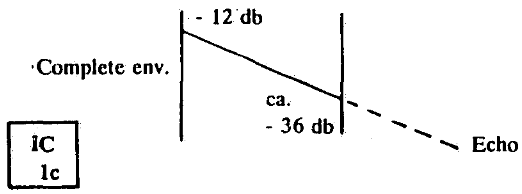


Fig. 35b. Production process used in three impulse-complexes (IC-1a,b,c) according to R. Toop. Used by permission.

- Cut result after 380 cm.
- Mix normal and reverberated, as IC_{1a}:



AA-frequency range unaltered.
Imp. frequency between 3 and 6 imp./sec. Duration ca. 7 sec.

- AA over ca. 7 sec., as IC_{1b} $\alpha-\varepsilon$, each pair of layers with same curve.
- Cut result after 512 cm.
- Mix normal and reverberated, as IC_{1a}:

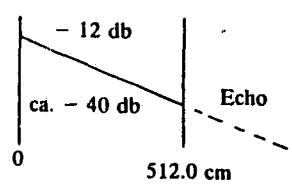


Fig. 35c. Production process used in three impulse-complexes (IC-1a,b,c) according to R. Toop. Used by permission.

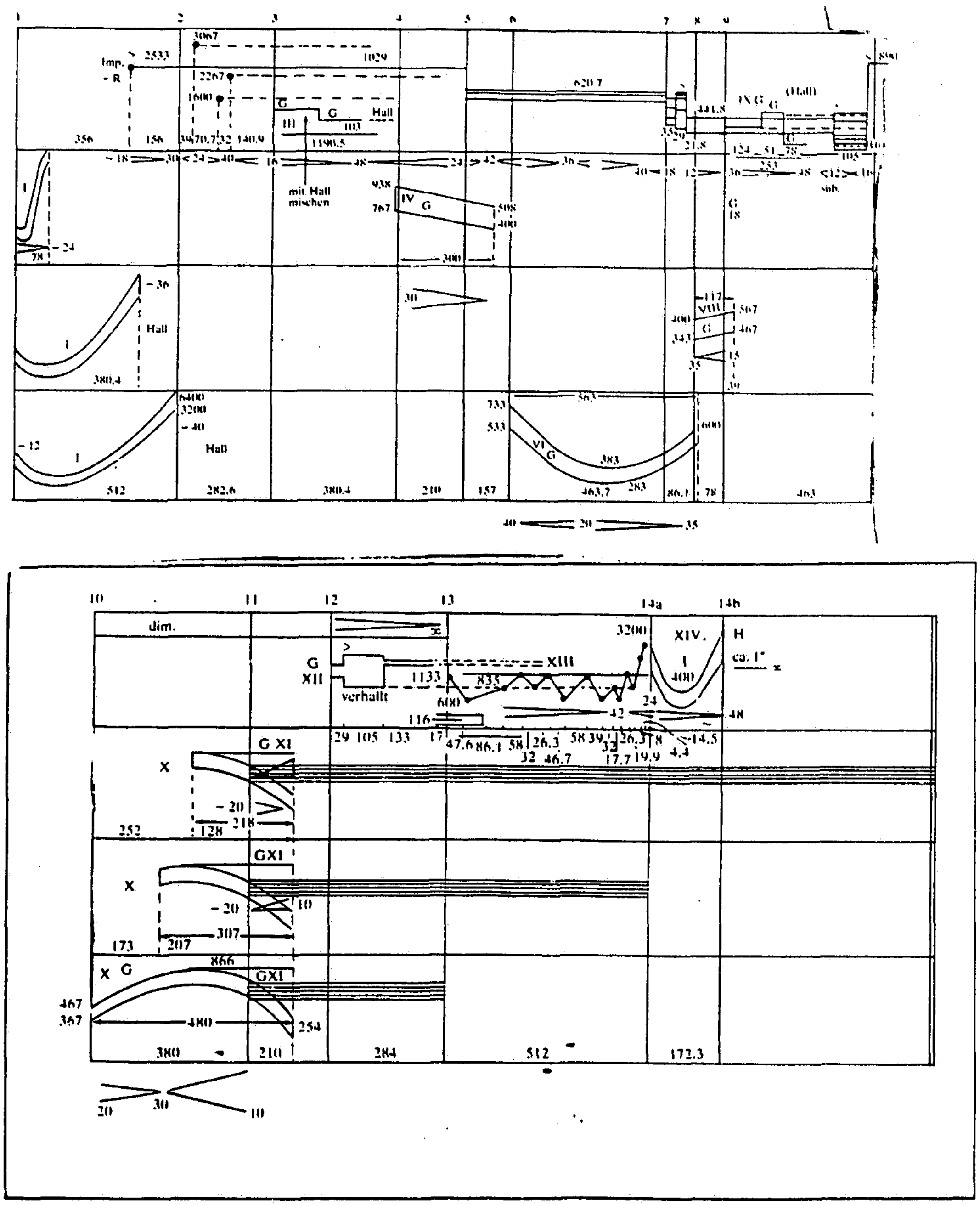


Fig. 36. GESANG DER JÜNGLINGE: sample of pages one and two of score (according to Richard Toop). Statistical 'impulse-showers' are indicated by curved outlines in this four-layer score; straight lines and dots signify precise pitches. 'Hall' means 'Nachhall', i.e. reverberation; 'verhallt' means 'reverberated'. Five-line staves indicate material which is spoken or sung. c Universal Edition AG Wien. Reproduction in Robin Maconie, "The Works of Karlheinz Stockhausen", 2nd edition, Oxford, 1990, p. 60.

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