AN ABSTRACT OF THE THESIS OF

Karen S. Piepmeier for the degree of Doctor of Philosophy in Educational Foundations presented on April 1, 1987

Title: Determining Readability by Computer Analysis Using the Fourier Transform to Calculate the Spatial Frequencies of Words

Abstract approved: Redacted for privacy

Kenneth M. Ahrendt

The black and white pattern formed when an individual word is printed on a page was analyzed by the Fourier transform. The Fourier transform produces a sequence of sinusodial functions, usually called spatial frequencies, whose amplitudes depend upon the particular pattern analyzed. These amplitudes were examined to determine if the amplitudes of the spatial frequencies with particular frequencies indicated a level of readability.

An extensive literature search indicated that there were no studies using the Fourier transform to study the readability of words. There were, however, many studies that indicated a renewed interest in a fast and easy method of determining readability.

Words for this study were randomly chosen from Dale's 769 Word List, easier words, and Fry's word list of Spelling Demons, harder words. The data from the statistical analysis of the amplitudes of the spatial frequencies of these words correctly predicted whether the word was on the hard list of words or on the easy list of words with over 80 percent accuracy.

Determining Readability by Computer Analysis Using the Fourier Transform to Calculate The Spatial Frequencies of Words

by

Karen S. Piepmeier

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed April 1, 1987

Commencement June 1987

APPROVED:

Redacted for privacy

Associate Professor of Educational Foundations in charge of major

Redacted for privacy

Head of Department of Educational Foundations

Redacted for privacy

Dean of School of Education

Redacted for privacy

Dean of Graduate School

Date thesis is presented April 1, 1987

Typed by author Karen S. Piepmeier

ACKNOWLEDGEMENT

To Dr. Kenneth M. Ahrendt, with sincere appreciation for his never failing encouragement and expertise; to Dr. Edwin Strowbridge, my department chairman, for his help and support; to Dr. Charlotte Hendrick, an outstanding graduate representative; to Dr. Richard Forcier, and Dr. Linc Kessler for their contributions on my committee.

To my husband, Dr. Edward H.Piepmeier, for his loving support of my work; to my daughter, Kristen S. Piepmeier for her inspiration, help and patience; to my son, Eric S. Piepmeier for his steadfast encouragement, help and understanding; to my son Edward H. Piepmeier, Jr. for his support and earnest faith that I would reach my goal.

To my Pastor, John Dennis for helping me to meet my personal challenges and leading me to understand that this has all been accomplished with God's loving help.

TABLE OF CONTENTS

INTRODUCTION	1
Purpose of the Study	1
Relevance of the Study	2
Spatial Frequencies of a Word	5
Limitations	8
Definitions of Terms	9
REVIEW OF RELATED RESEARCH AND LITERATURE	11
Readability	11
Word Lists	12
Word Recognition	13
Summary	14
Presentation of Hypotheses	14
RESEARCH DESIGN	16
Methodology	16
Analysis Procedures	17
Sample	18
Method of Analysis	19
Design Matrix	20
ANALYSIS OF DATA	21
Data Entry	22
Method of Analysis	29
Summary	35
SUMMARY, ANALYSIS OF FINDINGS AND RECOMMENDATIONS	37
Summary	37
Recommendations	38
BIBLIOGRAPHY	41
APPENDICES	43

LIST OF FIGURES

Figure		Page
1.	Figure 1. a) a sine wave, and b) a horizontal sine wave H, a vertical sine wave V, and two other sine waves at other angles (45 degrees).	7
2.	Copy of the computer screen showing the grid used to input the shape of the letters.	24

LIST OF TABLES

Table		Page
1.	Design Matrix	20
2.	A Center Section of the Fourier Transform Amplitude Table for the Word "Season."	26
3.	Analysis of Frequency Amplitudes	30
4.	Results of Multivariant Analysis (MANOVA)	31
5.	Results of Univariate Tests	33
6.	Predictive Values	34
7.	Classification Matrix	36

DETERMINING READABILITY BY COMPUTER ANALYSIS USING THE FOURIER TRANSFORM TO CALCULATE THE SPATIAL FREQUENCIES OF WORDS.

INTRODUCTION

Purpose of the Study

The purpose of this study was to analyze words using the Fourier transform to mathematically synthesize the spatial frequencies of a printed word and to determine if the amplitudes of the spatial frequencies indicated a level of readability. Words from Dale's 769 Word List (Harrison, 1980, pp. 160) and Fry's Word List of Spelling Demons (Fry, 1984 pp. 56) were analyzed. In determining the readability of a passage the words on Dale's list are considered to be less difficult than the words that are not on the list. Dale's 769 Word List was chosen because it is used not only in the Dale/Chall Readability Formula but also in the Spache Readability Formula to indicate the level of difficulty of words in a reading passage. The Dale/Chall formula is one of the two formulas that is used most often to test readability (Duffy, Roehler, and Mason, 1984, pp. 129). The Spache Readability Formula is not only one of the most recently developed readability formulas but is also considered to be sensitive through the middle school or approximately thirteen years of age (Harrison, 1980, pp. 114). Fry's list of words was chosen because they are difficult words for secondary students. Since readability formulas are word based, and predictions about the difficulty of the material to be read are based on the number of words which will be difficult for the reader, this one aspect of analysis, a pattern analysis of words found in readability lists was chosen for examination.

Relevance of the Study

Recent research studies such as Readability in the Classroom (Harrison, 1980), Orthography and Word Recognition in Reading (Henderson, 1982), and the chapter entitled "Readability" in the Handbook of Reading Research (Pearson, 1984), indicate a dramatic renewal of interest in readability formulas and word recognition. Several recent research studies: "Assessing Readability Formulas and Alternatives", and "A Readability Review: Important Trends since 1979" further attest to a renewed interest in a method of determining readability that is both convenient and a reliable indicator of the difficulty of reading material. To help meet this need, new mathematical software, available for personal computers, has made it possible to use the Fourier transform to investigate an important aspect of readability, the amplitudes of the spatial frequencies associated with the black and white patterns of words.

The Fourier transform was chosen as the method of analysis of words based on the work of Karl Pribram and others. In an interview, Pribram stated:

> "...Fourier analysis ...is a form of calculus that transforms a complex pattern into its component sine waves. Helmholtz showed that this kind of analysis could explain the functioning of the auditory system. Then an entirely different line of research, done in Russia by N. Bernstein in the 1930's, showed the same type of analysis fit the motor [nerve] system."
>
> "In 1968 or so, I got a note from Fergus Campbell at Cambridge University. His group had just shown that the visual system also worked as a frequency analyzer for patterns."
>
> "It's not that cells in the visual system are detecting only a certain line. What they respond to is the patterns of shadow and light. Everywhere one looks there are light and dark areas. It is these areas the eyes take in and transmit to the visual cortex. The light-to-dark alternations are measured in terms of spatial frequency--whereas the auditory signal is measured in terms of a temporal frequency. Cells in the visual cortex are frequency analyzers; they fire in response to a particular spatial frequency. With visual patterns, the alternations are rather complex, but the Fourier theorm says that no matter how complicated a wave form is, you can break it down into its component sine waves."
>
> "Russell Devalois at Berkeley has recently performed a critical experiment. He mathematically converted a plaid pattern into the Fourier domain by computer and then recorded how the cells in the visual cortex responded to the same plaid. David Hubel and Torsten Wiesel at Harvard Medical School had shown in the late 1950s that those cells are selective of certain spatial patterns. DeValois pointed out that the plaid pattern and its Fourier transform are different. What he found was that the cells were selective for the Fourier transform of the plaid, not the pattern of the original plaid itself."
>
> "By now, evidence from a half-dozen laboratories from Leningrad and Cambridge to Harvard and Berkeley; and our own laboratories at Stanford, supports the conception that this is how the visual system does, in fact, work." (Goleman, 1979, pp. 74)

If, as suggested, cells respond to the Fourier transform spatial frequencies of a pattern, rather that to the pattern itself, then it may be that the readability of a word depends on these spatial frequences. The ability of the eye and mind to respond correctly to these frequencies might determine whether a word is easily recognized.

The spatial frequency generally refers to the number of times per centimeter a pattern is repeated. If the pattern is repeated along a printed line, then the frequency is called a horizontal frequency. If the pattern is repeated in a vertical direction, then the frequency is called a vertical frequency. For example, consider a page that has been typed full of the letter "l" with an elite typewriter using single spaced lines. Letters of elite type are repeated with a fundamental horizontal frequency of 12 letters per inch, and the single spaced lines are repeated with a vertical frequency of 6 lines per inch. If the letter "l" is repeated close together, the fundamental horizontal spatial frequency would be higher than if they were spaced farther apart. As the letter "l" is placed closer and closer together, the image blurs. This point at which the eye can no longer see each letter demonstrates the highest spatial frequency that the eye can discern (Beck, Hope, Rosenfeld, 1983, pp. 386). Each cell in the sensory membrane of the eye is a detector that receives part of the image formed by the lens. The highest frequency that the eye can discern is determined approximately by the spatial frequency (cells per centimeter) of the cells in the retina.

As indicated in Pribram's quotation above, transforming a visual pattern (such as a printed word) into its spatial frequencies is analogous to transforming music into its different temporal frequency components. A person's hearing is analyzed in a doctor's office by determing the volume (amplitude) of different notes (frequencies) that the patient can hear through a set of earphones. The ability to observe high spatial frequencies can be approximately measured in the ophthalmologist's, optician's or optometrist's office by an eye chart. The letter "E" is often used to examine the patient's ability to discern with the eyes both vertical and horizontal spatial frequencies. Smaller letters on the eye chart test the ability of the eye to detect higher frequencies. At times the eye, like a sound system that is not very good, may reject the higher frequencies and produce a visual image that looks like it is out of focus. Even when the eye is able to focus clearly there are some high frequency patterns that the eye does not distinguish. For example, a television picture that is made up of separate horizontal lines looks like a smooth picture to the viewer, except when examined immediately adjacent to the television screen. The fundamental vertical spatial frequency of the closely spaced horizontal lines is too high for the eye to distinguish the lines separately.

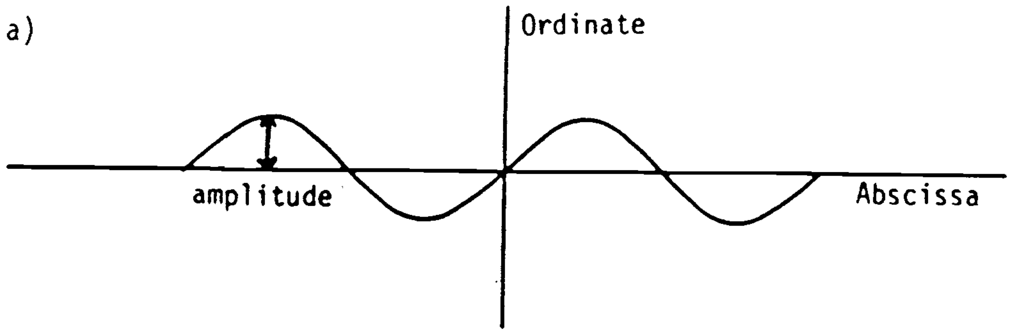
Spatial Frequencies of a Word.

The Fourier transform of a pattern calculates a sequence of sinusoidal functions of different frequencies whose amplitudes (strengths) depend uniquely upon the particular pattern analyzed. The amplitudes for the various frequencies depend uniquely upon the particular pattern analyzed. In keeping with the literature (Goleman, 1979) the phrase "spatial frequencies of a word" will be understood to mean the sinusoidal functions that are calculated when the Fourier transform is applied to the light and dark pattern of a printed word. The "amplitudes of a spatial frequency" will be understood to mean the amplitude of the sinusoidal function having that frequency.

Figure 1a shows the shape of a sinusoidal function. This shape is known as a sine wave. The horizontal axis of the plot in Figure 1a is distance if the sine wave represents a spatial frequency, and is time if the sine wave represents a temporal frequency (musical). Notice that the shape of a sine wave is an infinite repetition of the pattern of a hill followed by a valley. The frequency of the sine wave is the number of times per centimeter that this hill-valley pattern is repeated if the sine wave represents a spatial pattern. If it represents a temporal pattern (musical note) then the frequency is the number of times per second that the hill-valley pattern is repeated. The amplitude is shown by the vertical arrow as the height of a hill (or also the depth of the valley.)

The sinusoidal functions produced by the Fourier transform represent sine waves that go horizontally across the word, vertically down the word, and at other angles across the word. Figure 1b shows sine waves that go in four different directions.

a)



b)

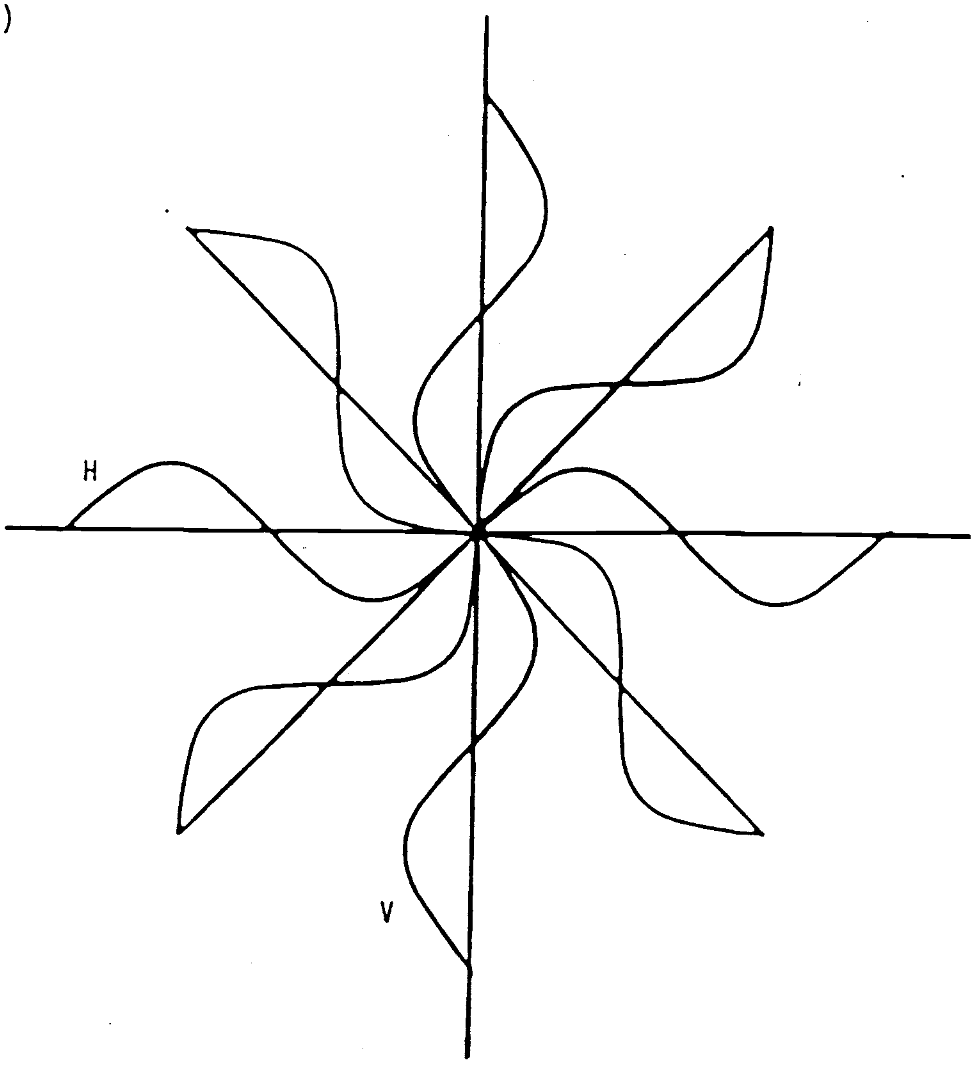


Figure 1. a) a sine wave, and b) a horizontal sine wave H, a vertical sine wave V, and two other sine waves at other angles (45 degrees).

Limitations

There were three major limitations in this study. First, the computer program limited the size of the words that could be entered. No word larger than ten letters could be entered in the matrix. Since the words that were randomly chosen in this study happened to be not longer than ten letters, this was not a problem. Further research will in all probability need a program that can process all the different lengths of words in the language being studied. Secondly, two lists were analyzed. Many lists of words should be studied and determinations made not only between two levels, but also for many difficulty levels, for example, the word lists in basal readers. Third, a personal computer was used rather than a main frame computer. With the additional space on a main frame, more data on each word could be analyzed. In addition, phrases, sentences, paragraphs and pages might be able to be entered on a main frame and analyzed in this manner.

Definitions of Terms

For the purpose of clarifying terms used in the study, the following definitions were used:

Amplitude: One half of the height of a sine wave from its highest peak to its lowest valley.

Computer Analysis: The use of a data processor to perform substantial computation, including numerous arithmetic operations or logic operations using a program that will input data and display results.

Fourier Transform: A calculus equation that transforms a pattern into component sine waves.

Frequency: The number of repetitions per unit time.

Level of Readability: The term readability refers to the ease of reading. The readability level is quantified on a single scale by a variable.

Readability Formula: A predictive device intended to provide quantitative and objective estimates of reading difficulty. Readability is partially predicted by using lists of words of various levels of difficulty, independently determined by research and observation in classrooms and reading clinics.

Sinusoidal Function: The trigonometric function that for an angle is the ratio between the side opposite the angle when it is considered part of a right triangle (a triangle with one 90 degree angle) and the hypotenuse of the right triangle (its longest side).

Sine Wave: The smooth oscillatory pattern that occurs when the sine function of an angle is plotted on the vertical axis and the angle itself is plotted on the horizontal axis.

Spatial Frequency: The number of times per centimeter that a pattern is repeated.

Spatial Frequencies of a Word: The frequencies of the sinusoidal functions that are calculated when the Fourier transform is applied to the light and dark pattern of a printed word.

Word List: A group of words with similar characteristics, often tabulated from the frequency with which words occur in print and/or can indicate the difficulty of recognition and understanding.

Word Recognition: The ability of the reader to discern, identify, a word. "Word recognition is a central presumably neural event taking place in the eyes, optic nerves and brain" (Pearson, 1984, pp. 226)

REVIEW OF RELATED RESEARCH AND LITERATURE

This section contains a discussion of recent research on readability, word lists and word recognition.

Readability

Readability, the ease of reading material, has been assessed by numerous readability formulas (Allen, 1985, pp.216). These formulas have recently been studied to determine which factors, such as words, syllables and/or sentences, are most important and what other factors, such as context, might be just as important, if not more important. George Klare presents an excellent account of past and recent readability research which includes a survey of the history and development of readability in Chapter 22, entitled "Readability", in the Handbook of Reading Research (Pearson, 1984). Klare traces the development of word lists from the first lists of frequent words, to ones that are more complex, and finally to the word lists presently used in determining readability.

Since the early 1900's many new readability formulas have been developed. Most formulas are based on sentence length, syllable length, and/or word lists. "By 1973, formula developers had tried well over 200 different language variables and had, in fact, developed almost as many different formulas," (Pearson, 1984, p. 688). Recently developed formulas have been designed for a specific language (i.e. foreign language, a content area vocabulary).

Readability formula validity has been examined and agreement has been found between formula results and the judgment of teachers and students of particular reading material (Klare, 1963. pp. 139). Readability formulas appear to be convenient methods to predict the readability of reading materials and the use of word lists appears to be an accurate factor in determining readability (Pearson, 1984, p. 702).

In the past decade, computer programs have been written to enable teachers to use easily and quickly some of these complicated readability formulas. The Spache Formula, used in computer form by The Reading Center at Reading University in Great Britain is considered to "...be the best for middle and upper junior school analyses." The vocabulary factor is considered "...a sensitive one," (Harrison, 1980, p. 114). The Spache formula uses a percentage of words on the Dale 769 word list as a factor in determining readability. Difficulty of reading material is then determined, in part, by the number of words that are considered difficult to read.

Word Lists

Word lists have been created to divide words into categories of difficulty, because the difficulty of vocabulary has commonly been considered the most important factor in the level of difficulty of reading material. Word length, word frequency, and letter patterns have been examined. The Reading Teacher's Book of Lists (Fry, 1984) contains over a hundred word lists composed of words that are used most frequently in the spoken or written language in different circumstances. By determining how many of the words in a reading passage are in a particular word list, an indication of the number of words that may be difficult or the vocabulary load can be determined. Word lists are used in readability to indicate the words that are easy to read by most students at a certain age or grade level.

Word Recognition

Word recognition studies are characterized by Gough in the Handbook of Reading Research:

> "The student of word recognition must begin by acknowledging that it cannot be studied directly. Word recognition is a central, presumably neural, event taking place in the eyes, optic nerves, and brain. We do not know what form it takes there, so we cannot observe or directly measure its occurrence. (Pearson, 1984, pp. 226)

Leslie Henderson in her book Orthography and Word Recognition looks at word recognition in terms of translating print into sound (Henderson, 1982). The results of research by five separate investigators of orthographic structure and visual processing indicates that "...orthographic structure is an important component in letter and word recognition..." (Massaro, et al. , 1980, pp. 248). The authors examined the redundancy of letters, and the phonological and spelling constraints of words in English. Teaching children to recognize common letter patterns and locations of these patterns in words was recommended and thought to be "...beneficial in the development of reading instruction." The authors further state that "Delineating the best description of orthographic structure might facilitate the teaching and learning of this structure" (Massaro, et al., 1980, pp. 248).

Summary

The review of the literature revealed that there are discernible antecedents relative to readability, that readability formulas are a valid determiner of reading difficulty and word lists are a valid indicator of word difficulty. Numerous readability formulas have been developed in the past decades. These readability formulas have used word lists to predict the difficulty of the material to be read. Word recognition studies have looked at the patterns in words as important in teaching children to recognize words. However, extensive review of the literature revealed that no research was available on using the Fourier transform to analyze words and determine their readability.

Presentation of Hypotheses

Two hypotheses are fundamental to the research proposed. The first is that all words have different graphic patterns that can be analyzed using the spatial frequencies calculated by the Fourier transform. Second, is that the difficulty of a word is indicated by the amplitudes of the spatial frequences generated by the Fourier transform. Therefore, this study could indicate that spatial frequency and readability can be determined by computer analysis of word lists using the Fourier transform.

The null hypotheses are listed below.

1. There is no significant difference between words using the data from the Fourier transform.

   H1 : M1 = M2

2. There is no significant difference between the two word lists under study using the data from the Fourier transform.

   H2 : ML1 = ML2

RESEARCH DESIGN

Methodology

The purpose of this study was to use the Fourier transform to analyze printed words to determine if the mathematically synthesized spatial frequencies indicated a level of readability. Words on Dale's 769 word list (Harrison, 1980, pp. 160) and Fry's Spelling Demons word list (Fry, Polk & Fountoukidis, 1984, pp. 56) were analyzed to determine if there was a difference in the amplitudes of the spatial frequencies of the words on the lists, and if there was a greater difference between the words on different lists than there was between words within each list. The review of the literature indicated that word lists are a valid indicator of the readability of a written passage and that words are placed on word lists according to their difficulty. Further, an extensive search of the literature did not reveal any research available using the Fourier transform to analyze words or to determine their readability by analyzing their spatial frequencies.

Since readability formulas are word based and predictions about the difficulty of the material to be read are based on the number of words which will be difficult for the reader, this aspect of the spatial frequencies of words in readability lists was examined. Recently developed technology enabled the researcher to conduct this study.

Analysis Procedures

A study of this additional aspect of determining readability was made feasible by new mathematical software that is available for personal computers. A mathematical formula, the Fourier transform, allowed the researcher to identify the spatial frequencies of each word. The group of spatial frequencies, calculated by the Fourier transform, usually contained a series of sine waves with higher and higher frequencies and lower and lower amplitudes. These spatial frequency patterns were examined to determine if there was a correlation between the frequency patterns and the word lists, using the Dale 769 word list and Fry's Spelling Demons word list.

New mathematical software called ASYST (Macmillan Software Company, New York, New York, 1985), available for personal computers, made it feasible to conduct this study. An IBM - PC with an 8087 coprocessor, required by ASYST, and an EPSON FX - 80 dot matrix printer were used.

A comparison was made between the Fourier transform generated spatial frequency amplitude patterns of a random sample of words from Dale's word list of easy words and the patterns of a random sample of words from Fry's word list of more difficult words. The Dale word list (Appendix I), from the Dale-Chall Formula and the Spache Readability Formula, was used in this study and compared with a list of more difficult words from Fry's list of Spelling Demons-195 Words Misspelled by Secondary Students (Appendix II). The words on the Dale word list are those "best known by American eight-year-olds"(Harrison, 1980, pp. 57). Since the Dale-Chall formula is currently one of the most used readability formulas and the Spache formula is the most recently developed readability formula, the word list used in both of these formulas was chosen for analysis (Harrison, 1980, pp. 114). Fry's list of Spelling Demons was chosen because it contained words that secondary students find difficult to spell, in addition to not being on the Dale's list of easier words. The study examined the Fourier transform generated amplitudes of the spatial frequencies of the words on each list to determine whether the differences between the spatial frequencies of the words on the two different word lists were greater than the differences of the spatial frequencies within the word lists.

Sample

The sample size was 25 words randomly chosen from each word list, as recommended in the Handbook in Research and Evaluation (Isaac, Michael, 1983, pp. 96). This random sample of words was chosen using a random number table, Table 26.11, 2500 Five Digit Random Numbers, from The Handbook of Mathematical Functions with Formulas, Graphs and Mathematical Tables, Milton Abramowitz and Irene A. Stegun, editors, (Abramowitz, Stegun, 1965, pp. 991).

For the first word list, the first 25 numbers from the random number table were used. For the second list the next 25 numbers from the random number table were used. Each number from the table was considered to be a fraction (from 0 to 1). This fraction was multiplied by the total number of words in the list. The resulting number was used as a sequence number to identify a word in the list. A word so identified became one of the words in the random sample. The words that were chosen from the Dale word list were: have, round, sat, noise, walk, eight, jump, tail, wish, waste, sold, quiet, hair, season, the, cake, yard, war, mind, storm, wonder, broken, oak, heavy, and here. The words that were chosen from the more difficult word list were: shoulder, yacht, professor, height, sense, beneficial, definition, concede, writing, license, thorough, experience, guidance, sergeant, incredible, preferred, saucer, benefited, athlete, disastrous, leisurely, stationary, cite, moral, and council. These words were then analyzed using the Fourier transform to find the amplitudes of the spatial frequencies of each word.

Method of Analysis

The principle statistical methods used in this study were univariate F tests with (1, 48) degrees of freedom and the multivariate (MANOVA) analysis. An analysis was made between word lists and within word lists of the amplitudes of the spatial frequencies for each randomly chosen word. The matrix design used for analysis of the data is shown in Table 1. This matrix lists each word and the list that the word is from. List 1 is the Dale's list of easier words and list two is Fry's harder word list. Amplitudes were recorded from the center amplitude, horizontal and vertical sine wave amplitudes, and a section of sine waves in all directions labelled Quad. These amplitudes were then analyzed to determine if they were significant in determining the readability of the words.

Table 1.

Design Matrix

Word	List	Amplitudes			
First word	1 or 2	Center	Horizontal	Vertical	Quad
Second word	1 or 2	Center	Horizontal	Vertical	Quad
to	"	"	"	"	"
Fiftieth word	1 or 2	Center	Horizontal	Vertical	Quad

The words, word lists, the instruments, and the procedures used in organizing this study have been described in this chapter. In the next chapter the data are presented and analyzed.

ANALYSIS OF THE DATA

The purpose of this study was to analyze words using the Fourier transform to mathematically synthesize the spatial frequencies of a printed word and to determine if the amplitudes of those frequencies indicated a level of readability. The Fourier transform, a mathematical formula devised by Fourier, was used to generate the numbers that were studied. The amplitudes of high frequencies and low frequencies of randomly sampled words from two word lists (easy and difficult) were compared to determine the similarities and differences among words in those word lists. The pattern of those frequency amplitudes and the levels of difficulty were compared to determine the correlations.

The list of easy words used was Dale's 769 word list (Harrison, 1980, pp. 160) and the list of difficult words used was Spelling Demons, 195 Words - Misspelled by Secondary Students (Fry, Polk, and Fountoukidis, 1984 pp. 56). The Dale word list is used in the Dale-Chall formula and the Spache Readability Formula. The words on the Dale word list are those "best known by American eight-year-olds " (Harrison, 1980, pp. 57). The word list used in both these formulas was chosen for analysis because the Dale-Chall Readability Formula is currently one of the most used readability formulas and the Spache

Readability Formula is the most recently developed readability formula (Harrison, 1980, pp. 114).

A word list from The Reading Teachers' Book of Lists was chosen to obtain more difficult words that were outside the Dale word list. The list chosen, Fry's Spelling Demons, 195 Words - Misspelled by Secondary Students contains words that are often misspelled indicating some higher degree of difficulty of recognition than the words on Dale's word list. The study examined whether the differences between the amplitudes of the spatial frequencies of the words in each list were greater than the differences among the words within each list using a random sample of 25 words chosen from each of the two word lists (Dale's Word List and Fry's word list).

Data Entry

In order for the computer to process a word, the word first had to be put into the computer in numerical form. This was done by using a table of numbers (zeros and ones) to represent the word. The table for a word was actually assembled from smaller tables, each of which represented a letter. Letters for the words were entered individually into the computer using the display on the computer terminal screen. A checkerboard like grid was drawn on the screen with each square on the grid corresponding to an entry in the table of numbers. (See Figure 2.) The grid was 32 squares high and 23 squares wide representing a table of 32 rows and 23 columns. Large Letter Gothic style letters were visualized as being superimposed on the grid. For each square that was covered by the letter, its table entry was given a value of 1. For all squares that were not substantially covered by part of the letter, the table entry was given a value of zero. Therefore the background, like white paper, is represented by 0's, and the pattern of 1's produces a picture of the letter being entered into the computer table.

Letter Gothic style letters were used because similar tables for a letter quality laser printer could be used with only minor changes. Also the widths of the lines in this widely used letter style are uniform, and less artistic manipulation was therefore necessary to produce acceptable looking letters. A line width of three squares was chosen because it produced an easily recognizable letter.

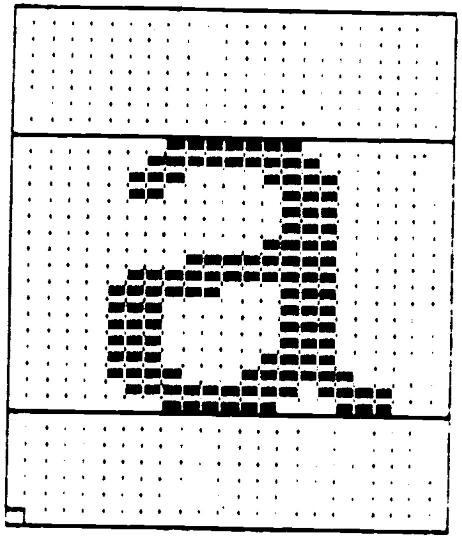
Words were made by combining the letter tables into a wider table, leaving fixed spacing (3 columns of zeros) between each letter in the word. The letters were thus positioned next to each other horizontally with spaces in between. The word was centered in the table. The top two rows and the bottom row were all zeros to simulate the white space that occurs between rows on a printed page. The word table was 256 columns wide and 32 rows long. This was the largest capacity that would fit into the computer's memory.

This technique of representing letters is used by dot matrix printers including letter quality laser printers. The squared edges of a letter appear to be smoothed out when reduced to the size of ordinary print. Within a factor of two, the print used in this study is as good as a letter quality laser printer, a printer whose letter quality matches that of a typewriter.

Font name:GOTHIC

Letter: a

32 HIGH BY 23 WIDE



---------------------MENU - Use ARROW keys to move cursor---------------------

F8 Fill in the box at cursor position F10 SAVE pattern on disk file

F7 Erase box at cursor position

F3 Put a letter from disk into REF. box

F4 Put a letter from disk into WORK box

F6 Change letter

F5 Replot dot grid

OK SCREEN.PRINT _

Figure 2. Copy of the computer screen showing the grid used to input the shape of the letters.

The words from the word lists were entered in this manner and stored in a computer disk file named "MATRIX 2". Words entered into the "MATRIX 2" file were then assessed using the Fourier transform. (See Appendix IV for the Fourier transform equation.) This assessment produced a table of amplitudes for each frequency and a graphic picture of the amplitudes. Table 2 shows part of a typical table of amplitudes. The actual table of amplitudes is 256 columns wide and 32 rows in length, the same size as the word table. (The equal size is a characteristic of the way the Fourier transform is calculated by ASYST.) The frequency for each table entry is proportional to the distance of the entry from the entry in the center of the table. Each sine wave also has a direction along which its horizontal axis points (Figure 1a). This direction on the printed page is the same as the direction along a line connecting the table entry with the entry in the center of the table. For example, the sine waves whose amplitudes are in the middle row, row 16, are horizontal sine waves, while those in the middle column, column 128, are vertical sine waves. For other entries the sine wave points in another direction, neither vertical nor horizontal.

To simplify the statistical analysis of the results, the 8,192 entries in the table were subdivided into seventeen groups. The amplitudes in each group were added together to produce a single number that was assessed by the statistical program. The first group (named Center) actually contained only one number, the table entry in the center of the table (e.g. the number 779 in row 16, column 128 in Table 2). This is the amplitude of a "zero frequency" sine wave.

Table 2

A center section of the Fourier transform amplitude table for the word "season". The original table has 256 columns and 32 rows.

Column: Row	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
1	15	17	12	14	16	11	4	9	11	7	7	13	13	8	9
2	12	30	28	22	21	10	28	38	25	7	13	14	20	17	3
3	4	21	31	28	18	5	7	12	9	3	15	21	17	8	1
4	2	8	20	22	11	5	11	9	7	2	9	14	9	1	4
5	3	4	4	2	1	1	8	13	11	6	2	6	11	11	5
6	5	3	15	18	9	7	11	7	10	9	2	8	9	7	7
7	11	20	21	12	5	14	43	59	48	22	4	6	16	16	7
8	7	18	22	11	9	13	12	18	21	18	16	18	21	16	5
9	4	9	9	8	2	26	54	59	35	5	27	24	3	15	20
10	14	13	33	43	25	20	50	56	45	33	14	15	22	12	30
11	17	38	40	58	48	49	167	233	191	79	12	31	42	40	16
12	4	37	40	12	32	49	90	137	134	74	17	32	38	45	12
13	6	26	14	42	43	59	134	152	89	19	56	45	17	12	9
14	25	14	19	7	15	17	63	86	66	40	42	28	21	38	37
15	48	66	11	99	90	96	344	447	314	78	97	66	38	58	23
16	28	110	40	138	152	142	573	779	573	142	152	138	40	110	28
17	23	58	38	66	97	78	314	447	344	96	90	99	11	66	48
18	37	38	21	28	42	40	66	86	63	17	15	7	19	14	25
19	9	12	17	45	56	19	89	152	134	59	43	42	14	26	6
20	12	45	38	32	17	74	134	137	90	49	32	12	40	37	4
21	16	40	42	31	12	79	191	233	167	49	48	58	40	38	17
22	30	12	22	15	14	33	45	56	50	20	25	43	33	13	14
23	20	15	3	24	27	5	35	59	54	26	2	8	9	9	4
24	5	16	21	18	16	18	21	18	12	13	9	11	22	18	7
25	7	16	16	6	4	22	48	59	43	14	5	12	21	20	11
26	7	7	9	8	2	9	10	7	11	7	9	18	15	3	5
27	5	11	11	6	2	6	11	13	8	1	1	2	4	4	3
28	4	1	9	14	9	2	7	9	11	5	11	22	20	8	2
29	1	8	17	21	15	3	9	12	7	5	18	28	31	21	4
30	3	17	20	14	13	7	25	38	28	10	21	22	28	30	12
31	9	8	13	13	7	7	11	9	4	11	16	14	12	17	15
32	14	10	5	15	17	9	37	51	37	9	17	15	5	10	14

This number seemed to be a measure of the numerical values assigned to the dark and white parts of the word table, dark = 1 and white = 0, as discussed above. This number changed, without changing any of the other amplitudes when dark = 0 and white = 1, or dark = 0.5 and white = -0.5.

Four groups were obtained from the middle row of Table 2. The amplitudes in this row were those of sine waves whose horizontal axis (Figure 1) points in the horizontal direction (along the printed line on which the word is written). The data in this row were subdivided into four groups (named Horz 1 through Horz 4) of essentially equal size (excluding the zero frequency table entry) starting in the center of the table and working to the right. The numbers in this row to the left of center are always the same as the numbers on the right and these numbers were therfore omitted. The next four groups (named Vert 1 through Vert 4) were obtained in a simillar manner from the lower half of the middle column of Table 2. These amplitudes were those of sine waves whose horizontal axis (Figure 1) points in the vertical direction. These data were also subdivided into four groups of essentially equal size (excluding the zero frequency table entry). These data were thought to be important because the amplitudes in the middle row and the middle column usually contained the largest amplitudes found in the tables, as observed from the graphical plots of the data. Also words are scanned horizontally by the eye, and the sine waves in the middle row of the table are pointed in the horizontal direction.

Finally, eight other groups of data were obtained in the following way. Two groups were obtained by identifying all table entries that were between the center of the table, zero frequency, and a frequency equal to one-fourth of the highest frequency. The first of these two groups (named Quad 1) contain all such frequencies whose horizontal axis pointed in any direction down and to the right of vertical. The other group (NQuad 1) contained all such frequencies whose angle axis pointed down and to the left of vertical. (Upward pointing directions contained redundant information; each entry in the upper part of the table was always equal to a corresponding entry in the lower part of the table.) In a similar manner, six more groups were identified, two for frequencies from one-fourth to one-half (Quad 2, NQuad 2), two for one-half to three-fourths (Quad 3, NQuad 3), and two for three-fourths to the maximum frequency (Quad 4, NQuad 4) for a total of eight such groups. These groups were chosen because they were grouped according to frequency and because they contained essentially all of the data (except for the entry in the center of the table, and entries at the far corners of the table).

Computer printouts of these sums, and also plots of the amplitudes for each word can be found in Appendix III. All the words that were analyzed were found to have different distributions of the amplitudes of the spatial frequencies. By comparing the spatial frequency amplitudes of the words in each list, significant differences were found between the frequencies of the word lists.

Method of Analysis

The computer program Number Cruncher Statistical System, Version 4.1 was used. The principle statistical technique utilized was the F test. Using this technique and the three way Analysis of Variance, ANOVA (fixed design), data from four of the frequencies were compared for each of the randomly chosen sample words from the two word lists. This preliminary test determined that significant differences existed between some of the frequencies of words on the two lists.

The information in Table 3 indicated that frequency amplitudes in list one (A 2) are significantly different from the frequency amplitudes in list two (B 3). Further that the list that the words are in was a significant factor (C 4). There was also interaction indicated between frequencies, which indicated that some frequencies were the same (AC and BC). The important significance was that there was a difference between lists according to the amplitudes of the spatial frequencies.

With "A" representing the amplitudes of the middle vertical frequency group, "B" representing the amplitudes of the middle horizontal group and "C" representing the word list, these results are in Table 3.

Table 3.

Analysis of Frequency Amplitudes

Source	DF	Sum-Squares	Mean-Squares	F-ratio	Prob > F
A 2	1	1806.066	1806.066	35.7	0
B 3	1	32998.56	32998.56	652.29	0
C 4	1	41145.2	41145.2	813.33	0
AB	1	776.7711	776.7711	15.35	0
AC	1	386.7257	386.7257	7.64	.006
BC	1	15398.9	15398.9	304.39	0
ABC	1	114.8068	114.8068	2.27	.13

All F's were tested using df = 1, 42 at x = .05. Critical F = 4.07 (tabular).

The major hypotheses indicated that :

1. There was a significant difference between words using the data generated from the Fourier transform.

   $H_1 : \quad M_1 < M_2$

2. There was a significant difference between the words on the two word lists under study using the data from the Fourier transform.

   $H_2 : \quad M_2 > M_1$

Therefore, the significant difference between the list of easy words, list one and the list of harder words, list two, indicated that common spatial frequency factors existed that may indicate the difficulty of words. Words with similiar frequency amplitudes may have a similiar degree of difficulty in reading. The study also indicated that words do have different horizontal and vertical frequency amplitudes that may also indicate their difficulty.

The results of the Fourier transform were also compared visually, using computer printouts of plots of the amplitudes of the spatial frequencies versus frequency. Words on the easier word list were noted to have more rounded peaks than words on the harder word list which had sharper peaks (See Appendix III).

Finally, a one way multivariant analysis of variance (MANOVA) compared the lists with respect to the seventeen variables. The Computer Center at Oregon State University using data supplied by the researcher ran statistical tests that indicated a significant difference between the lists, as indicated in section one of Table 4, where all tests have a P - value (Significance of F) of less than or equal to .001 where .05 was significant.

Table 4.

Results of Mutivariant Analysis (MANOVA)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.65497	3.57333	17.00	32.00	.001
Hotellings	1.89833	3.57333	17.00	32.00	.001
Wilks	.34503	3.57333	17.00	32.00	.001

In addition, a Univariate Analysis was done comparing word list one, the easy word list, and word list two, a harder word list with respect to each of the seventeen variables. In Table 5, all F ratios were statistically significant at the .05 level with F (1, 48) equal to 4.07. The amplitudes therefore are more alike within the lists than they are between lists in all cases, that is, the between list differences are greater than the in list differences.

Levels of significance were calculated at the .05 level. The F statistic indicated that the variation between lists was greater than the variation within lists. In all cases the mean of list one, the easy list, was less than the mean of list two, the list of more difficult words. Therefore a significant difference between the amplitudes of the spatial frequencies of list one and list two was found. All F's were significant at .05 and were .001 or less.

The mean of list one was less than the mean of list two in all horizontal, vertical, and combined amplitudes. Using the Fourier transform to simulate sine waves and measuring the amplitudes of those sine waves has provided a measurable difference between words in word list one and word list two. This can be seen to indicated that the level of difficulty can be determined in most cases by the amplitudes of the sine waves produced by the Fourier transform.

Table 5

Results of Univariate Tests

Variable	Hypoth.SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
Center	1664217.680	1396845.8	1664217.6	29100.9	57.18	0
Horz 1	3737.838	5375.6	3737.8	111.9	33.37	.001
Horz 2	2537.568	8877.1	2537.5	184.9	13.72	.001
Horz 3	138.977	316.6	138.9	6.5	21.06	.000
Horz 4	448.022	1127.6	448.0	23.4	19.07	.000
Vert 1	1146.247	1138.2	1146.2	23.7	48.33	0
Vert 2	399.766	501.9	399.7	10.4	38.22	.000
Vert 3	8.056	17.1	8.0	.3	22.51	.000
Vert 4	12.310	14.9	12.3	.3	39.40	.000
Quad 1	38517864.500	40522748.8	38517864.5	844223.5	45.62	.000
Quad 2	62532025.852	61752318.3	62532025.8	1286506.2	48.60	0
Quad 3	8819218.817	20930874.0	8819218.8	436059.8	20.22	.000
Quad 4	21952574.100	23149663.3	21952574.1	482284.6	45.51	.000
NQuad 1	20862247.151	21313863.0	20862247.1	444038.2	46.98	.000
NQuad 2	59950833.900	67715830.4	59950833.9	1410746.8	42.49	.000
NQuad 3	7946912.365	17959851.7	7946912.3	374163.8	21.23	.000
NQuad 4	21649423.897	22482165.8	21649423.8	468378.5	46.22	.000

Univariate F - Tests with (1, 48) D.F.

To determine which variable best predicted the difficulty of a word, the list it belonged on, a stepwise discriminant analysis was run on the seventeen variables. List one, the easy word list was compared with list two, the harder word list to determine which variable would best predict which words belonged in list one and which words belonged in list two. The results indicate that Center and Quad 2 were the best predictive variables. These data are reported in Table 6.

Table 6

Predictive Variables

Variable	F	Variable	F	Variable	F	Variable	F
Center	57.19						
Horz 1	33.38	Vert 1	48.34	Quad 1	45.63	NQuad 1	46.98
Horz 2	13.72	Vert 2	38.23	Quad 2	48.61	NQuad 2	42.50
Horz 3	21.07	Vert 3	22.52	Quad 3	20.22	NQuad 3	21.24
Horz 4	19.07	Vert 4	39.41	Quad 4	45.52	NQuad 4	46.22

Using the data provided by this statistical analysis, a high percentage, (84%) of the words were correctly classified into each group or list of words. For the center variable a number of less than 704.55 would correctly predict that the word would be in list 1, the easier list (group A) and if the number was more than 704.55 the word would be predicted to be in on list 2, the harder list (group B).

These predictions were correct in choosing the words that would be in group A (list 1) 88 percent of the time and correct in choosing words in group B (list 2) 80 percent of the time. Using either the Center variable or the Quad 2 variable the researcher could again predict correctly which list the words were found in with the same high percentage rates. The data in the classification matrix, Table 7, shows the calculations for determining which words are predicted to be on the easier word list and which words are predicted to be on the more difficult word list.

Summary

The researcher was able to statistically analyze the amplitudes of the spatial frequencies generated by the Fourier transform for each word on two different word lists and then to use the results of the analysis to predict with a high rate of accuracy the difficulty of a word as indicated by the word list.

The next chapter will summarize the study, analyze the findings and make recommendations for further study.

Table 7

Classification Matrix

	Group A	Group B
Function: Center	.01794	.03048
Constant	-5.37844	-14.21351

From the above matrix $-5.37844 + .01794x = -14.21351 + .03048x$ (1)

$$704.55 = x \quad (2)$$

For Center < 704.55 predict list 1

> 704.55 predict list 2

	Group A	Group B
Function: Quad 2	.00643	.00817
Constant	-27.29583	-43.62369

From the above matrix $-27.29583 + .00643x = -43.62369 + .00817x$ (3)

$$-27.29583 + 43.62369 = (.00817 - .00643)x \quad (4)$$

$$9{,}383.83 = x \quad (5)$$

For Quad 2 < 9,383.83 predict list 1

> 9,383.83 predict list 2

SUMMARY, ANALYSIS OF FINDINGS, AND RECOMMENDATIONS

Summary

Interest in finding a method to determine readability that is an objective, convenient, and reliable indicator of the difficulty of words in reading material led to this study. This study analyzed the Fourier transform generated spatial frequencies of words to determine if those spatial frequencies indicated the level of readability of a word. New technology was used that allows the examination of this new aspect of readability. The study analyzed two lists of words, one of relatively easy words and one of more difficult words. It was first found that each word on both lists had different patterns of spatial frequency amplitudes. Secondly, an ANOVA study showed that spatial frequency amplitudes indicate whether the word is on the easy or difficult list. These predictions were corrrect in choosing the words that would be on the easy list 88 percent of the time and correct in choosing words in the difficult list 80 percent of the time. And third, since the spatial frequency amplitudes of the words indicate their difficulty, they may indicate a factor in readability of a passage independent of any semantic patterns.

The Review of Related Research and Literature in the second chapter indicated an interest in the development of new ways of conveniently predicting the readability of reading materials. Studies of readability formulas indicate that word lists are an accurate factor in determining readability. With this study the variation of spatial frequency amplitudes were found to be greater between the two lists of words than within the each list, indicating that the factor of Fourier transform generated spatial frequency amplitudes can be used to indicate the level of difficulty.

Recommendations

The method used in this study of identifying appropriate reading material could also theoretically be extended to the field of focus of an individual. Individuals with specific visual problems, that have or have not been identified, could have problem words identified and other words substituted by examination of the spatial frequency amplitudes of words that are difficult for them. Just as some people may have trouble hearing high or low auditory frequencies, it may be possible that some people may have trouble reading words with unusually high or low spatial frequencies.

A quick and inexpensive method of determining readability might be to examine the Fourier transform generated spatial frequencies of the words and/or sentences in a reading passage, page or book using a scanner that feeds directly into a computer. The computer could then print out the approximate level of difficulty as indicated by the spatial frequencies based on previously programmed lists of difficult frequency patterns. The Fourier transform data from new words could be compared with the data from words on accepted word lists and an indication of the difficulty of a new word might be possible. So that in the future, it might be possible to add new words automatically to key word lists and determine readability quickly and inexpensively. Of course, such an analysis is independent of an analysis of the content.

Recommendations for further investigation are:

1. Further study should include the examination of word lists in basal readers at several grade levels. This study could be done at all grade levels in one series and then for all lists at each grade level for several basal series.

2. A comparison to determine readability by this method, spatial frequency amplitudes, with other tested readability formulas would indicate whether or not a readability could be based only on Fourier transform generated spatial frequency amplitudes of words, sentences, phrases, etc.

3. An investigation could determine whether changing a word with a Fourier transform spatial frequency amplitude that was higher, to a word that had a Fourier transform generated spatial frequency amplitude that was lower, would enable a problem reader to recognize

words, letters, and/or sentences easier. This investigation might also discover a better method of working with remedial readers by determining if some of their problems in reading could be caused by the inability to process certain spatial frequencies. In addition, different print types and/or sizes could be analyzed using this method.

4. Studies could determine if there is a difference in the ability of students to process different spatial frequency amplitudes at different ages. Studies might also determine at what age there is likely to be a loss of the ability to process certain spatial frequencies.

5. Development of special materials for ease of reading could begin after the identification of words or combination of letters with unusual or difficult Fourier transform generated spatial frequency amplitudes. Reading materials could also be developed for newly identified reading problems.

6. Readability formulas, such as the Dale/Chall Readability Formula, could use this method to generate word lists, add to word lists and include this quantitative measurement to their formula.

BIBLIOGRAPHY

Allen, J., "A Readability Review: Important Trends Since 1979." Teaching English in a Two Year College, October, 1985, pp. 214 to 220.

Beck, Jacob, Barbara Hope and Azriel Rosenfeld, Editors, Human and Machine Vision, Academic Press, New York, 1983.

Breitmeyer, Bruno, Visual Masking, An Integrative Approach, Oxford University Press, New York, 1984.

Breitmeyer, Bruno and Leo Ganz, "Implications of Sustained and Transient Channels for Theories of Visual Pattern Masking, Saccadic Suppression and Information Processing.", Psychological Review, January, 1976, pp. 1 to 33..

Broadbent, Donald, "The Hidden Preattentive Process," American Psychologist, February, 1977, pp. 109-118.

Carterette, Edward and Morton Friedman, Handbook of Perception, Seeing, Academic Press, New York, 1975.

Courtney, E. Wayne, Techniques of Research, Oregon State University, Corvallis, 1982.

Douglass, Malcolm, Editor, Claremont Reading Conference, Forty-Ninth Yearbook, Claremont Reading Conference, Claremont, California, 1985.

Duffieux, P.M., The Fourier Transform and Its' Applications to Optics, John Wiley and Sons, New York, 1983.

Fry, Edward, Jacqueline Polk and Dona Fountoukidis, The Reading Teachers' Book of Lists, Prentice-Hall, Englewood Cliffs, New Jersey, 1984.

Gelsema, Edzard, and Laveen Kanal, Pattern Recognition in Practice, North-Holland Publishing Company, Amsterdam, N.D. 1980.

Geyer, John, "Comprehensive and Partial Models Related to the Reading Process." Reading Research Quarterly, Summer, 1972, pp. 543 to 585

Goleman, Daniel, "Holographic Memory", Psychology Today, February, 1979.

Harrison, Colin, Readability in the Classroom, Cambridge University Press, Cambridge, G.B. , 1980.

Henderson, Leslie, Orthography and Word Recognition in Reading, Academic Press, London, 1982.

Isaac, Stephen, and Michael, William, Handbook in Research and Evaluation, Edits, San Diego, 1983.

Klare, George, The Measurement of Readability, Iowa State University Press, Ames, Iowa, 1963.

Massaro, D.W. , G.A. Taylor, R. L Venezky, J.E. Jastrzembski, and P.A. Lucas, Letter and Word Perception, North-Holland Publishing Company, Amsterdam, 1980.

Pearson, P.David, Editor, Handbook of Reading Research, Longman, New York, 1984.

Rush, R.Timothy, "Assessing Readability: Formulas and Alternatives, Reading Teacher, December, 1985, pp. 274 to 283.

Singer, Harry and Robert Ruddell, Editors, Theoretical Models and Processes of Reading, Third Edition, International Reading Association, Newark, Delaware, 1985.

Steward, E. G., Fourier Optics, An Introduction, Ellis Horwood Limited, Chichester, G.B., 1983.

Tzeng, Ovid and Harry Singer, Perception of Print, Reading Research in Experimental Psychology, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1981.

Weaver, J. Joseph, Applications of Discrete and Continous Fourier Analysis, John Wiley and Sons, New York, 1983.

APPENDICES

APPENDIX I

Dale's 769 word list

a	bag	book	catch	cover
about	ball	born	cause	cow
above	band	both	cent	cried
across	bank	bottom	center	cross
act	basket	bow	chair	crowd
afraid	be	box	chance	crown
after	bear	boy	change	cry
afternoon	beat	branch	chief	cup
again	beautiful	brave	child	cut
against	because	bread	children	dance
ago	bed	break	choose	dark
air	bee	breakfast	Christmas	day
all	been	bridge	church	dead
almost	before	bright	circle	dear
alone	began	bring	city	deep
along	begin	broken	class	did
already	behind	brother	clean	die
also	being	brought	clear	different
always	believe	brown	clock	dinner
am	bell	build	close	do
American	belong	building	cloth	doctor
an	beside	built	clothes	does
and	best	burn	cloud	dog
animal	better	busy	coal	done
another	between	but	coat	don't
answer	big	butter	cold	door
any	bill	buy	color	double
anything	bird	by	come	down
apple	bit	cake	coming	draw
are	black	call	company	dream
arm	bless	came	cook	dress
around	blind	can	cool	drink
as	blood	cap	corn	drive
ask	blow	captain	corner	drop
at	blue	car	cost	dry
away	board	care	could	dust
baby	boat	careful	count	each
back	body	carry	country	ear
bad	bone	case	course	early

earth	field	go	hill	lake
east	fight	God	him	land
easy	fill	going	himself	large
eat	find	gold	his	last
edge	fine	golden	hold	late
egg	finger	gone	hole	laugh
eight	finish	good	home	lay
either	fire	got	hope	lead
else	first	grain	horse	learn
end	fish	grass	hot	leave
England	fit	gray	house	left
English	five	great	how	leg
enough	fix	green	hundred	lesson
even	floor	grew	hunt	let
evening	flower	ground	hurry	letter
ever	fly	grow	hurt	lie
every	follow	guess	I	lift
everything	food	had	ice	light
except	foot	hair	if	like
expect	for	half	in	line
eye	forget	hall	Indian	lion
face	forth	hand	instead	lips
fair	found	hang	into	listen
fall	four	happy	iron	little
family	fresh	hard	is	live
fancy	friend	has	it	load
far	from	hat	its	long
farm	front	have	jump	look
farmer	fruit	he	just	lost
fast	full	head	keep	lot
fat	game	hear	kept	loud
father	garden	heard	kill	love
feed	gate	heart	kind	low
feel	gave	heavy	king	made
feet	get	help	kiss	mail
fell	gift	her	knee	make
fellow	girl	here	knew	man
felt	give	herself	know	many
fence	glad	hide	lady	march
few	glass	high	laid	mark

market	neighbor	own	ready	send
matter	neither	page	real	sent
may	nest	paint	reason	serve
me	never	pair	red	set
mean	new	paper	remember	seven
measure	New York	part	rest	several
meat	next	party	rich	shake
meet	nice	pass	ride	shall
men	night	path	right	shape
met	nine	pay	ring	she
middle	no	pen	river	sheep
might	noise	people	road	shine
mile	none	pick	rock	ship
milk	noon	picture	roll	shoe
mill	nor	piece	roof	shop
mind	north	place	room	short
mine	nose	plain	rose	should
minute	not	plant	round	shoulder
miss	note	play	row	show
money	nothing	please	run	shut
month	now	point	said	sick
moon	number	poor	sail	side
more	oak	post	salt	sign
morning	ocean	pound	same	silk
most	of	present	sand	silver
mother	off	press	sat	sing
mountain	office	pretty	save	sir
mouth	often	pull	saw	sister
move	old	put	say	sit
Mr.	on	quarter	school	six
Mrs.	once	queen	sea	size
much	one	quick	season	skin
music	only	quiet	seat	sky
must	open	quite	second	sleep
my	or	race	see	slow
myself	other	rain	seed	small
name	our	ran	seem	smile
near	out	rather	seen	smoke
neck	outside	reach	self	snow
need	over	read	sell	so

soft	sure	to	water	work
sold	surprise	today	wave	world
soldier	sweet	together	way	would
some	table	told	we	write
something	tail	tomorrow	wear	wrong
sometime	take	tongue	weather	yard
song	talk	too	week	year
soon	tall	took	well	yellow
sound	taste	top	went	yes
south	teach	touch	were	yesterday
space	teacher	town	west	yet
speak	tear	trade	what	you
spot	tell	train	wheat	young
spread	ten	tree	wheel	your
spring	than	true	when	
square	thank	try	where	
stand	that	turn	whether	
star	the	twelve	which	
start	their	twenty	while	
station	them	two	white	
stay	then	uncle	who	
step	there	under	whole	
stick	these	until	whom	
still	they	up	whose	
stone	thick	upon	why	
stood	thin	us	wide	
stop	thing	use	wild	
store	think	valley	will	
storm	this	very	win	
story	those	visit	wind	
straight	though	wait	window	
street	thought	walk	wing	
strike	thousand	wall	winter	
strong	three	want	wish	
such	through	war	with	
sugar	throw	warm	without	
suit	tie	was	woman	
summer	till	wash	wonder	
sun	time	waste	wood	
suppose	tire (d)	watch	word	

From Readability in the Classroom
by Colin Harrison.
Cambridge University Press.
New York, New York. 1980 pp. 160

APPENDIX II

Spelling Demons—195 Words Frequently Misspelled by Secondary Students

absence
acceptable
accommodate
accustom
ache
achievement
acquire
across
adolescent
advantageous
advertisement

advice
against
aisle
amateur
analyze
annually
anticipated
apparent
appreciate
arctic
arguing

argument
arrangement
athlete

bargain
belief
beneficial
benefited
breathe
Britain
bury
business

calendar
category
cemetery
certainly
cite
comparative
concede
conceive
condemn
conscience
conscientious

conscious
controversial
controversy
council
criticize

definitely
definition
descendant
describe
description
desert

dilemma
diligence
dining
disastrous
discipline
disease
dissatisfied

endeavor
effect
embarrass
emigrate
environment
especially
exaggerate
exceed
except
exercise
exhausted
existence
experience
explanation

fascinate
formerly

gaiety
gauge
grammar
guarantee
guidance

height
heroes
hypocrite

incredible
interest
interrupt
irrelevant
its

jealousy

led
leisurely
license
lieutenant
listener
lose
luxury

magnificent
maneuver
marriage
mathematics
medicine
mere
miniature
miscellaneous
mischief
moral
muscle
mysterious

necessary
niece
noticeable
numerous

occasion
occurred
occurrence
occurring
opinion
opportunity

paid
parallel
paralyzed
particular
performance
personal
personnel
pleasant
politician
portrayed
possession
possible
practical
preferred
prejudice
prepare
prescription
prestige

prevalent
principal
principle
privilege
probably
procedure
proceed
profession
professor
prominent
pursue

quiet

receipt
receive
recommend
referring
renowned
repetition
restaurant
rhythm

saucer
seize
sense
separate
sergeant
shining
similar
sincerely

sophomore
stationary
studying
substantial
subtle
succeed
succession
supersede
surprise
susceptible

technique
thorough
tragedy
transferred
tremendous

unnecessary

vacuum
valuable
vegetable
vengeance
villain
visible

waive
woman
wrench
write
writing

yacht

Spelling Demons - 195 Words Frequently Misspelled by Secondary Students
The Reading Teacher's Book of Lists
by E. Fry, J. Polk, and D. Fountoukidis.
Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1984 pp. 56

APPENDIX III

WORD	LENGTH	DIF	CENTER	HORZ-1	HORZ-2	HORZ-3	HORZ-4
shoulder	8	2	959	112.59	71.76	16.90	29.73
yacht	5	2	564.00	108.56	46.62	16.25	23.52
professor	9	2	1046.00	119.50	58.33	15.27	24.77
height	6	2	749.00	125.13	64.43	18.55	31.08
sense	5	2	674.00	93.63	25.68	8.68	14.16
beneficial	10	2	1082.00	136.51	83.27	19.47	34.33
definition	10	2	1035.00	121.81	91.79	18.23	37.31
concede	7	2	888.00	99.99	47.36	11.28	20.81
writing	7	2	726.00	116.22	72.44	15.22	29.97
license	7	2	780.00	106.31	64.37	12.21	22.82
thorough	8	2	980.00	126.32	70.14	17.58	30.59
experience	10	2	1150.00	118.04	59.95	14.76	26.55
guidance	8	2	1008.00	118.07	68.53	16.06	29.20
sergeant	8	2	1002.00	123.49	54.24	15.41	24.76
incredible	10	2	1088.00	124.55	88.35	13.67	34.55
preferred	9	2	1035.00	134.94	65.96	17.10	28.95
saucer	6	2	692.00	100.73	43.20	11.23	17.73
benefited	9	2	1105.00	134.18	69.67	19.96	33.89
athlete	7	2	802.00	130.33	55.08	15.15	26.74
disastrous	10	2	1154.00	124.20	77.65	14.60	28.42
leisurely	9	2	922.00	117.84	75.09	14.62	30.35
stationary	10	2	1046.00	129.77	69.51	17.11	28.83
cite	4	2	396.00	94.70	43.45	11.48	20.23
moral	5	2	582.00	109.75	61.80	12.59	26.51
council	7	2	712.00	105.91	65.43	13.32	27.17
have	4	1	483.00	101.32	42.34	12.80	19.01
round	5	1	591.00	105.31	54.98	14.38	25.33
sat	3	1	353.00	99.13	29.42	12.88	14.64
noise	5	1	579.00	93.09	45.51	11.53	19.39
walk	4	1	469.00	94.28	60.77	7.80	23.24
eight	5	1	610.00	113.65	60.30	15.81	27.21
jump	4	1	554.00	100.77	73.99	12.14	27.23
tail	4	1	354.00	112.31	47.19	11.34	24.92
wish	4	1	476.00	87.30	54.01	12.89	22.46
waste	5	1	631.00	102.00	34.20	9.15	16.41
sold	4	1	493.00	101.74	49.52	12.35	21.65
quiet	5	1	569.00	108.65	65.89	14.01	25.62
hair	4	1	391.00	96.44	60.63	13.11	23.71
season	6	1	779.00	99.93	38.58	10.22	15.89
the	3	1	370.00	103.28	48.50	10.35	20.02
cake	4	1	494.00	97.48	36.92	9.02	18.04
yard	4	1	454.00	99.47	44.38	10.81	18.56
war	3	1	332.00	76.75	31.15	6.65	13.10
mind	4	1	534.00	101.91	71.44	12.39	28.50
storm	5	1	611.00	105.33	54.75	11.98	23.24
wonder	6	1	749.00	94.14	48.96	11.81	21.62
broken	6	1	737.00	115.76	59.19	16.14	26.09
oak	3	1	371.00	88.05	39.03	8.47	17.77
heavy	5	1	587.00	101.85	40.65	12.98	18.94
here	4	1	484.00	100.82	45.60	12.33	20.71

WORD	VERT-1	VERT-2	VERT-3	VERT-4	QUAD-1	QUAD-2
shoulder	24.84	13.28	2.54	2.45	8879.90	10837.42
yacht	14.03	7.05	1.97	1.85	7730.41	8856.17
professor	28.34	18.02	2.77	3.27	9906.81	11013.92
height	16.29	9.66	1.66	2.38	8290.15	9488.71
sense	18.31	14.40	2.48	2.05	7053.65	8212.09
beneficial	26.49	14.82	3.19	2.87	9775.52	12477.13
definition	26.07	13.51	2.88	3.14	9314.15	11537.84
concede	27.04	13.08	2.49	2.31	8411.65	9823.44
writing	17.36	8.48	3.05	3.10	8219.66	9729.79
license	20.02	12.35	2.27	1.99	7767.62	10111.79
thorough	25.53	12.27	2.63	3.42	9476.52	10260.03
experience	32.46	19.41	3.06	4.07	9777.16	11946.60
guidance	26.80	12.90	2.87	2.43	9270.88	11433.96
sergeant	25.34	17.28	2.90	2.81	9338.35	10886.18
incredible	28.37	14.35	2.74	2.89	9646.78	12374.10
preferred	27.23	18.12	2.53	3.17	10371.71	11210.81
saucer	20.17	12.42	2.69	1.85	7796.73	9444.41
benefited	27.46	17.02	3.05	3.12	9871.13	11645.82
athlete	18.28	12.65	2.66	2.34	8352.60	9978.22
disastrous	31.20	20.05	4.41	3.91	9573.77	12031.74
leisurely	19.89	12.62	2.68	2.12	8756.41	11750.29
stationary	26.57	15.90	4.24	3.50	9574.11	11974.74
cite	10.64	5.96	1.04	1.23	6426.08	7485.87
moral	16.07	8.13	2.36	1.99	7855.33	8930.42
council	21.16	7.07	1.47	2.11	8225.89	9309.40
have	11.86	7.54	1.84	1.47	6688.01	8493.60
round	17.97	7.55	1.62	1.75	8256.63	7812.32
sat	8.98	7.06	1.89	1.32	5827.06	6592.36
noise	15.74	9.67	1.55	1.76	6992.69	8736.58
walk	9.95	4.53	2.10	1.38	6456.38	8750.45
eight	13.01	8.07	1.29	1.82	7720.18	8880.60
jump	14.53	5.87	2.11	1.74	7582.47	8221.43
tail	7.68	4.84	1.73	1.16	6168.29	6797.29
wish	11.33	5.90	2.14	2.02	6004.12	8159.72
waste	15.61	10.46	2.69	1.85	7023.30	9265.33
sold	12.49	6.60	1.56	1.46	7248.00	7922.52
quiet	14.40	7.89	1.59	1.54	7357.72	8887.82
hair	9.90	6.38	2.06	1.65	6089.03	7748.76
season	21.40	15.17	3.04	2.16	7620.84	9455.91
the	8.85	5.92	1.00	1.23	6039.53	7110.60
cake	12.62	7.27	1.64	1.41	7145.60	8588.08
yard	11.23	6.12	1.77	1.17	7533.37	8186.42
war	9.01	4.72	1.97	1.55	5712.10	6930.54
mind	15.60	6.75	2.31	1.66	7353.30	8119.88
storm	18.19	9.71	2.17	2.37	7654.56	8497.97
wonder	21.30	9.64	1.86	2.42	8156.42	9488.46
broken	19.62	9.70	1.86	2.01	8960.10	9573.52
oak	9.20	4.83	1.33	1.03	6236.46	7498.95
heavy	13.36	7.87	2.19	1.77	7170.85	9180.75
here	12.73	9.36	1.25	1.86	6780.96	7935.01

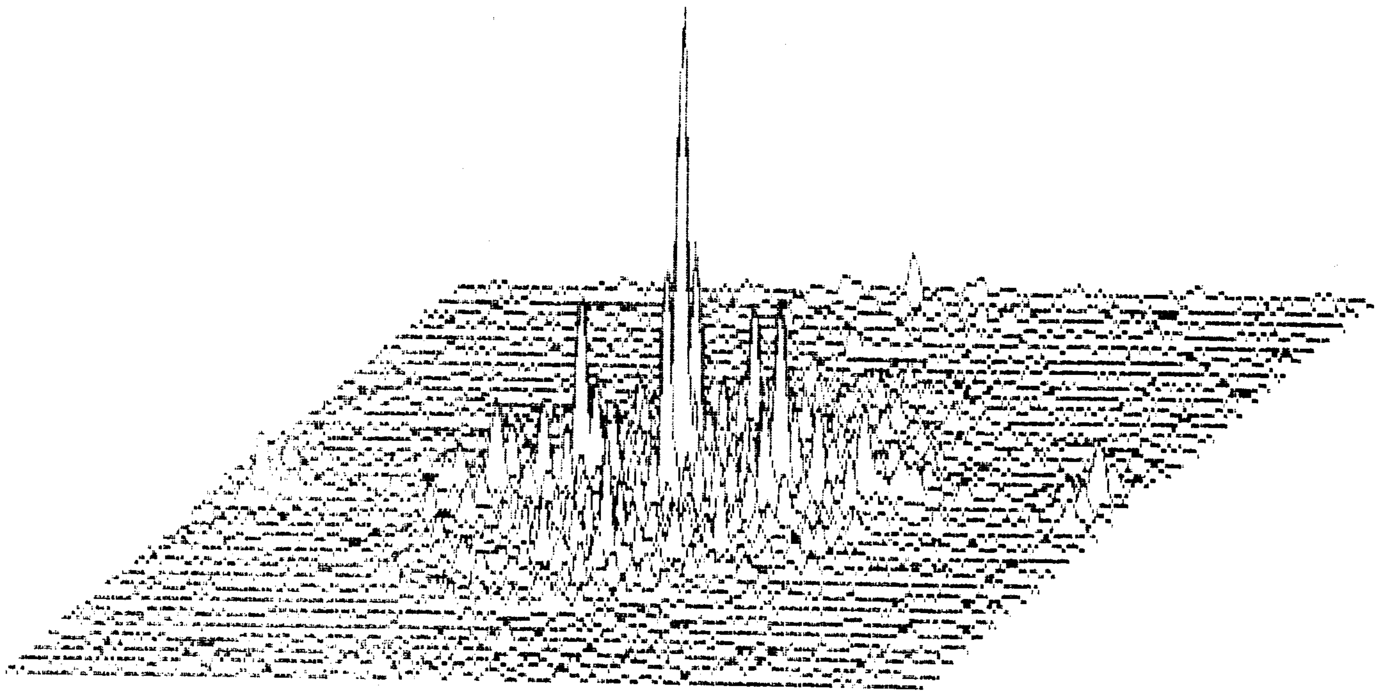
WORD	QUAD-3	QUAD-4	NQUAD-1	NQUAD-2	NQUAD-3	NQUAD-4
shoulder	4936.08	6432.29	8190.91	11153.93	4867.25	6596.49
yacht	5194.69	5229.46	7329.32	8289.97	4910.96	5398.66
professor	5162.62	7149.58	8053.68	11343.48	4893.13	6944.70
height	4770.77	5702.83	8125.42	9420.79	4691.53	5714.68
sense	4046.11	5249.19	6228.08	8730.20	3833.53	5698.23
beneficial	5864.02	7064.75	9031.88	11947.42	5643.13	6933.71
definition	5233.74	6615.59	8342.21	11521.10	5156.19	6751.62
concede	4582.00	6003.73	7509.51	9609.16	4469.73	5783.66
writing	5418.52	5970.11	7664.27	9715.06	5135.90	6004.54
license	4501.09	5889.06	7320.12	10543.88	4312.64	6171.08
thorough	5157.15	6294.35	8871.47	10523.69	4978.35	6330.13
experience	5831.77	7266.47	8314.59	11662.77	5816.40	6725.29
guidance	5760.85	6614.04	8264.69	10953.17	5566.09	6586.94
sergeant	5842.84	6738.39	8057.04	10977.95	5638.53	6843.47
incredible	5231.93	6912.92	8656.28	11900.18	5087.48	6823.77
preferred	5277.23	7023.05	8502.76	10828.48	5014.39	6106.39
saucer	4801.29	5783.09	6873.09	9523.73	4638.40	5742.45
benefited	5535.56	7032.48	8892.97	11445.96	5365.41	6756.85
athlete	4930.66	5901.95	8646.86	9294.11	5117.43	5813.90
disastrous	5731.44	7201.45	8512.94	12693.65	5695.54	7602.74
leisurely	5568.74	6620.96	7903.45	11719.61	5188.81	6794.25
stationary	6568.62	6927.05	8536.58	11895.84	6339.19	7266.17
cite	3452.78	4391.33	6398.02	7364.60	3465.17	4282.46
moral	4377.62	5209.27	7419.65	8483.36	4104.20	5319.29
council	4220.46	5385.54	7576.97	9373.76	4217.08	5652.64
have	4746.94	4897.28	6953.64	8048.90	4538.30	4847.27
round	3888.97	4961.01	7121.89	8178.40	3937.40	4965.25
sat	3789.21	4074.11	6091.32	7107.65	3773.34	4461.87
noise	3988.37	5202.75	6551.46	8933.03	3868.79	5510.19
walk	5237.44	5084.80	6420.35	8194.99	4839.69	4856.82
eight	4425.39	5178.29	7378.60	8729.68	4335.89	5234.43
jump	3755.16	4782.46	6577.18	8628.36	3694.55	4845.86
tail	3707.52	3874.56	6438.33	6313.81	3582.40	4224.67
wish	4381.89	5096.94	6045.28	9084.40	4328.87	5385.94
waste	5201.48	5715.98	6996.65	9308.89	5267.39	5950.95
sold	3494.97	4734.21	6912.32	8523.59	3455.47	5119.49
quiet	4051.72	4935.52	6935.29	8543.38	4181.49	4888.60
hair	3775.51	4262.13	5964.66	7402.75	3670.10	4135.55
season	4905.90	5881.42	7058.31	9823.80	4711.62	6288.50
the	3003.23	3951.27	6621.81	7205.16	3190.20	4023.01
cake	4588.19	5042.18	6743.13	7857.09	4383.85	4485.35
yard	4781.44	4726.74	6360.95	7560.51	4419.95	4698.98
war	4380.01	4331.03	5068.11	6520.57	4349.75	4219.10
mind	3664.83	4725.42	6598.17	8329.60	3650.05	4967.31
storm	4038.35	5368.73	7123.84	9262.76	3845.69	5689.44
wonder	5143.08	6199.13	7113.06	9603.81	5011.93	5880.59
broken	4987.77	5920.42	7936.46	9495.43	4645.64	5408.39
oak	4129.58	4436.39	6072.73	6883.26	3988.01	3942.08
heavy	5335.43	5356.56	7278.68	8671.34	5073.69	5283.18
here	3597.13	4739.12	6563.29	7954.88	3468.87	4430.36

Computer Printouts of Sums and Plots of the Amplitudes for Each Word

athlete

FOURIER TRANS-
FORM OF WORD:
athlete_

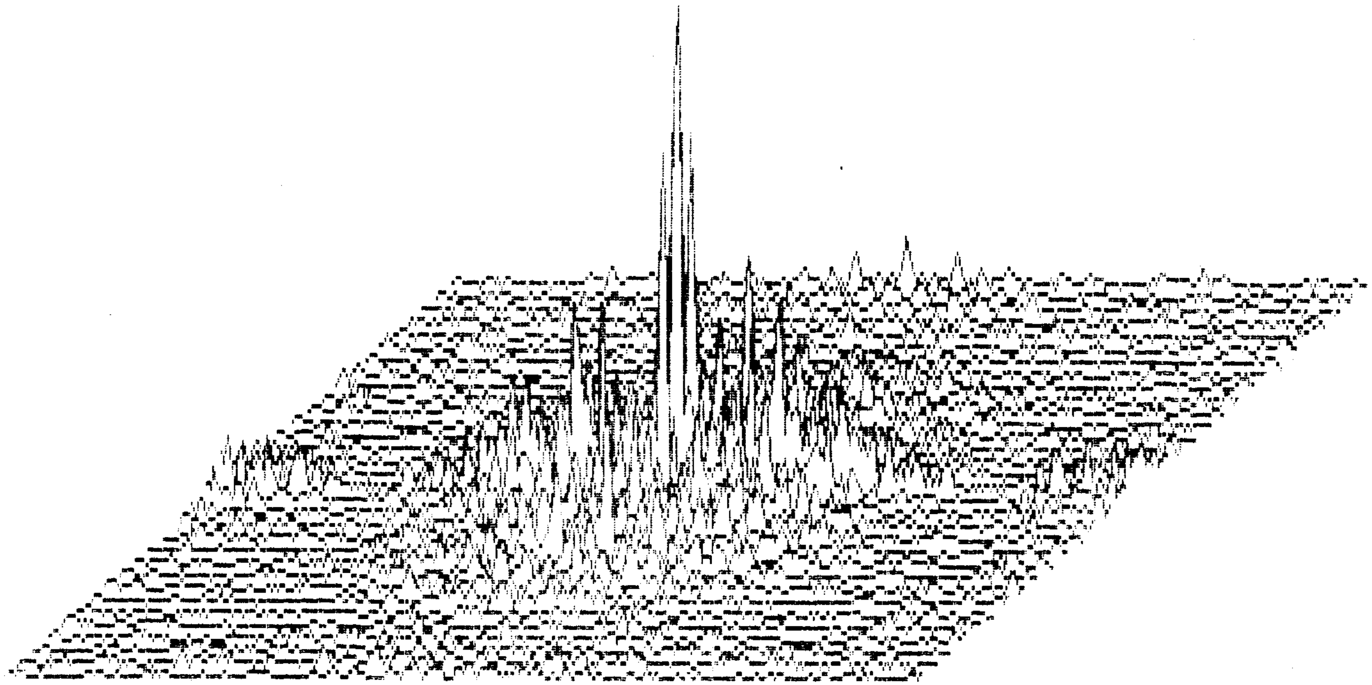
2.3444 2.6551 12.6461 18.2779 802.000 130.325 55.0819 15.1472 26.7390
5813.90 5117.43 9294.11 8646.8594 8352.60 9978.21 4930.66 5901.9473



beneficial

FOURIER TRANSFORM OF WORD:
beneficial_

2.8743 3.1941 14.8246 26.4918 1082.00 136.505 83.2722 19.4699 34.3345
6933.71 5643.13 11947.4 9031.8799 9775.52 12477.1 5864.02 7064.7490

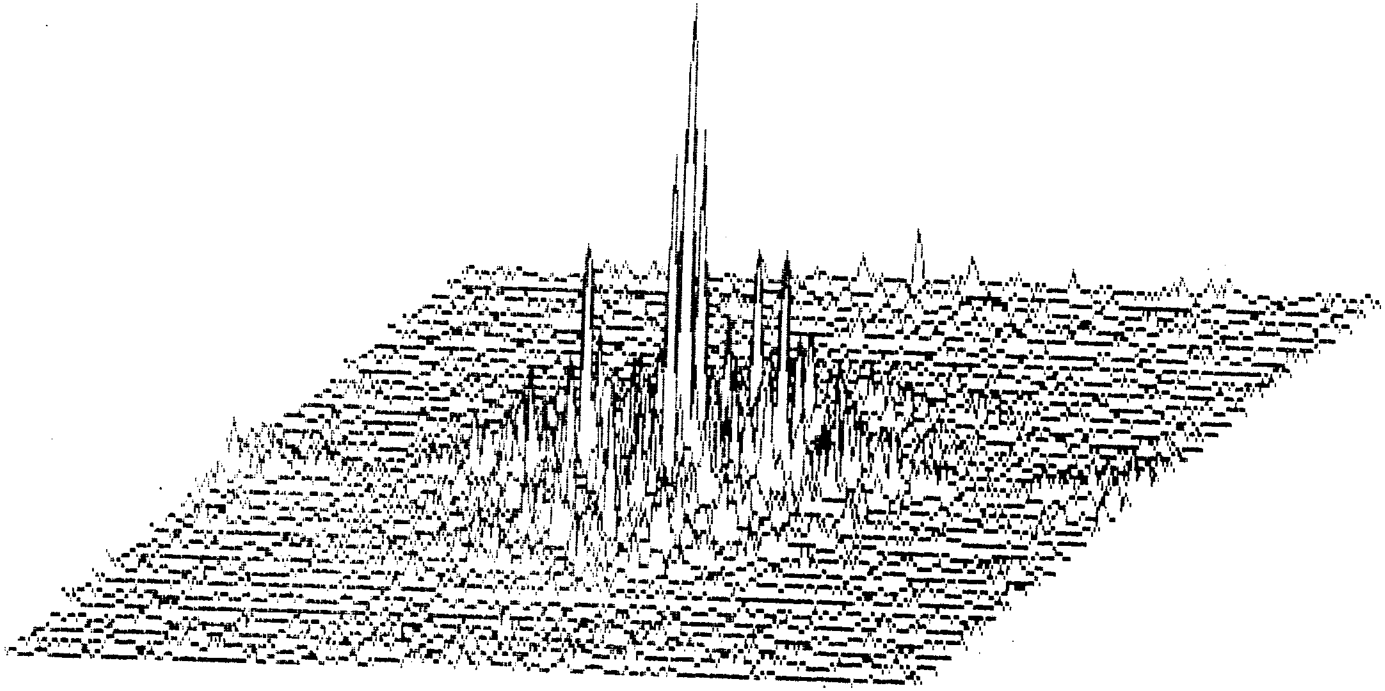


benefited

FOURIER TRANSFORM OF WORD:
benefited_

3.1169 3.0472 17.0201 27.4644
6756.84 5365.41 11445.9 8892.9678

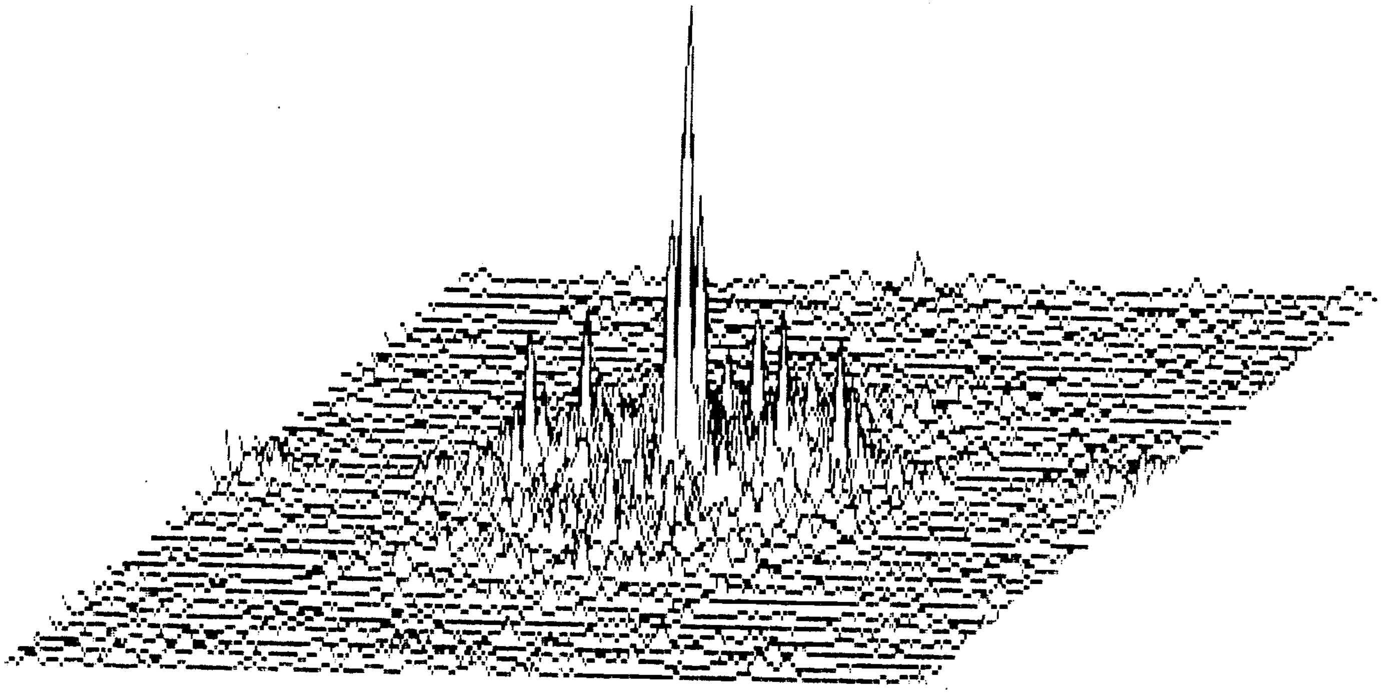
1105.00 134.176 69.6682 19.9632 33.8918
9871.13 11645.8 5535.55 7032.4849



broken

FOURIER TRANS-
FORM OF WORD:
broken_

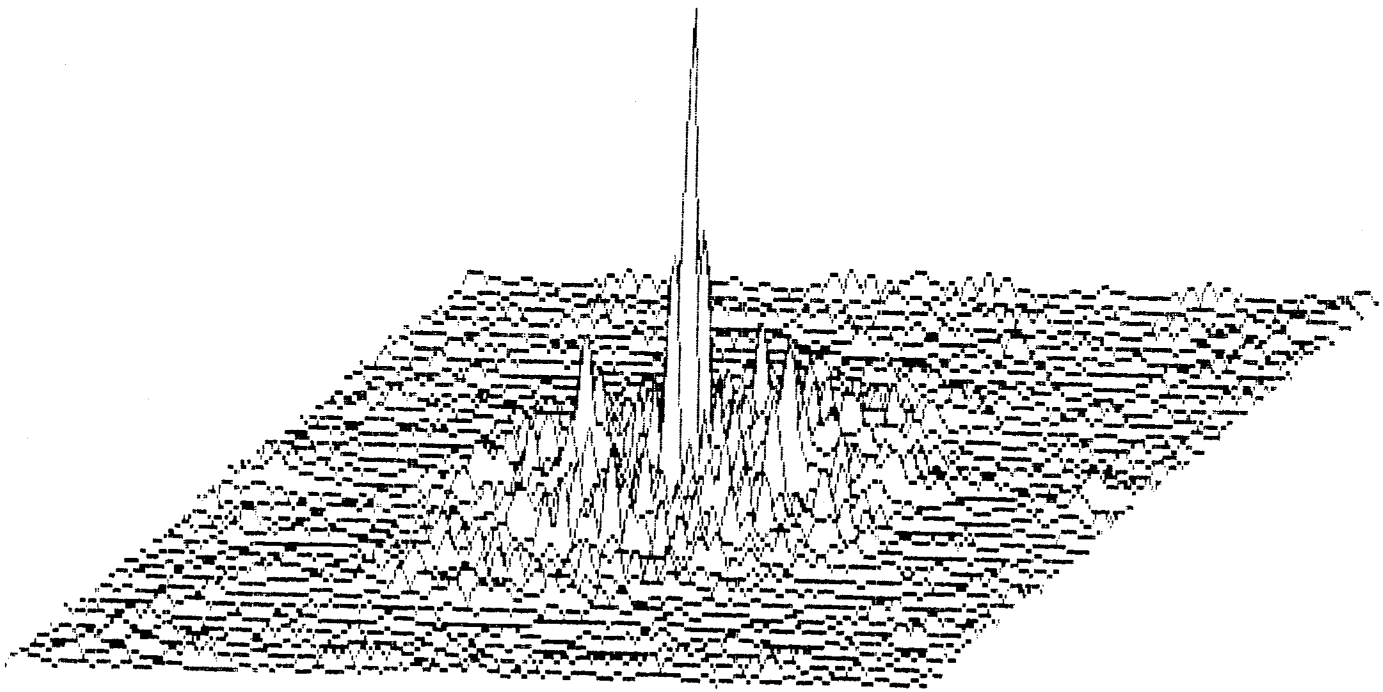
2.0086 1.8637 9.6959 19.6232 737.000 115.761 59.1890 16.1447 26.0889
5408.38 4645.63 9495.43 7936.4551 8960.10 9573.52 4987.76 5920.4229



cake

FOURIER TRANS-
FORM OF WORD:
cake_

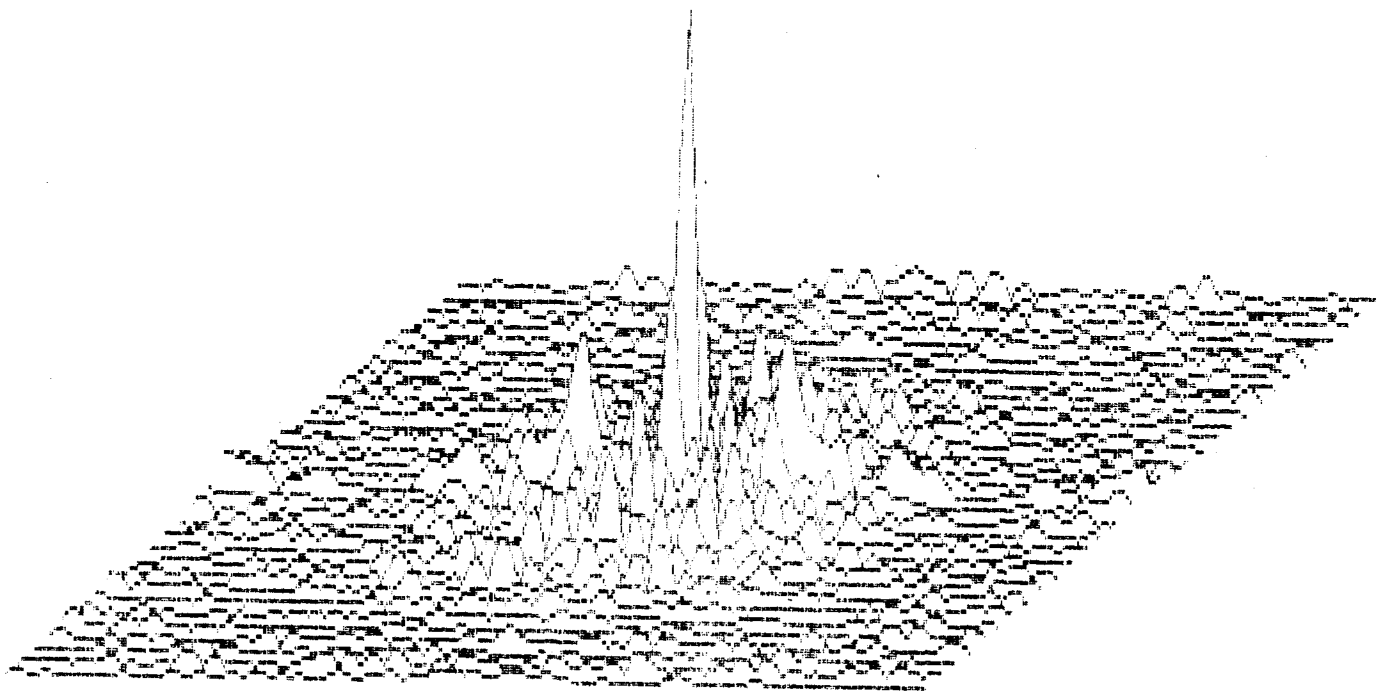
1.4118 1.6402 7.2696 12.6168 494.000 97.4796 36.9241 9.0185 18.0351
4485.34 4383.84 7857.08 6743.1289 7145.59 8588.07 4588.19 5042.1777



cite

FOURIER TRANS-
FORM OF WORD:
cite_

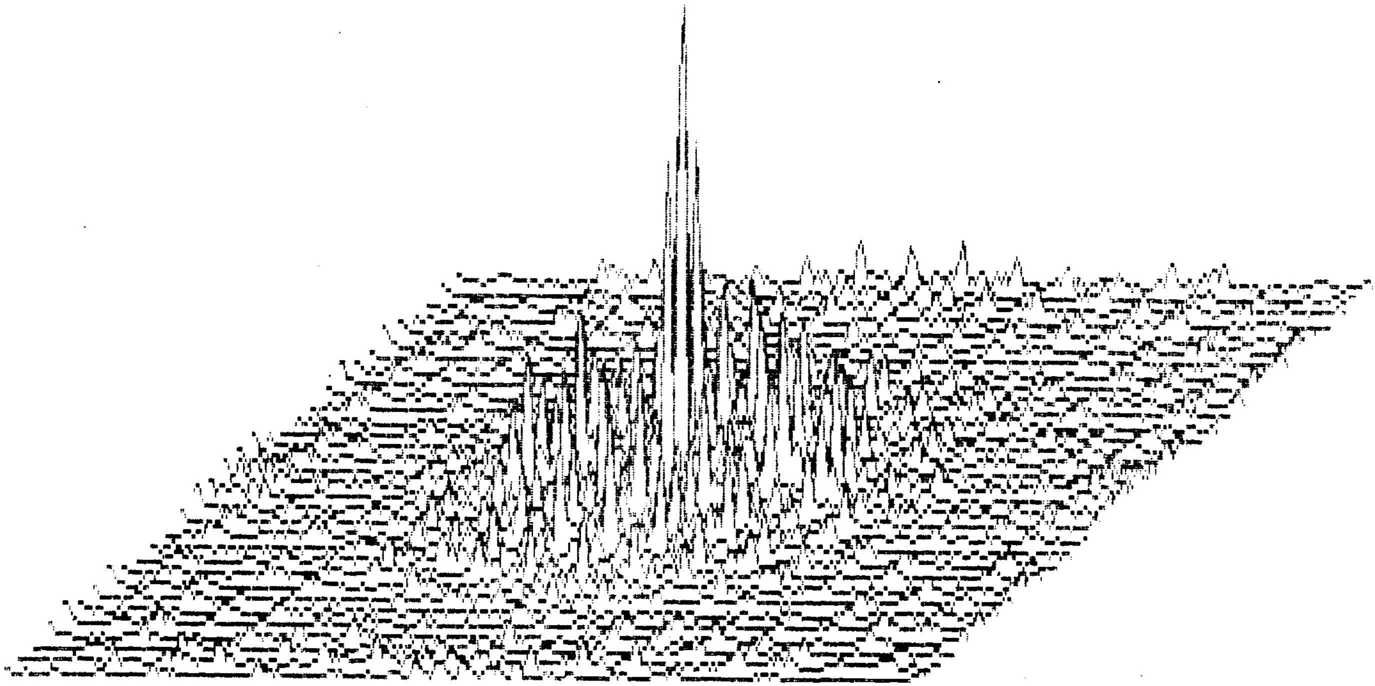
1.2285 1.0420 5.9628 10.6401 396.000 94.7024 43.4533 11.4801 20.2274
4282.46 3465.17 7364.60 6398.0186 6426.09 7485.86 3452.77 4391.3315



FOURIER TRANS-
FORM OF WORD:
concede_

concede

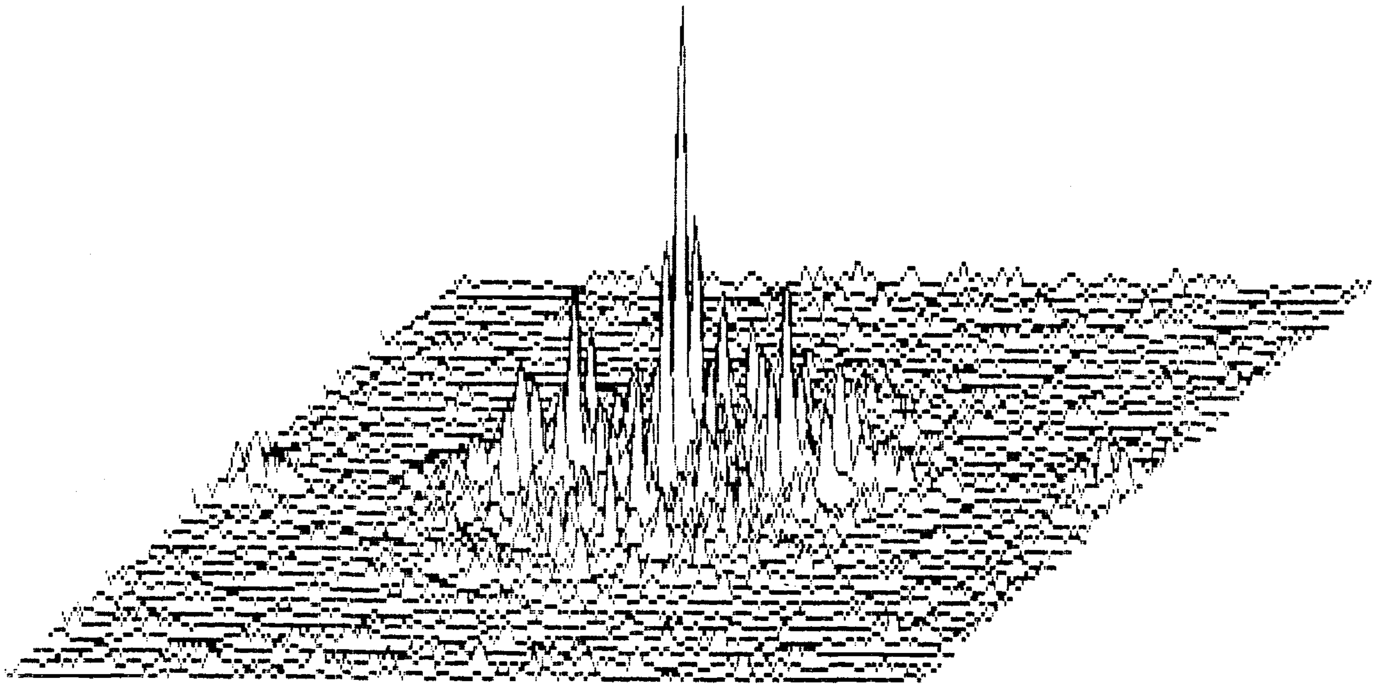
2.3127 2.4889 13.0809 27.0413 888.000 99.9861 47.3587 11.2813 20.8109
5783.65 4469.73 9609.15 7509.5098 8411.65 9823.43 4582.00 6003.7295



council

FOURIER TRANS-
FORM OF WORD:
council_

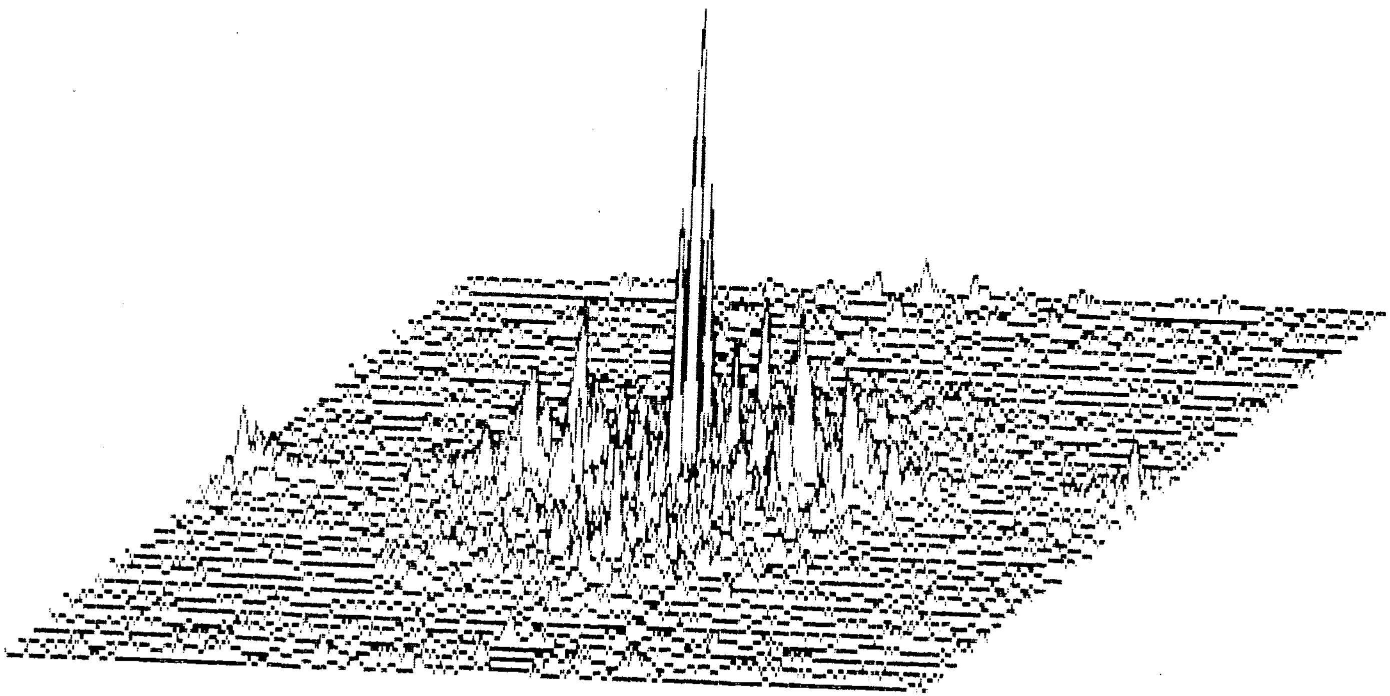
2.1147 1.4700 7.0674 21.1594 712.000 105.914 65.4259 13.3197 27.1678
5652.64 4217.07 9373.76 7576.9746 8225.89 9309.39 4220.45 5385.5376



definition

FOURIER TRANSFORM OF WORD:
definition_

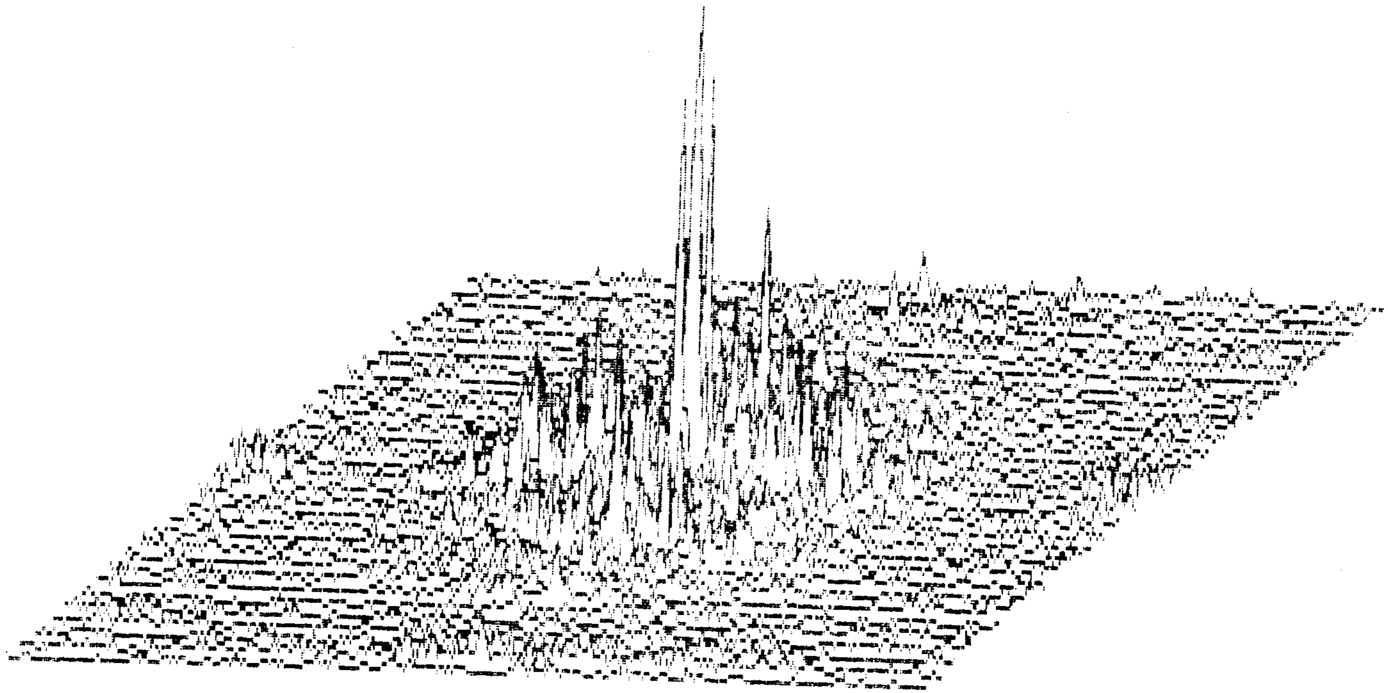
3.1402 2.8822 13.5115 26.0742 1035.00 121.806 91.7907 18.2342 37.3083
6751.62 5156.18 11521.1 8342.2109 9314.15 11537.8 5233.74 6615.5918



disastrous

FOURIER TRANS-
FORM OF WORD:
disastrous_

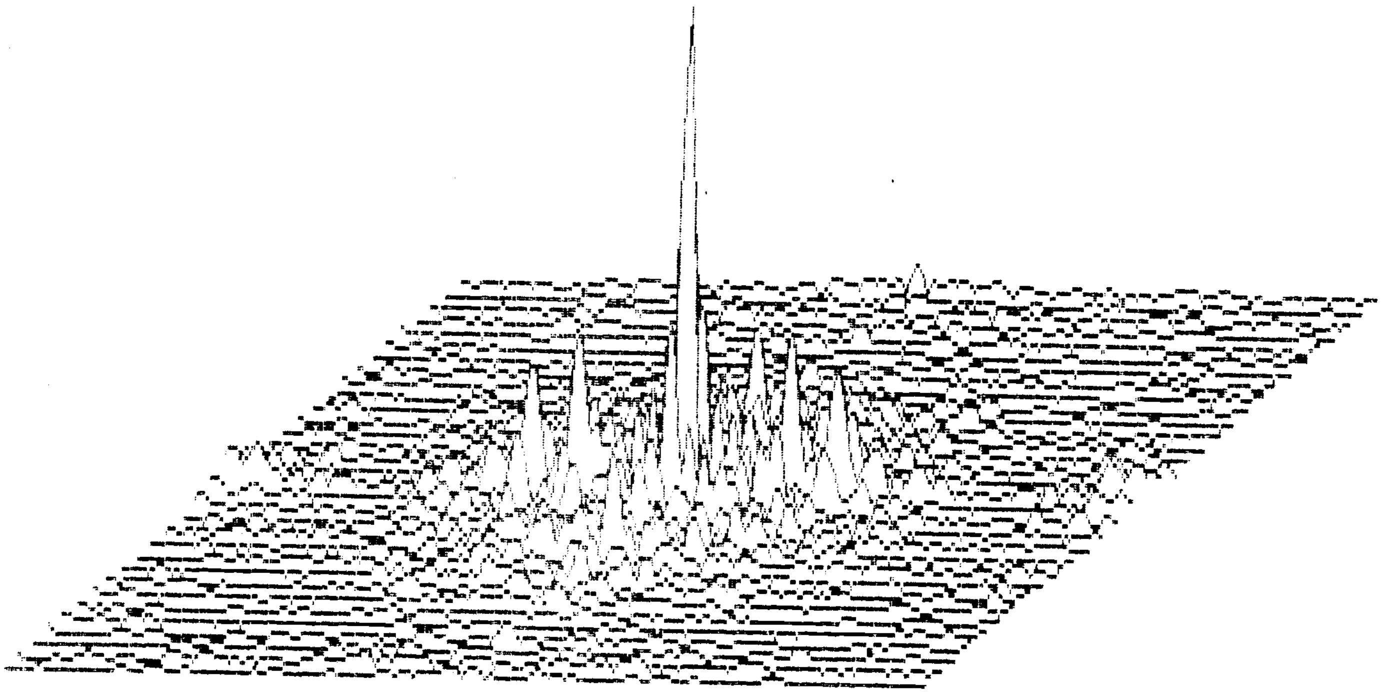
3.9110 4.4116 20.0471 31.2031 1154.00 124.202 77.6486 14.6003 28.4159
7602.74 5695.53 12693.6 8512.9355 9573.77 12031.7 5731.43 7201.4526



eight

FOURIER TRANSFORM OF WORD:
eight_

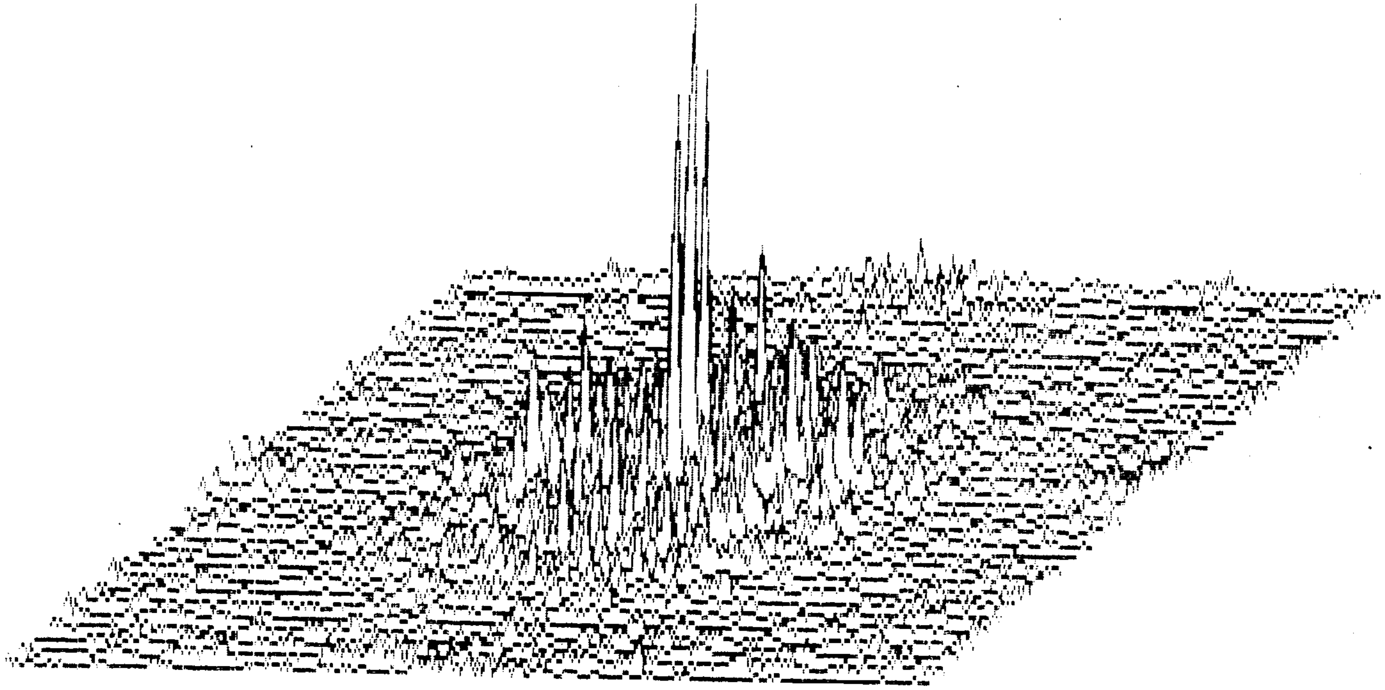
1.8158 1.2902 8.0677 13.0118 610.000 113.652 60.3044 15.8082 27.2070
5234.43 4335.89 8729.67 7378.6016 7720.17 8880.60 4425.38 5178.2939



experience

FOURIER TRANSFORM OF WORD:
experience_

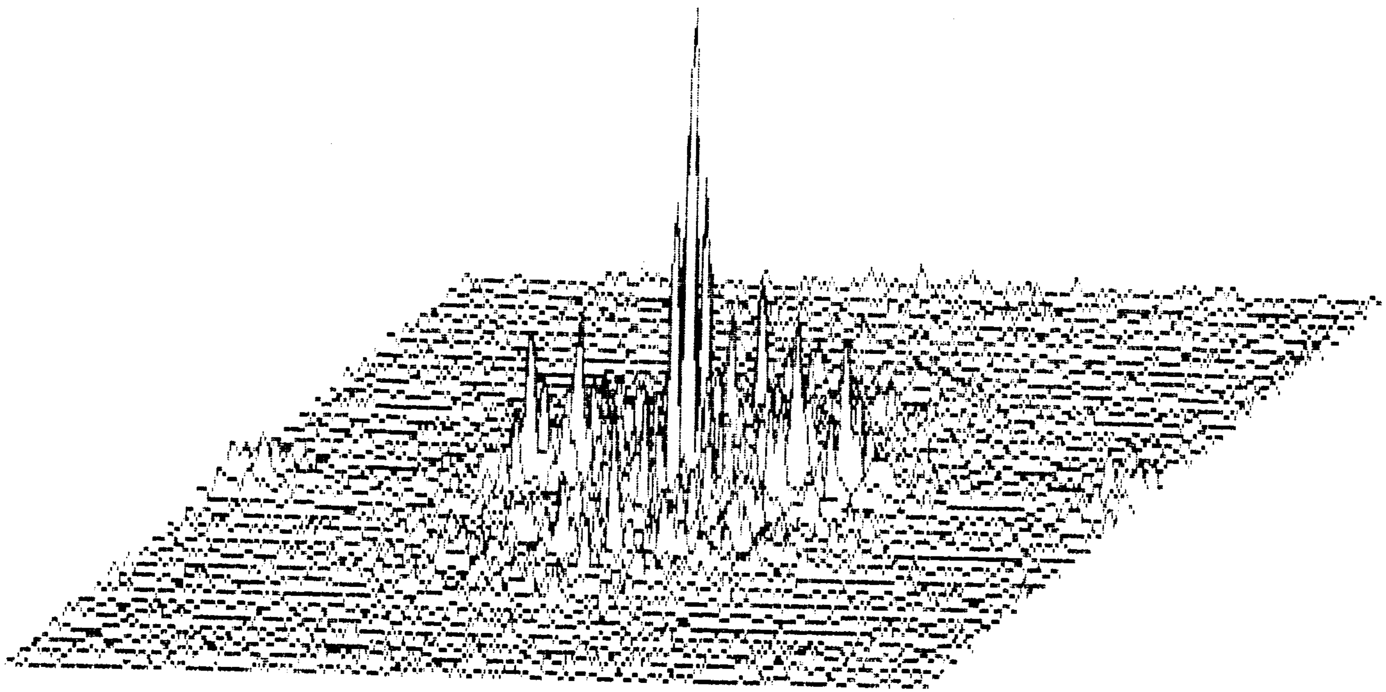
4.0669 3.0569 19.4140 32.4550 1150.00 118.036 59.9453 14.7622 26.5503
6725.29 5816.39 11662.7 8314.5869 9777.15 11946.6 5831.77 7266.4658



guidance

FOURIER TRANSFORM OF WORD:
guidance_

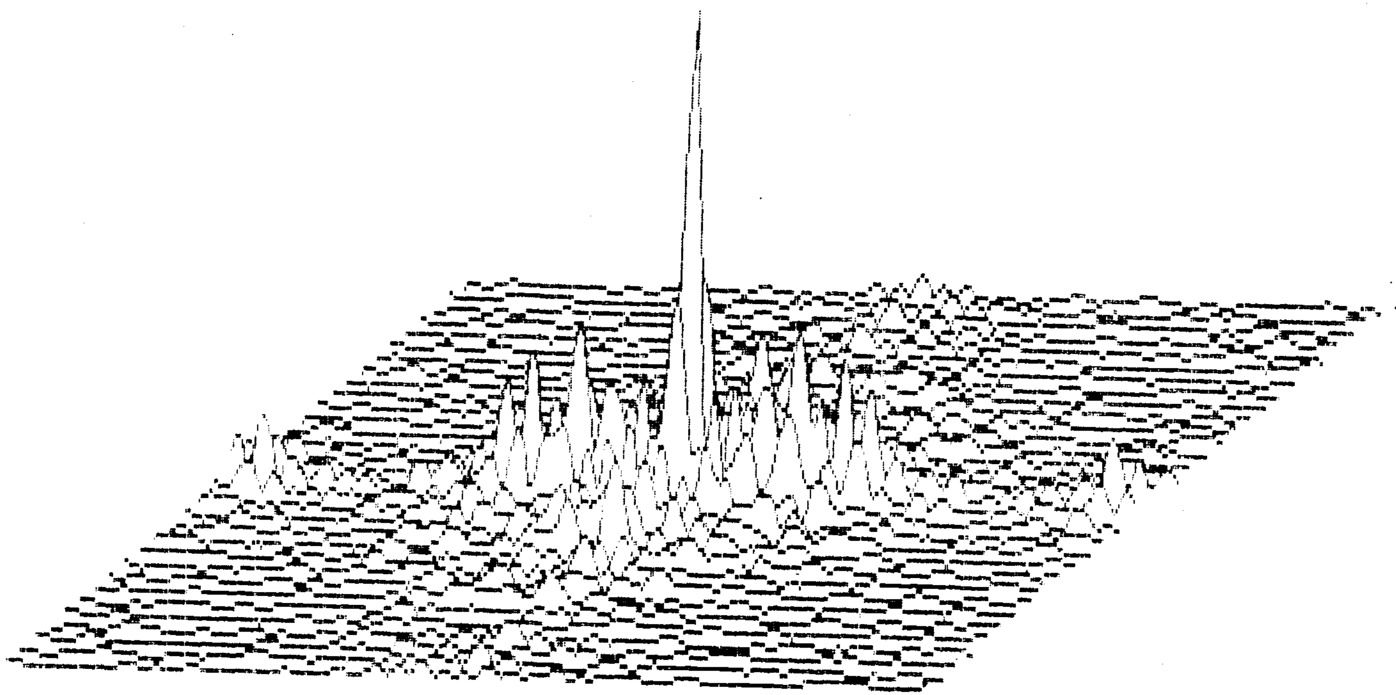
2.4313 2.8711 12.8968 26.7958 1008.00 118.067 68.5292 16.0604 29.2039
6586.93 5566.08 10953.1 8264.6904 9270.88 11433.9 5760.84 6614.0405



hair

FOURIER TRANS-
FORM OF WORD:
hair_

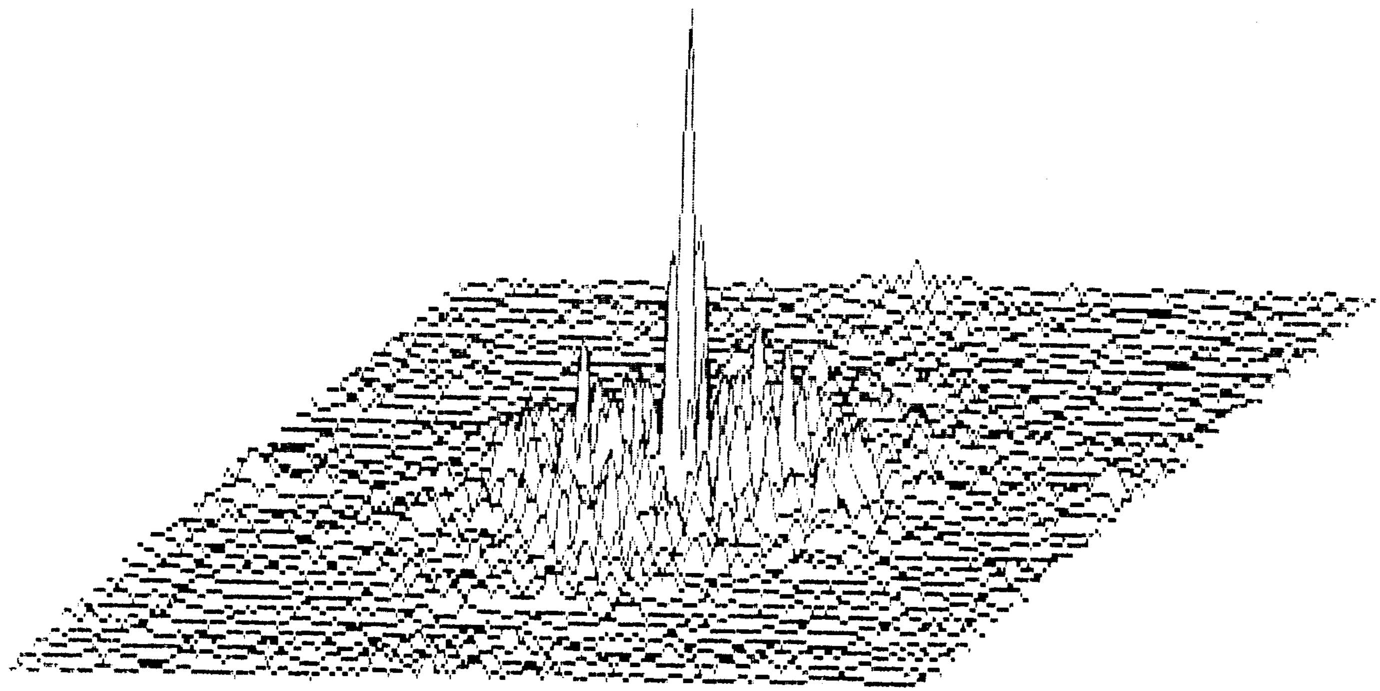
1.6451 2.0641 6.3797 9.8971 391.000 96.4445 60.6273 13.1053 23.7090
4135.54 3670.09 7402.75 5964.6592 6089.03 7748.76 3775.50 4262.1279



have

FOURIER TRANS-
FORM OF WORD:
have_

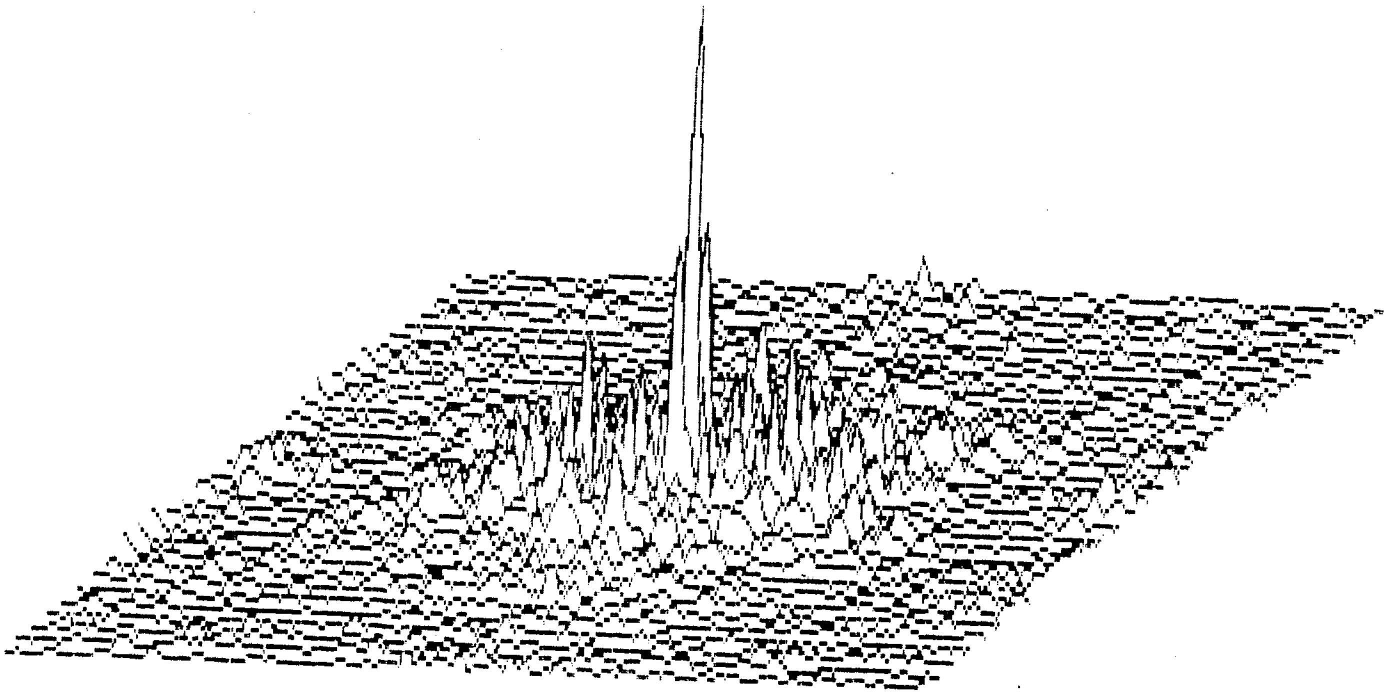
1.4697 1.8374 7.5370 11.8582 483.000 101.319 42.3392 12.7973 19.0054
4847.26 4538.29 8048.90 6953.6426 6688.00 8493.60 4746.93 4897.2837



heavy

FOURIER TRANS-
FORM OF WORD:
heavy_

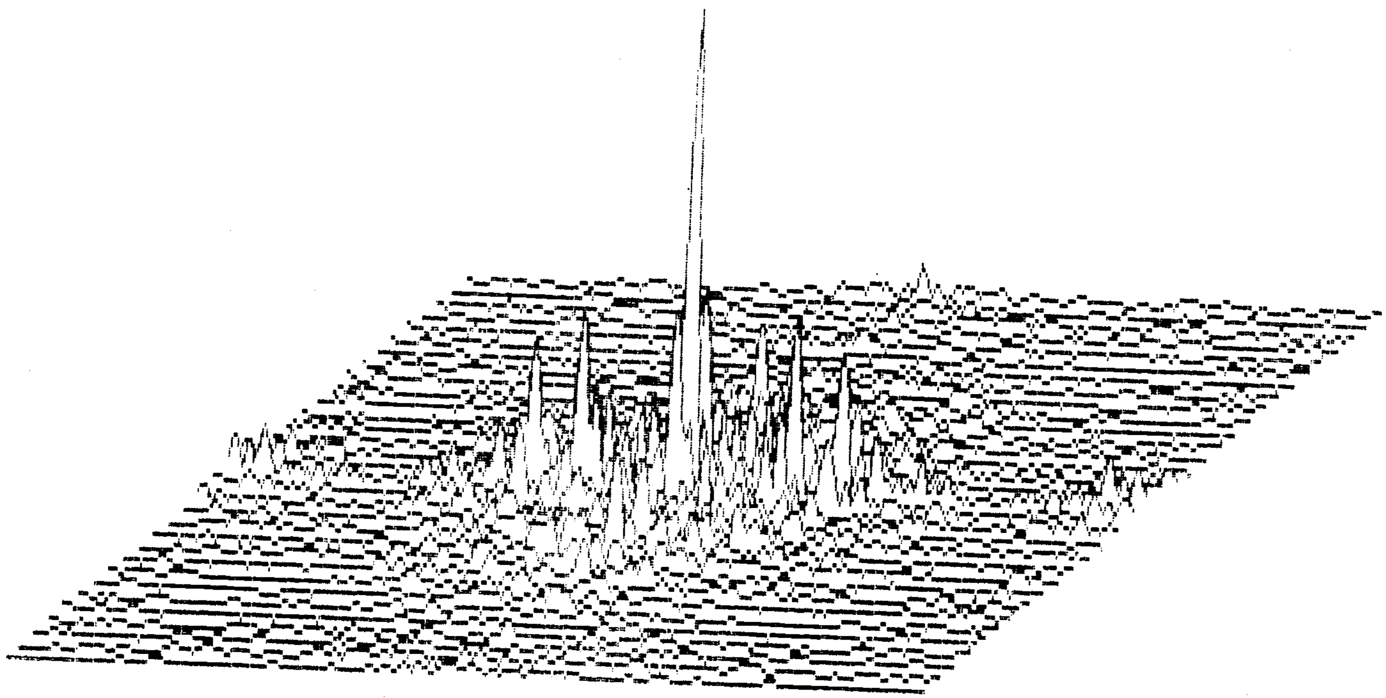
1.7659 2.1879 7.8710 13.3649 587.000 101.852 40.6481 12.9816 18.9394
5283.17 5073.68 8671.34 7278.6846 7170.85 9180.75 5335.42 5356.5635



height

FOURIER TRANS-
FORM OF WORD:
height_

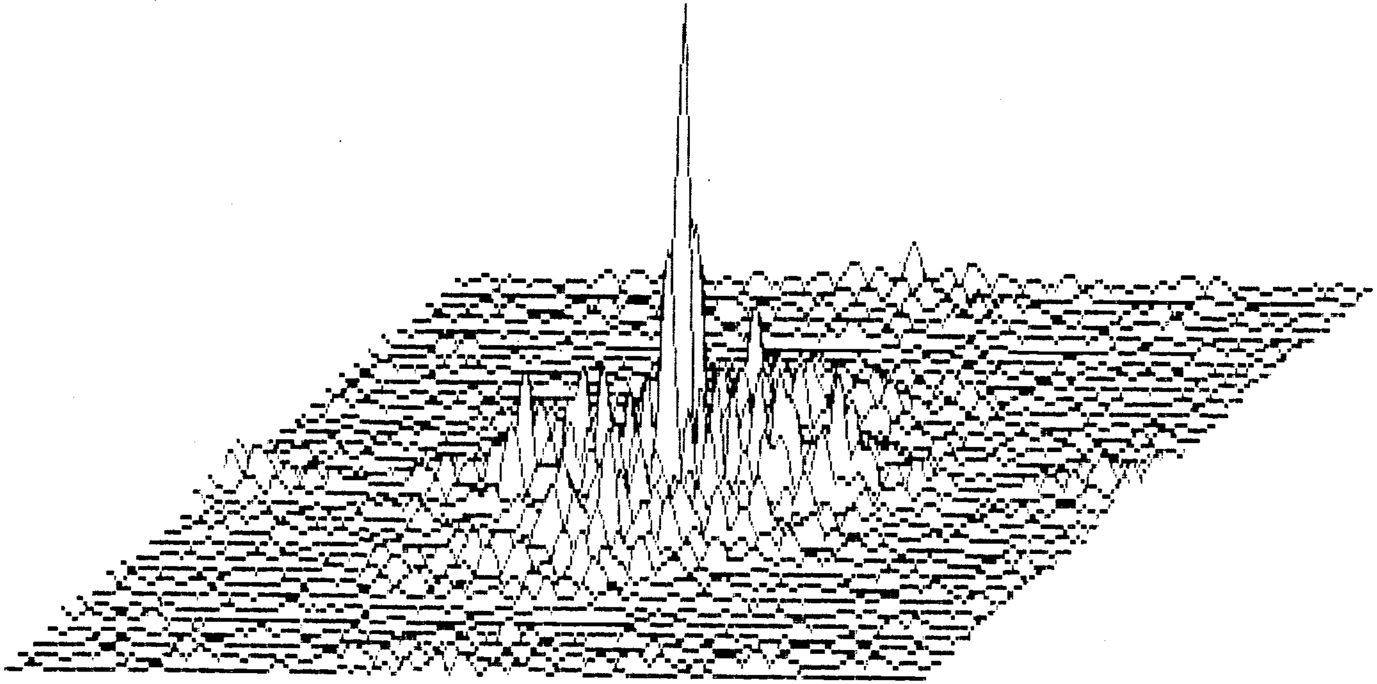
2.3777 1.6554 9.6611 16.2890 749.000 125.125 64.4297 18.5467 31.0790
5714.68 4691.53 9420.79 8125.4180 8290.14 9488.70 4770.77 5702.8340



FOURIER TRANS-
FORM OF WORD:
here_

here

1.8619 1.2520 9.3606 12.7332 484.000 100.823 45.5999 12.3252 20.7080
4430.36 3468.86 7954.88 6563.2910 6780.95 7935.01 3597.13 4739.1182

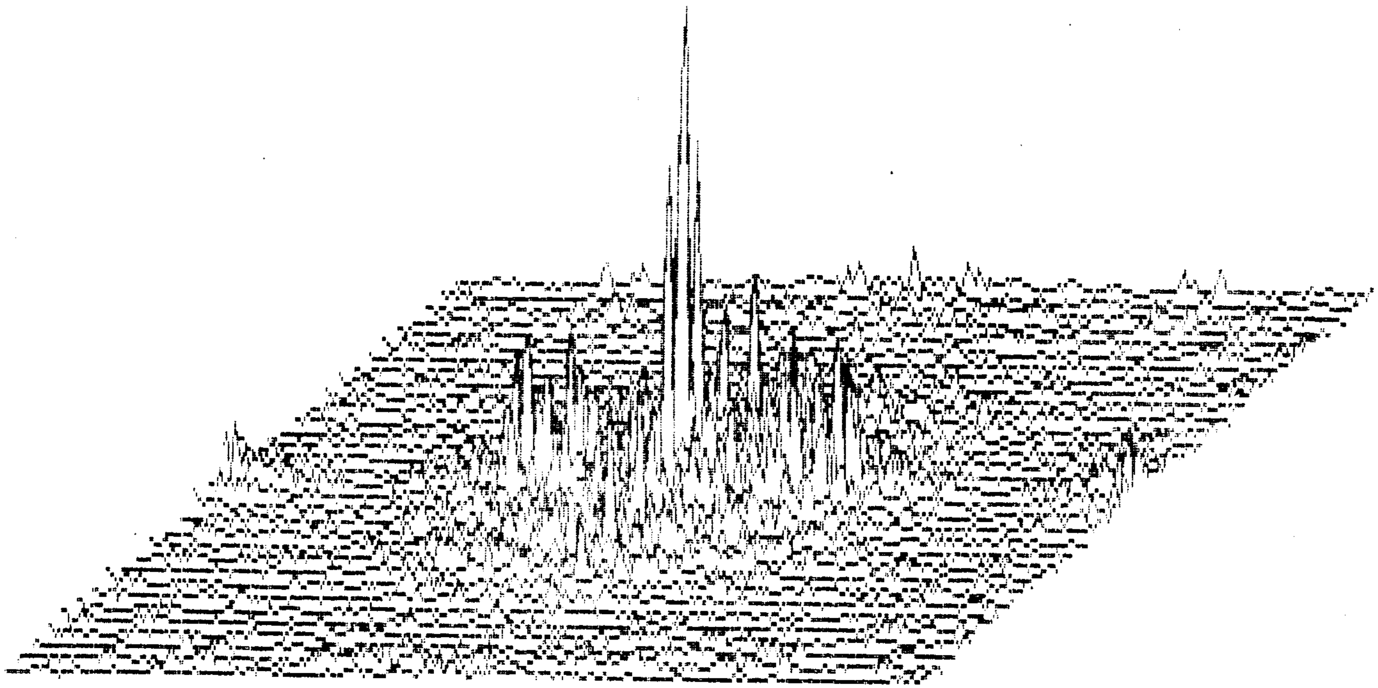


incredible

FOURIER TRANS-
FORM OF WORD:
incredible_

2.8891 2.7402 14.3529 28.3684
6823.77 5087.47 11900.1 8656.2754

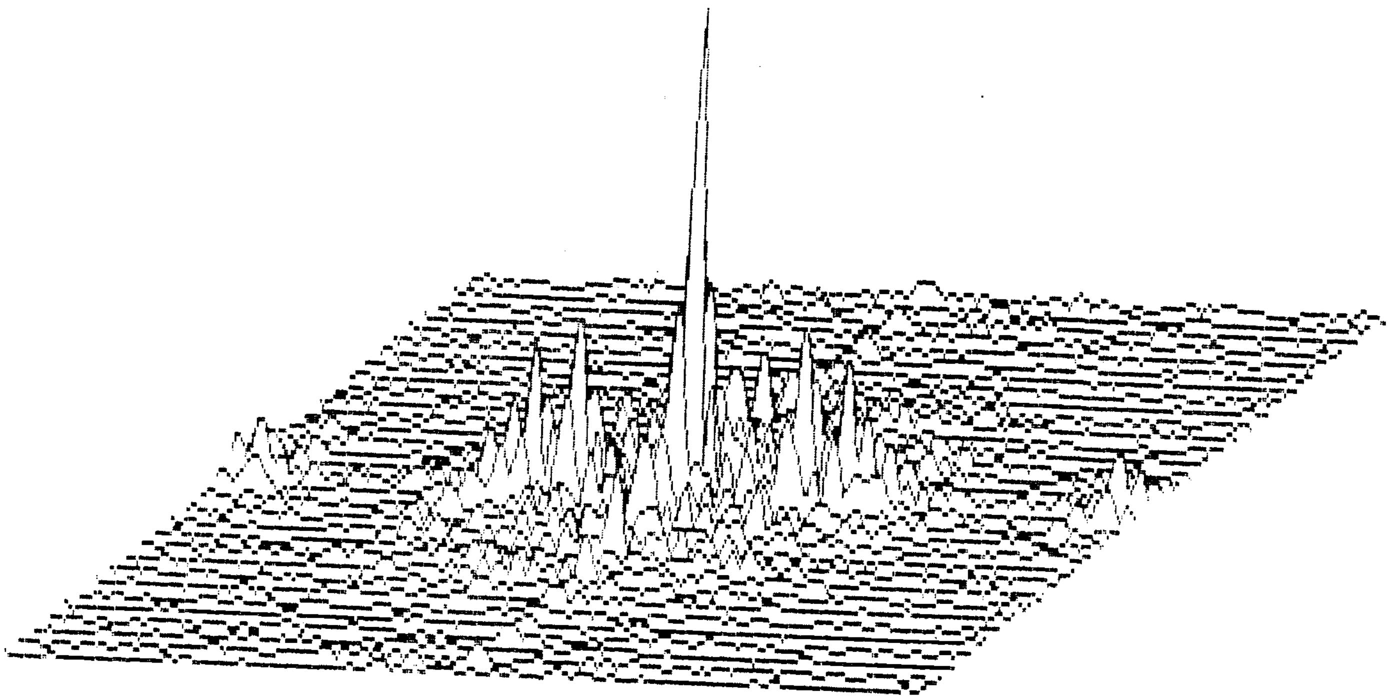
1088.00 124.548 88.3458 13.6674 34.5481
9646.78 12374.0 5231.93 6912.9219



FOURIER TRANSFORM OF WORD:
jump_

jump

1.7421 2.1122 5.8685 14.5282 554.000 100.771 73.9850 12.1416 27.2316
4845.86 3694.55 8628.35 6577.1758 7582.46 8221.42 3755.16 4782.4648

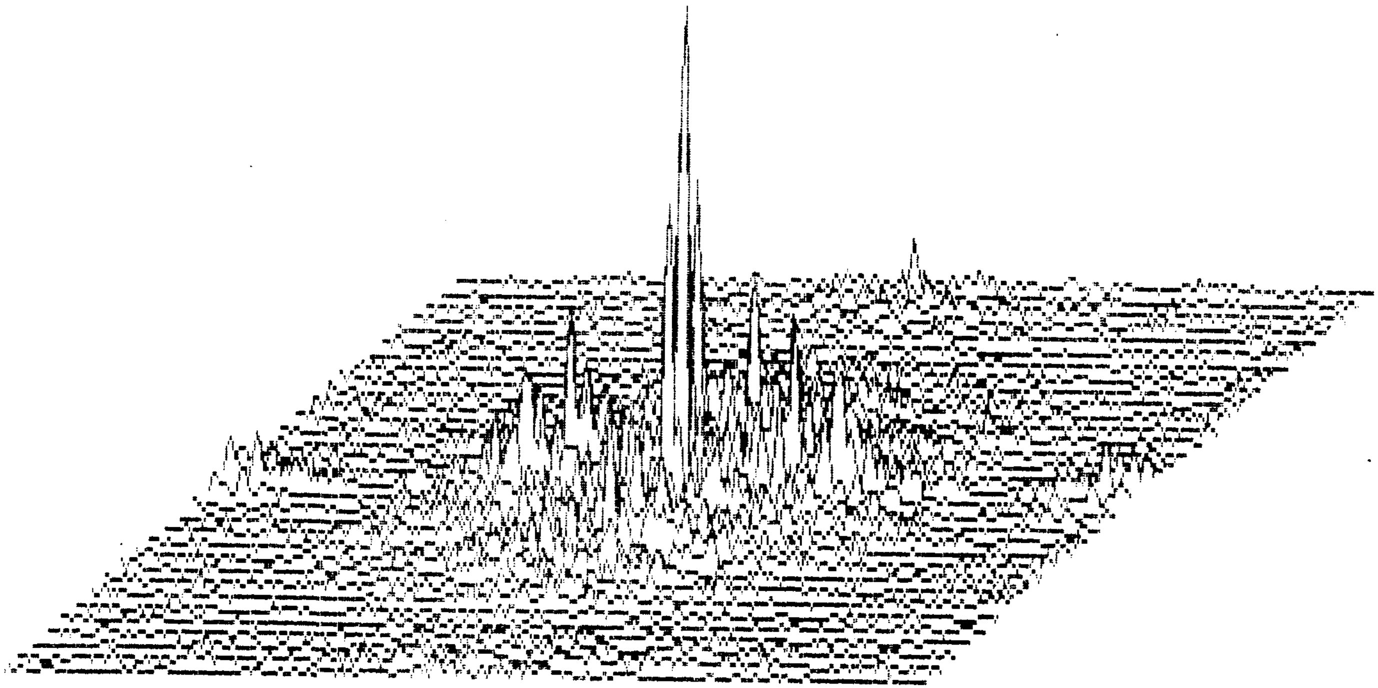


leisurely

FOURIER TRANS-
FORM OF WORD:
leisurely_

2.1159 2.6846 12.6226 19.8898
6794.25 5188.81 11719.6 7903.4531

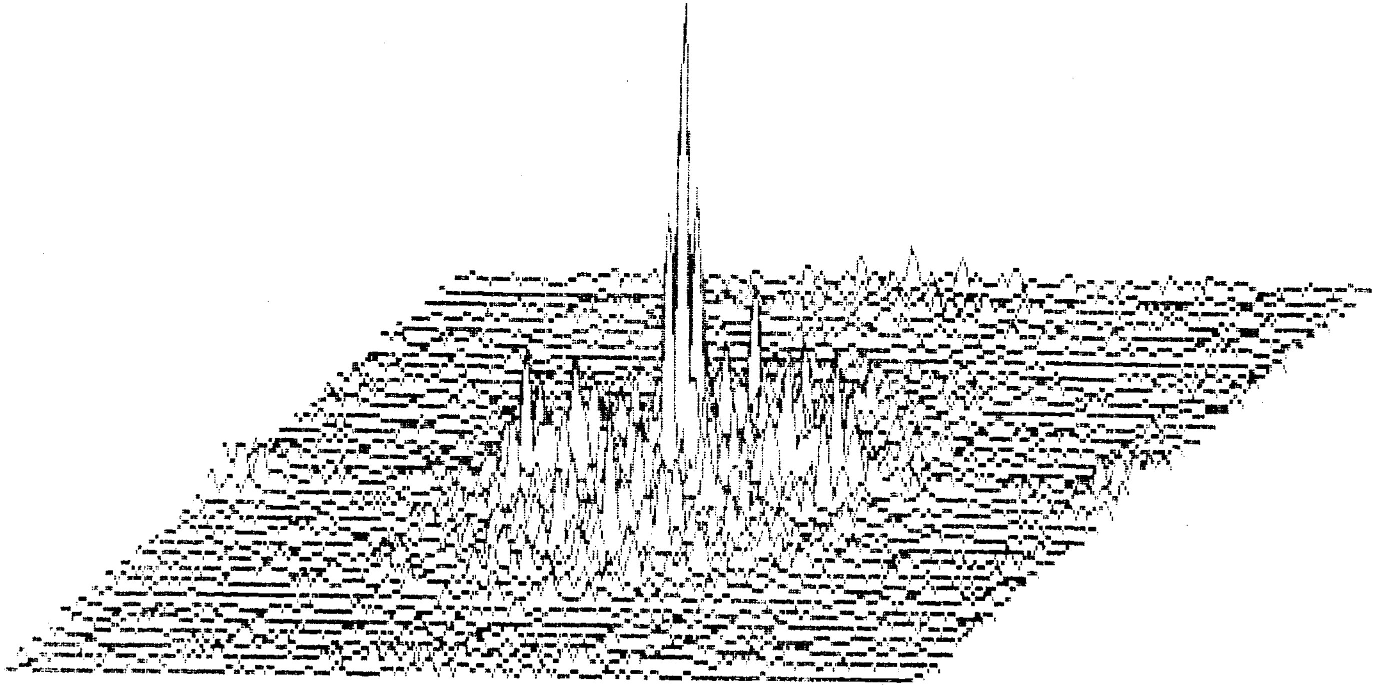
922.000 117.841 75.0856 14.6205 30.3522
8756.40 11750.2 5568.74 6620.9604



license

FOURIER TRANS-
FORM OF WORD:
license_

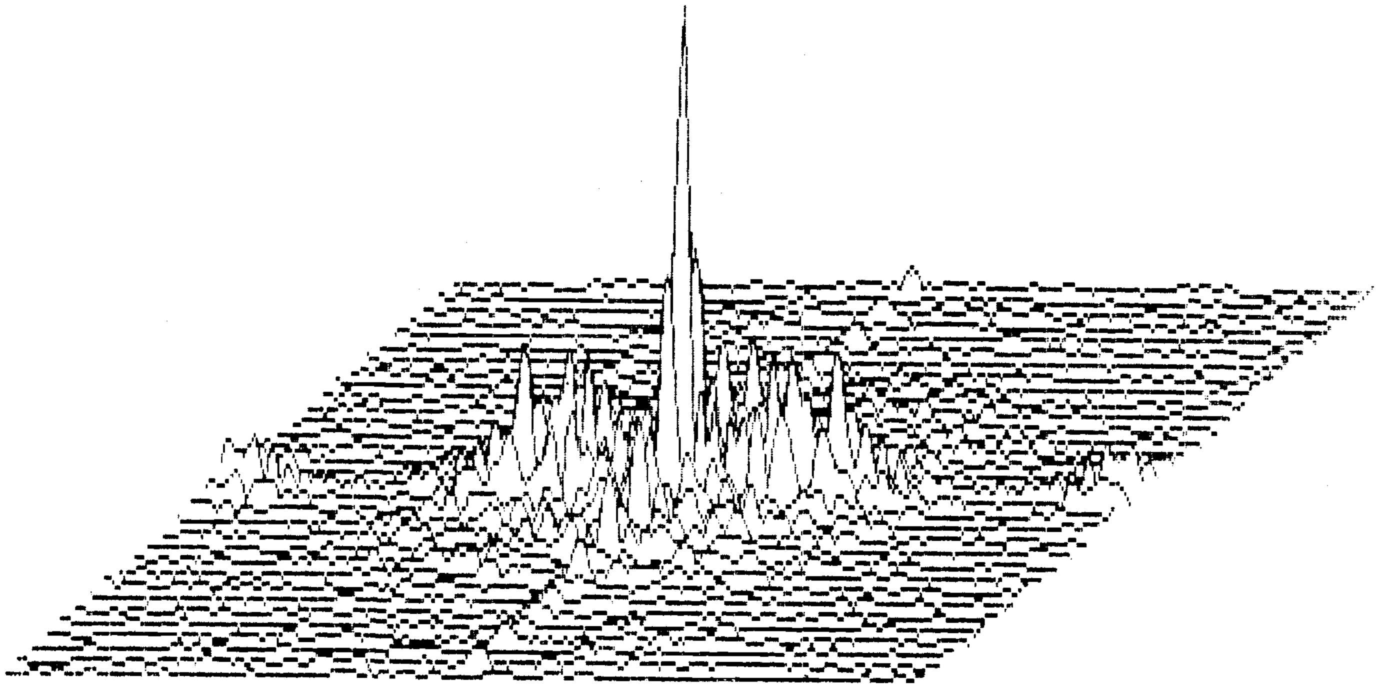
1.9899 2.2734 12.3502 20.0184 780.000 106.305 64.3658 12.2103 22.8243
6171.08 4312.64 10543.8 7320.1216 7767.61 10111.7 4501.09 5889.0640



mind

FOURIER TRANS-
FORM OF WORD:
mind_

1.6612 2.3055 6.7494 15.6039 534.000 101.907 71.4438 12.3934 28.5001
4967.30 3650.04 8329.60 6598.1689 7353.29 8119.87 3664.82 4725.4233

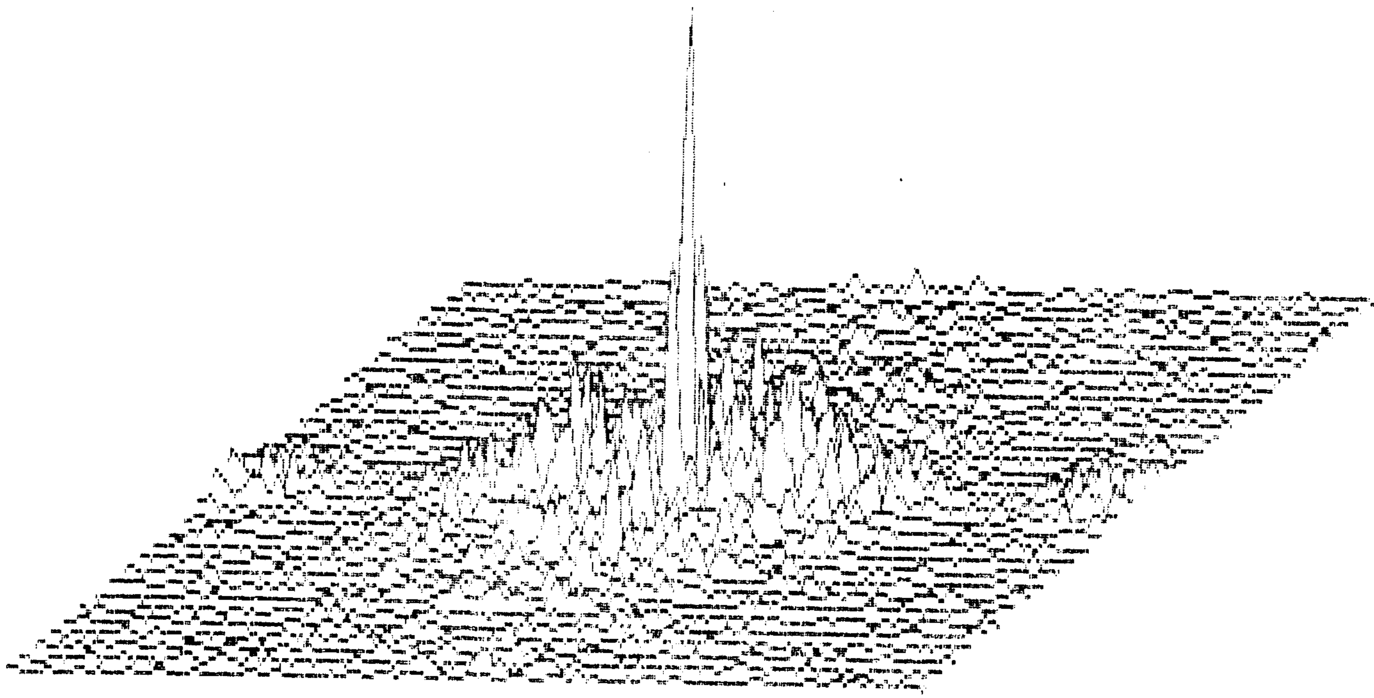


moral

FOURIER TRANS-
FORM OF WORD:
moral

1.9887 2.3584 8.1291 16.0684
5319.28 4104.19 8483.35 7419.6548

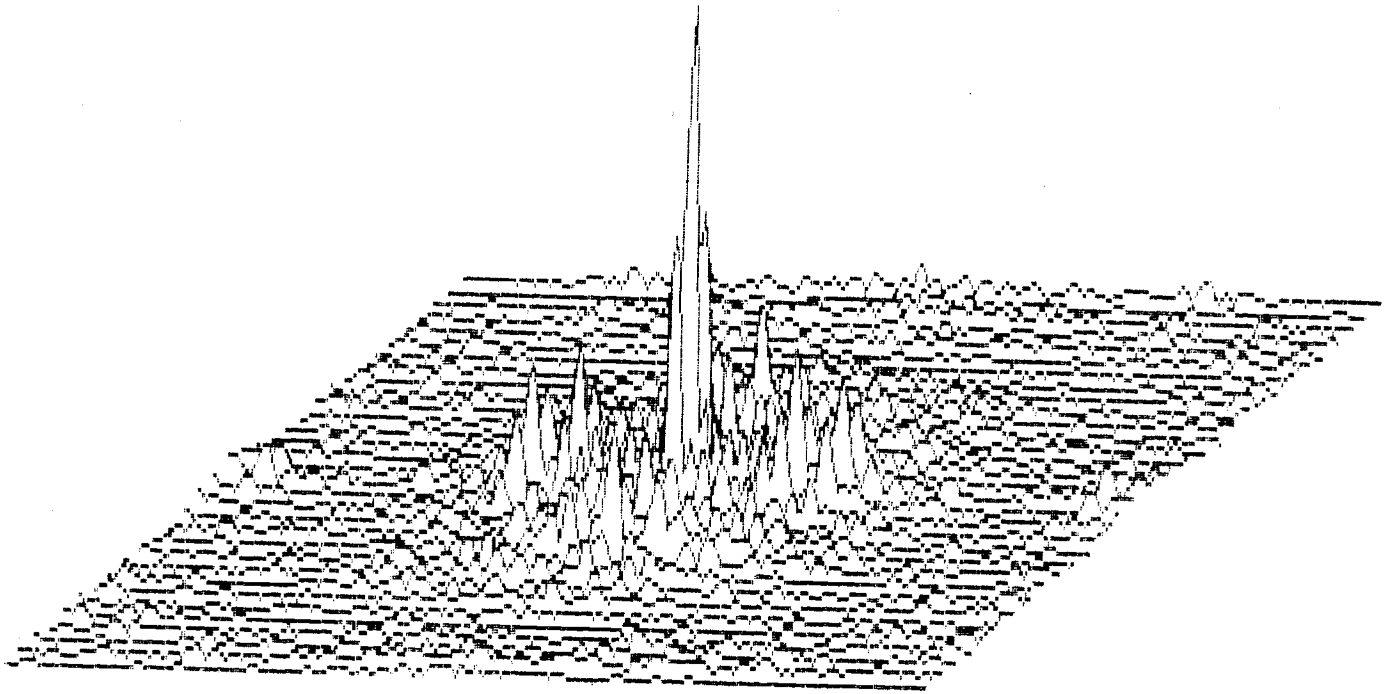
582.000 109.748 61.7953 12.5866 26.5076
7855.33 8930.42 4377.62 5209.2666



noise

FOURIER TRANS-
FORM OF WORD:
noise_

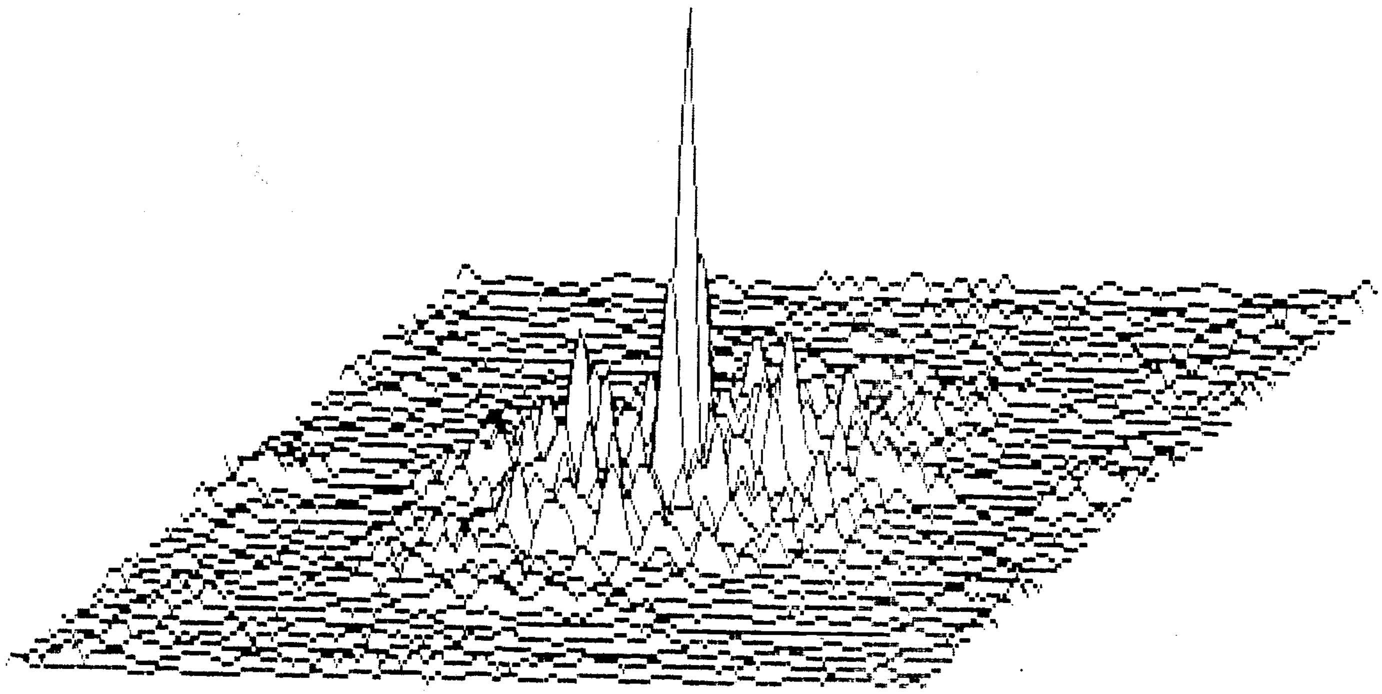
1.7626 1.5521 9.6736 15.7433 579.000 93.0907 45.5146 11.5328 19.3890
5510.19 3868.79 8933.02 6551.4600 6992.68 8736.58 3988.36 5202.7485



oak

FOURIER TRANSFORM OF WORD:
oak_

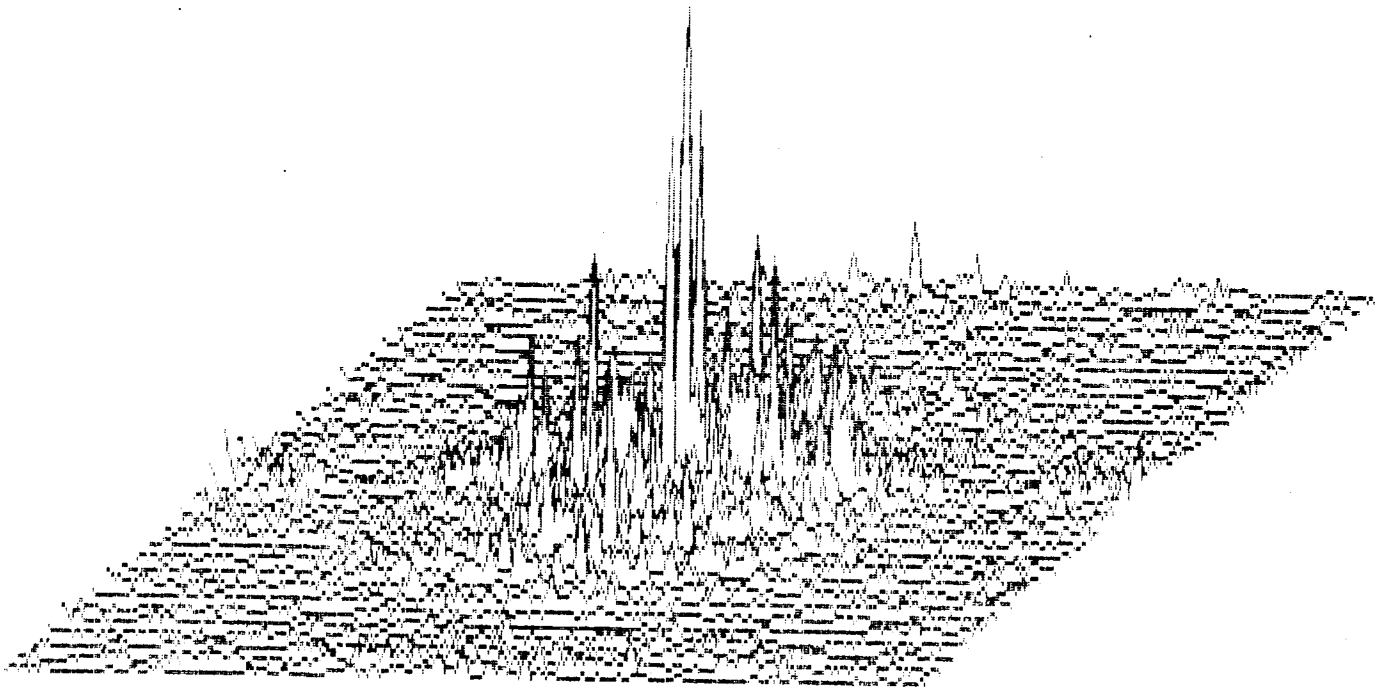
1.0339 1.3251 4.8278 9.1972 371.000 88.0465 39.0259 8.4707 17.7719
3942.08 3988.00 6883.26 6072.7271 6236.45 7498.95 4129.57 4436.3945



preferred

FOURIER TRANS-
FORM OF WORD:
preferred_

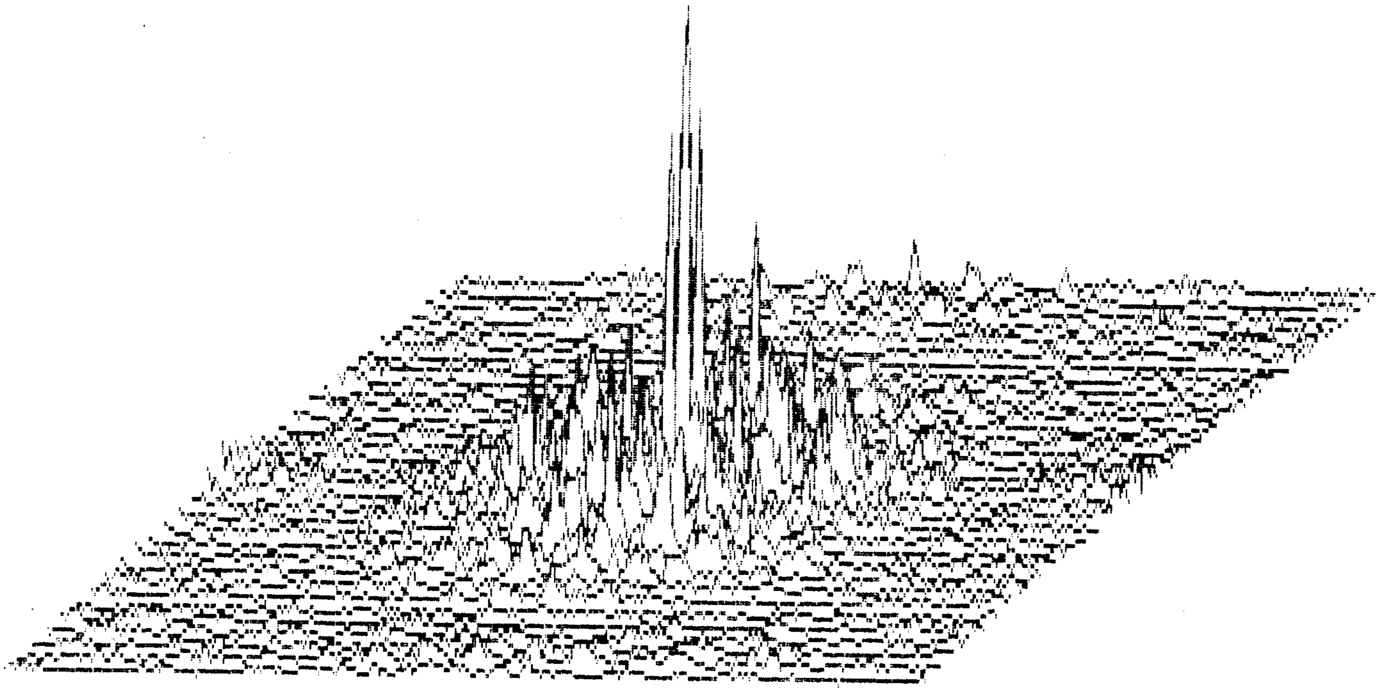
3.1673 2.5262 18.1191 27.2272 1035.00 134.939 65.9599 17.0990 28.9533
6106.38 5014.38 10828.4 8502.7607 10371.7 11210.8 5277.22 7023.0498



professor

FORM OF WORD:
professor_

3.2719 2.7669 18.0249 28.3373 1046.00 119.504 58.3328 15.2660 24.7716
6944.70 4893.12 11343.4 8053.6797 9906.81 11013.9 5162.61 7149.5820

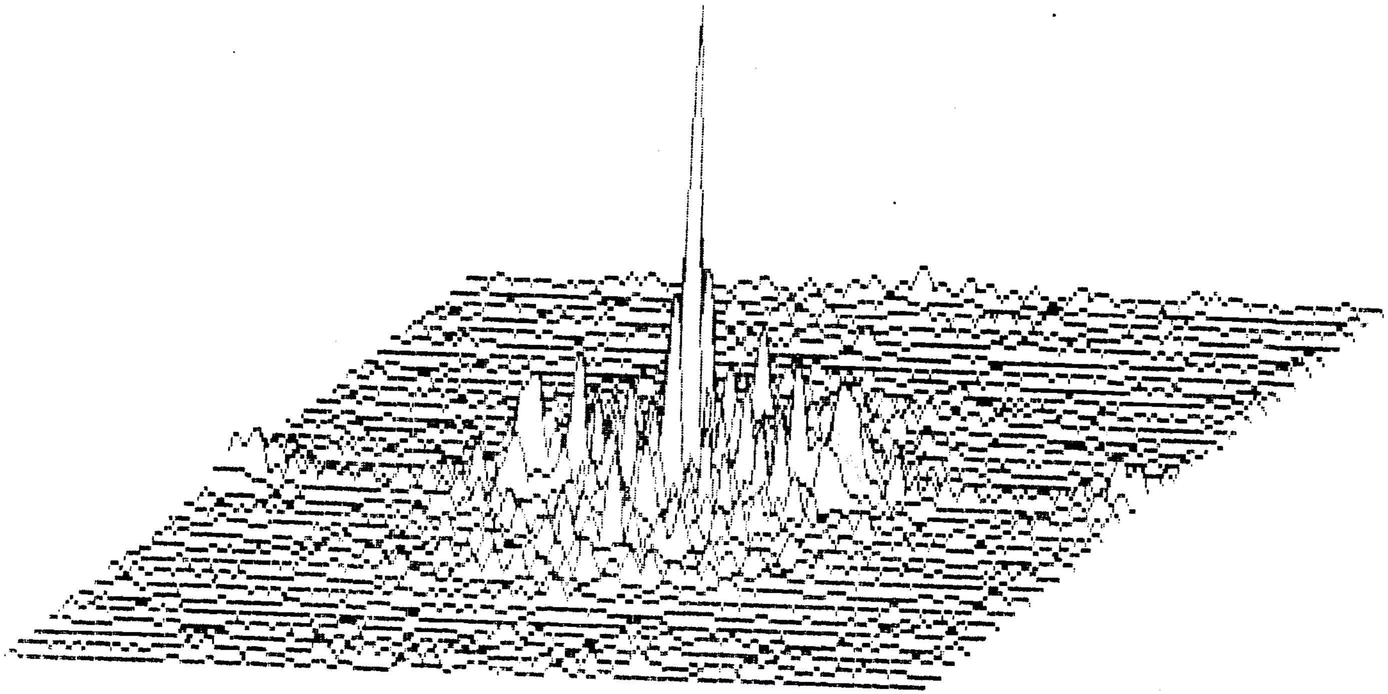


quiet

FOURIER TRANS-
FORM OF WORD:
quiet_

1.5417 1.5893 7.8901 14.3955
4888.60 4181.49 8543.37 6935.2861

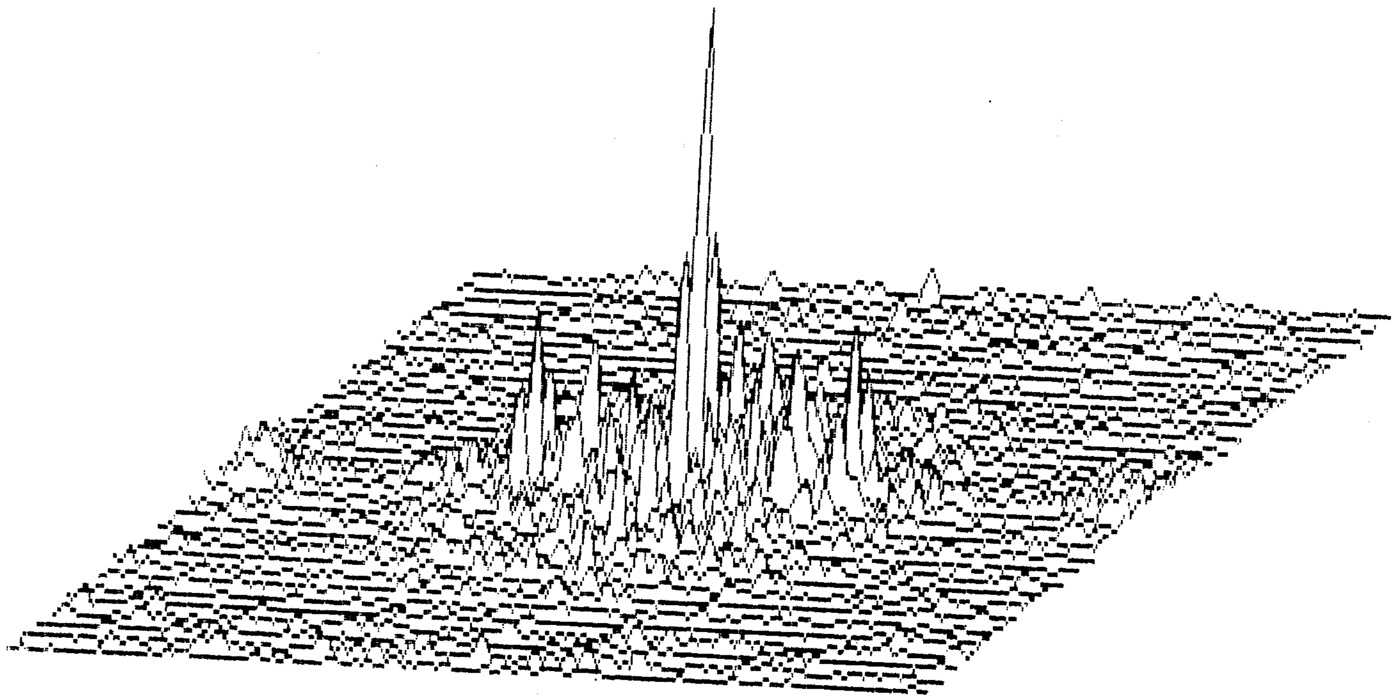
569.000 108.646 65.8852 14.0111 25.6188
7357.72 8887.82 4051.71 4935.5161



round

FOURIER TRANS-
FORM OF WORD:
round_

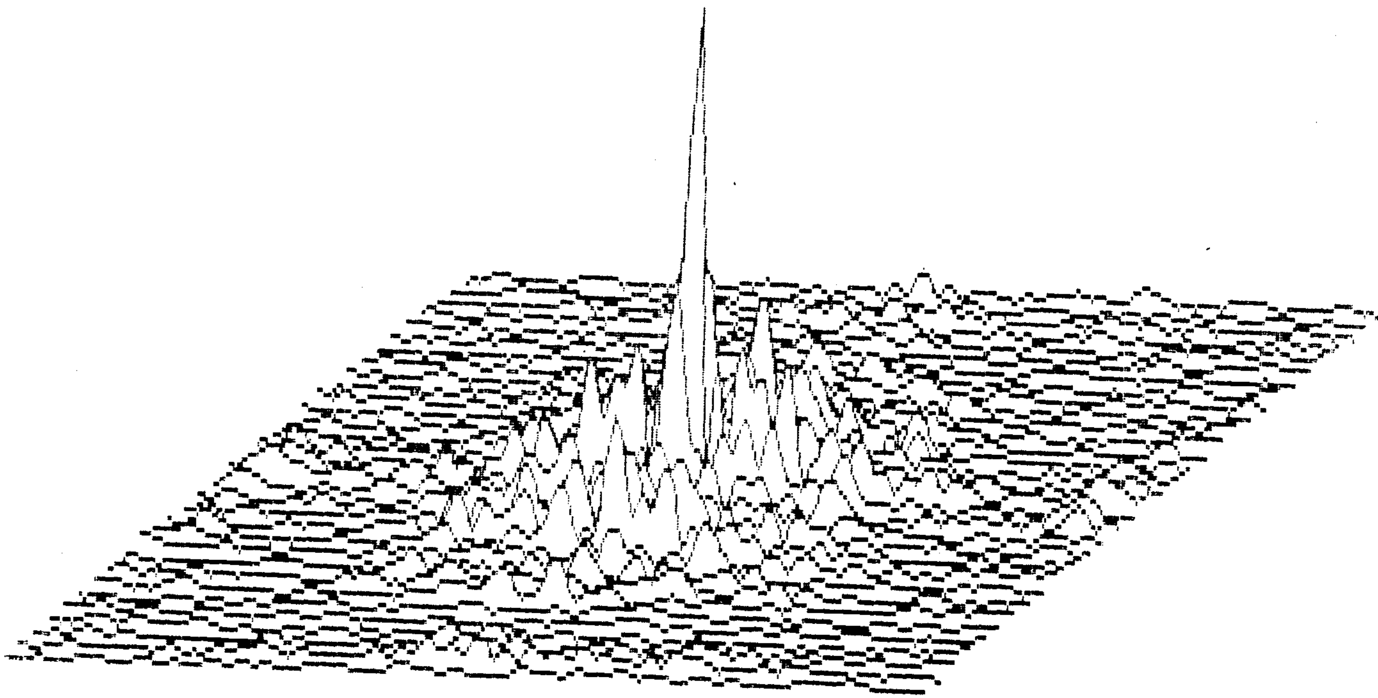
1.7479 1.6243 7.5465 17.9711 591.000 105.313 54.9828 14.3843 25.3253
4965.25 3937.40 8178.39 7121.8887 8256.62 7812.31 3888.97 4961.0142



sat

FOURIER TRANSFORM OF WORD:
sat_

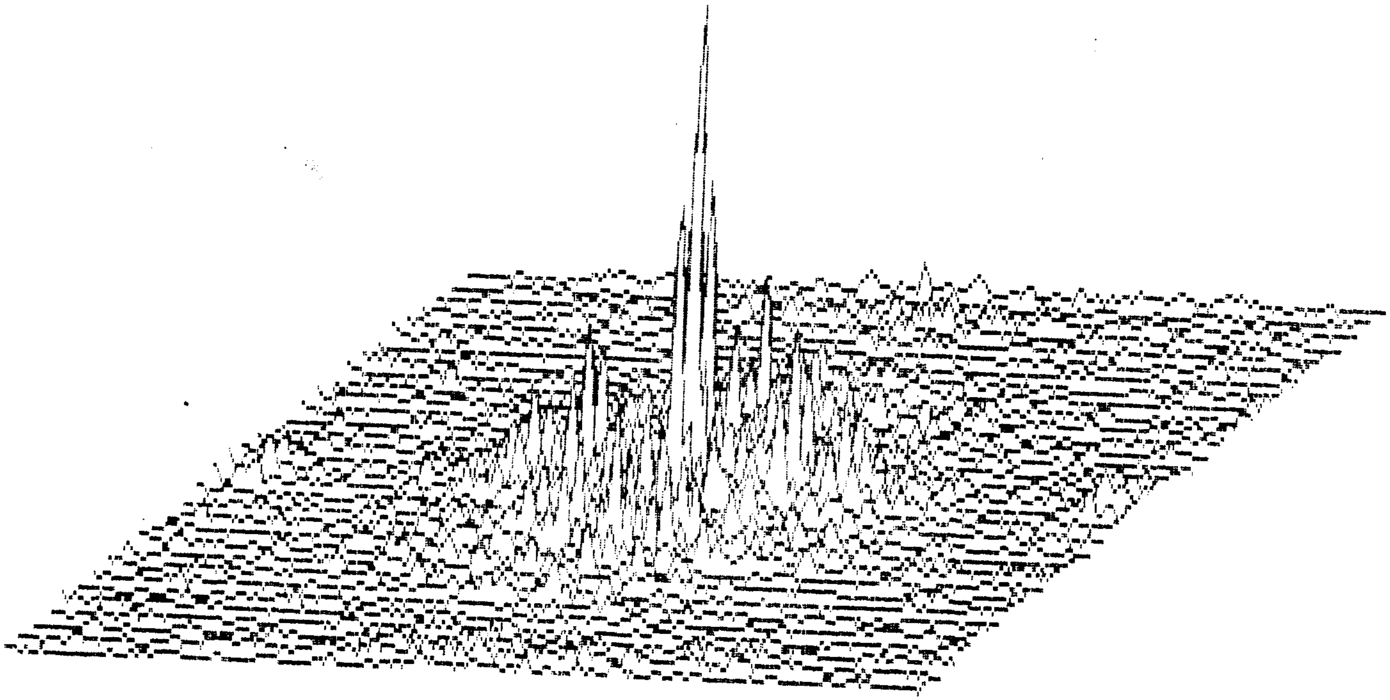
1.3163 1.8901 7.0561 8.9836 353.000 99.1291 29.4215 12.8767 14.6379
4461.86 3773.34 7107.65 6091.3179 5827.06 6592.36 3789.20 4074.1067



saucer

FOURIER TRANS-
FORM OF WORD:
saucer_

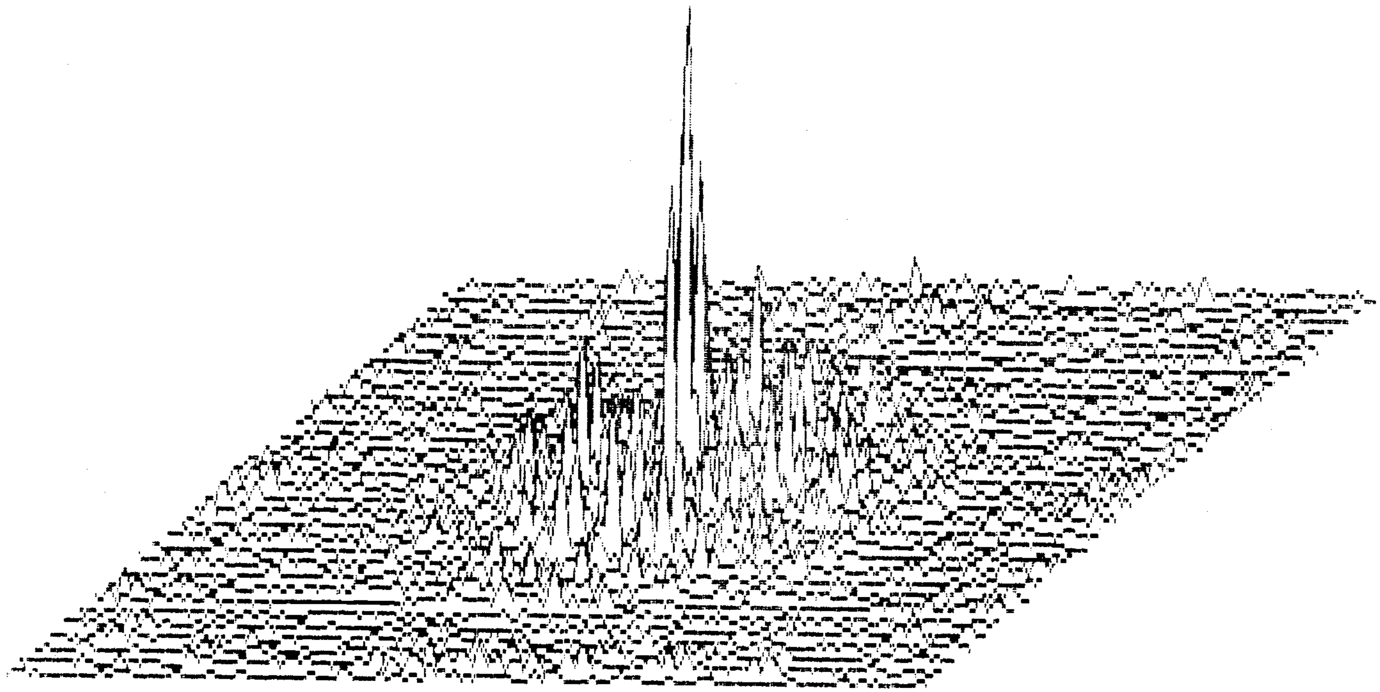
1.8487 2.6929 12.4188 20.1702 692.000 100.725 43.1995 11.2296 17.7268
5742.45 4638.39 9523.72 6873.0947 7796.73 9444.41 4801.29 5783.0923



season

FOURIER TRANS-
FORM OF WORD:
season_

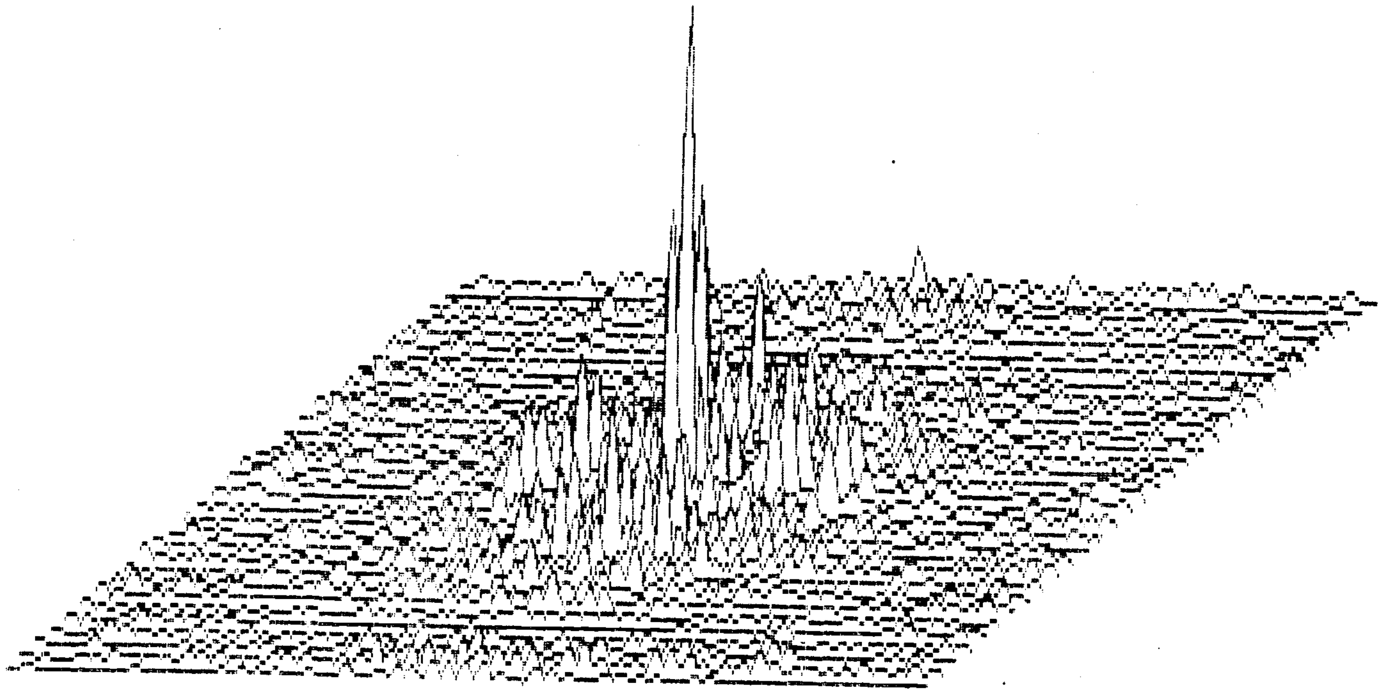
2.1618 3.0357 15.1702 21.4017 779.000 99.9305 38.5847 10.2235 15.8859
6288.50 4711.62 9823.79 7058.3081 7620.83 9455.91 4905.90 5881.4194



sense

FOURIER TRANS-
FORM OF WORD:
sense_

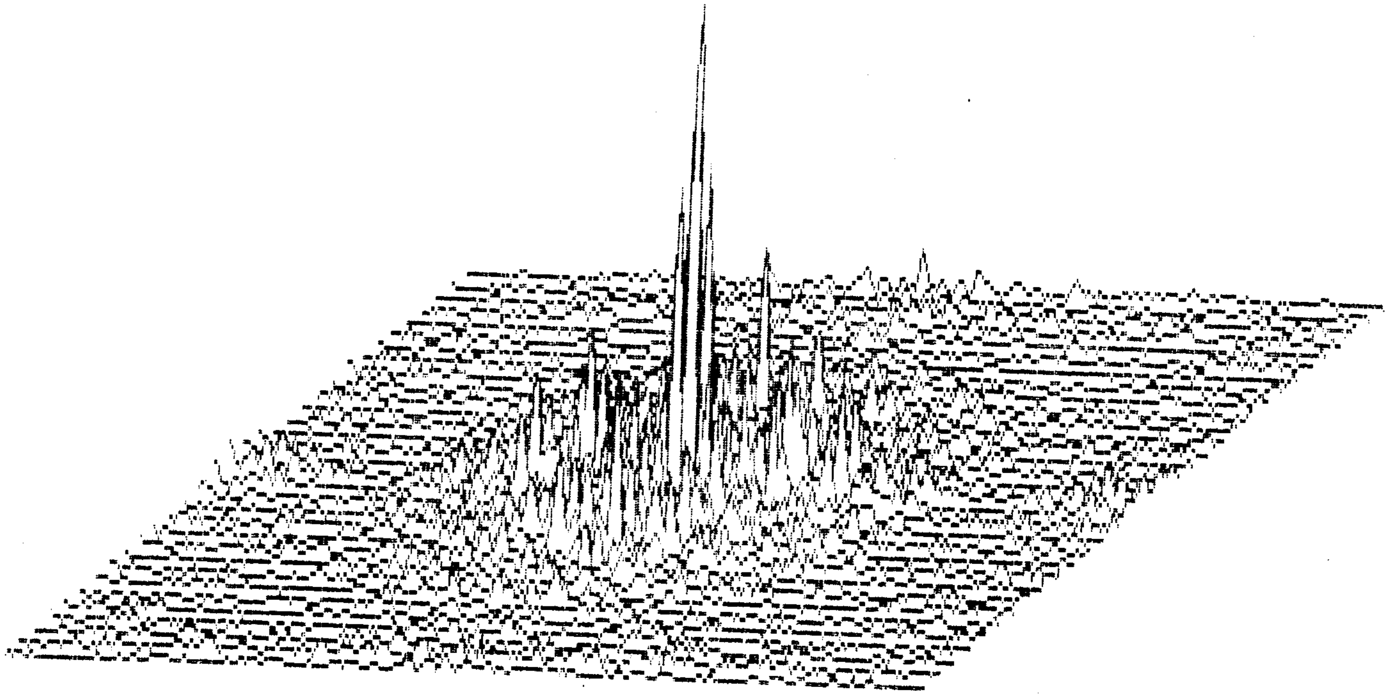
2.0528 2.4835 14.3956 18.3084 674.000 93.6319 25.6810 8.6764 14.1614
5698.23 3833.53 8730.19 6228.0820 7053.65 8212.08 4046.11 5249.1875



sergeant

FOURIER TRANS-
FORM OF WORD:
sergeant_

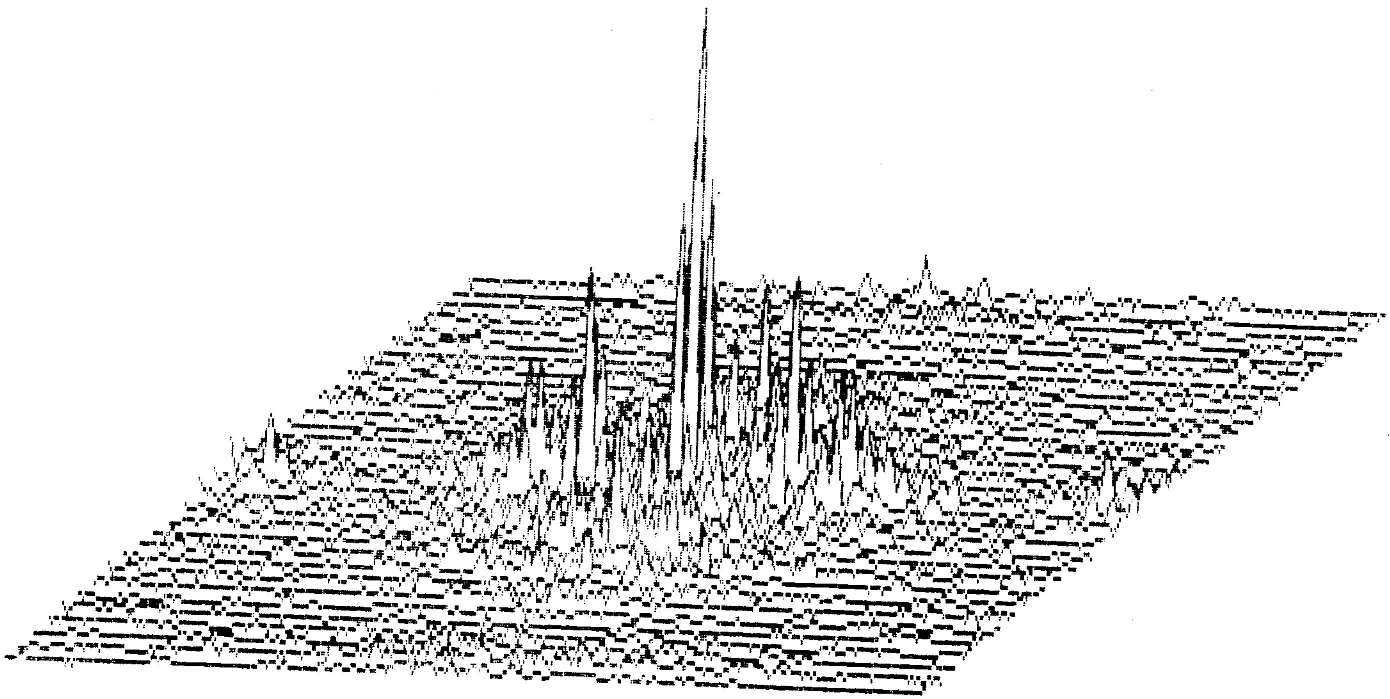
2.8051 2.9039 17.2758 25.3369 1002.00 123.492 54.2380 15.4057 24.7579
6843.46 5638.52 10977.9 8057.0381 9338.35 10886.1 5842.83 6738.3872



shoulder

FOURIER TRANS-
FORM OF WORD:
shoulder_

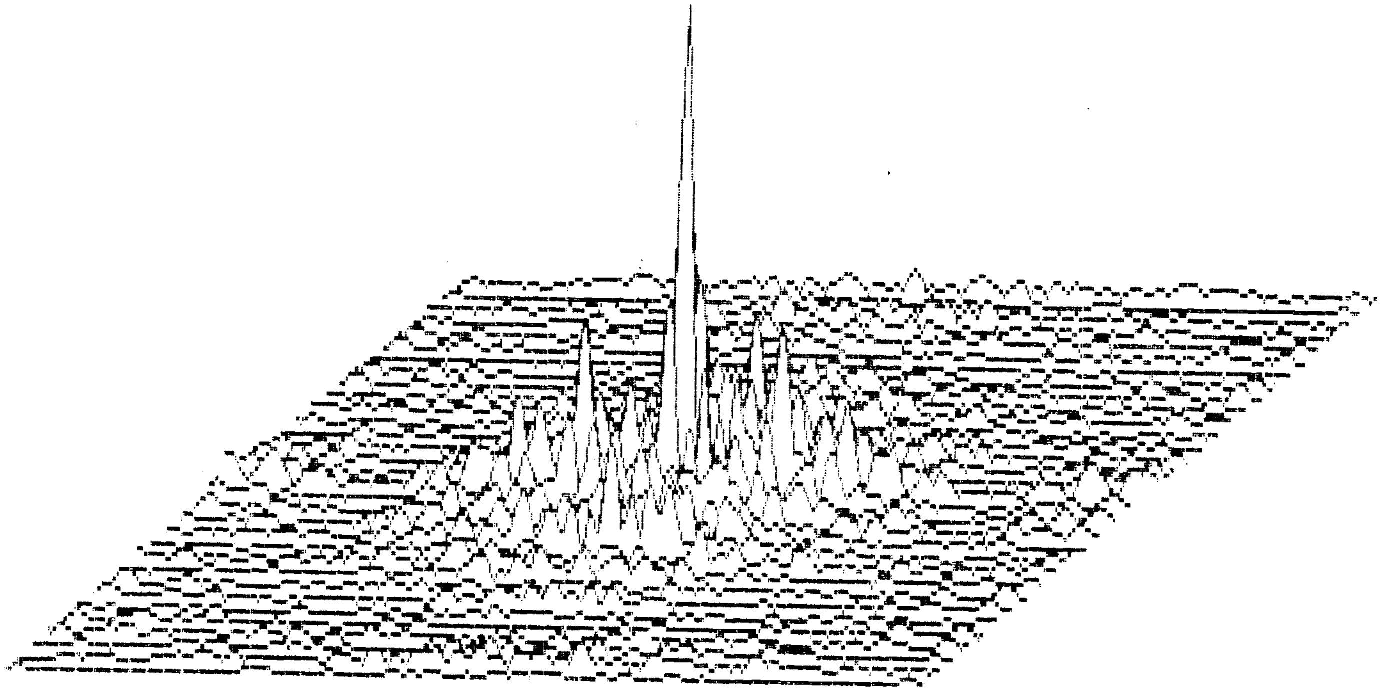
2.4472 2.5424 13.2752 24.8415 959.000 112.589 71.7558 16.9024 29.7349
6596.48 4867.25 11153.9 8190.9062 8879.90 10837.4 4936.08 6432.2891



sold

FOURIER TRANS-
FORM OF WORD:
sold_

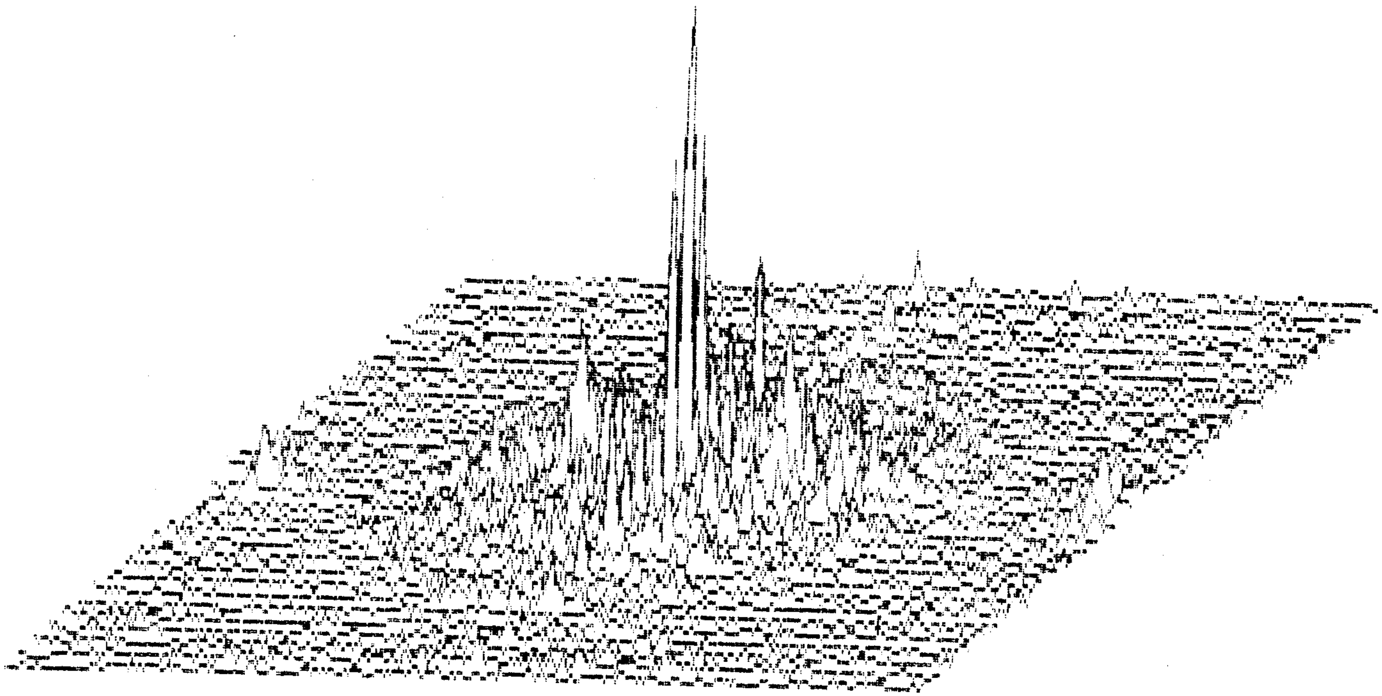
1.4556 1.5644 6.5952 12.4853 493.000 101.740 49.5153 12.3508 21.6514
5119.49 3455.46 8523.59 6912.3237 7247.99 7922.52 3494.96 4734.2104



stationary

FOURIER TRANS-
FORM OF WORD:
stationary_

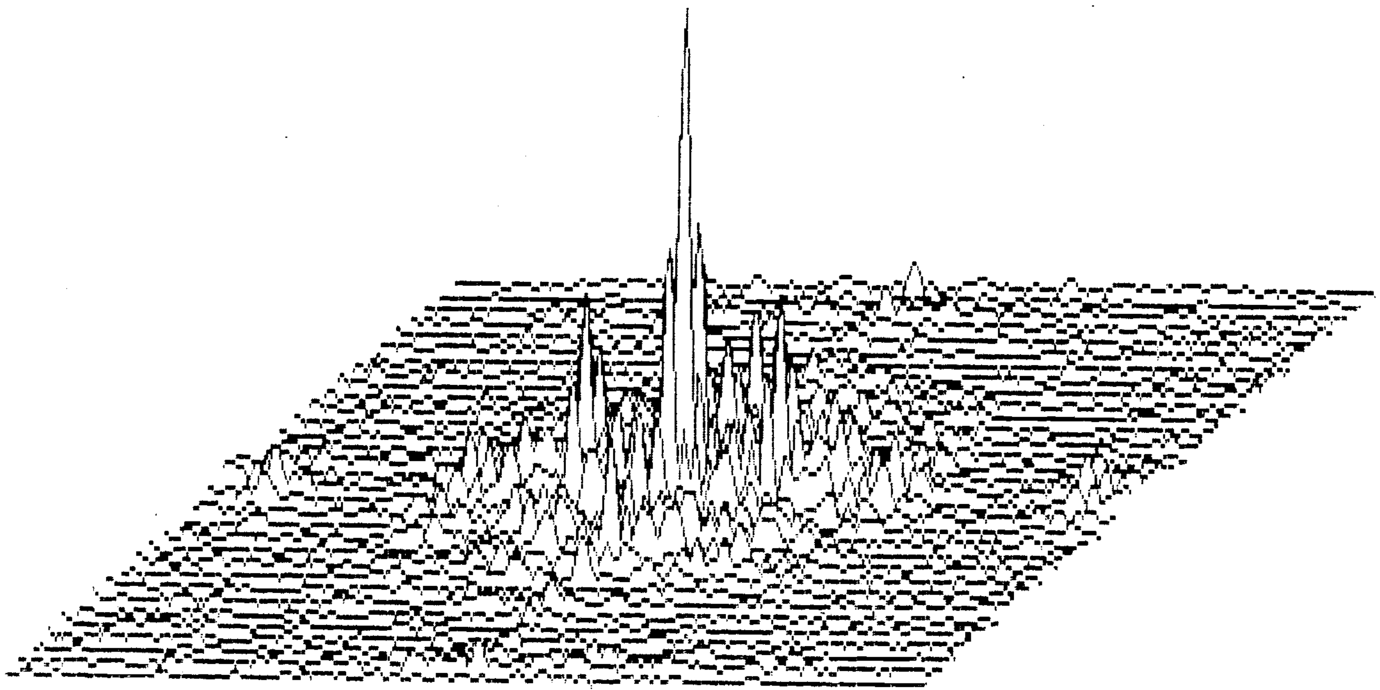
3.5011 4.2413 15.9010 26.5702 1046.00 129.770 69.5051 17.1113 28.8326
7266.16 6339.18 11895.8 8536.5791 9574.11 11974.7 6568.62 6927.0518



storm

FOURIER TRANS-
FORM OF WORD:
storm_

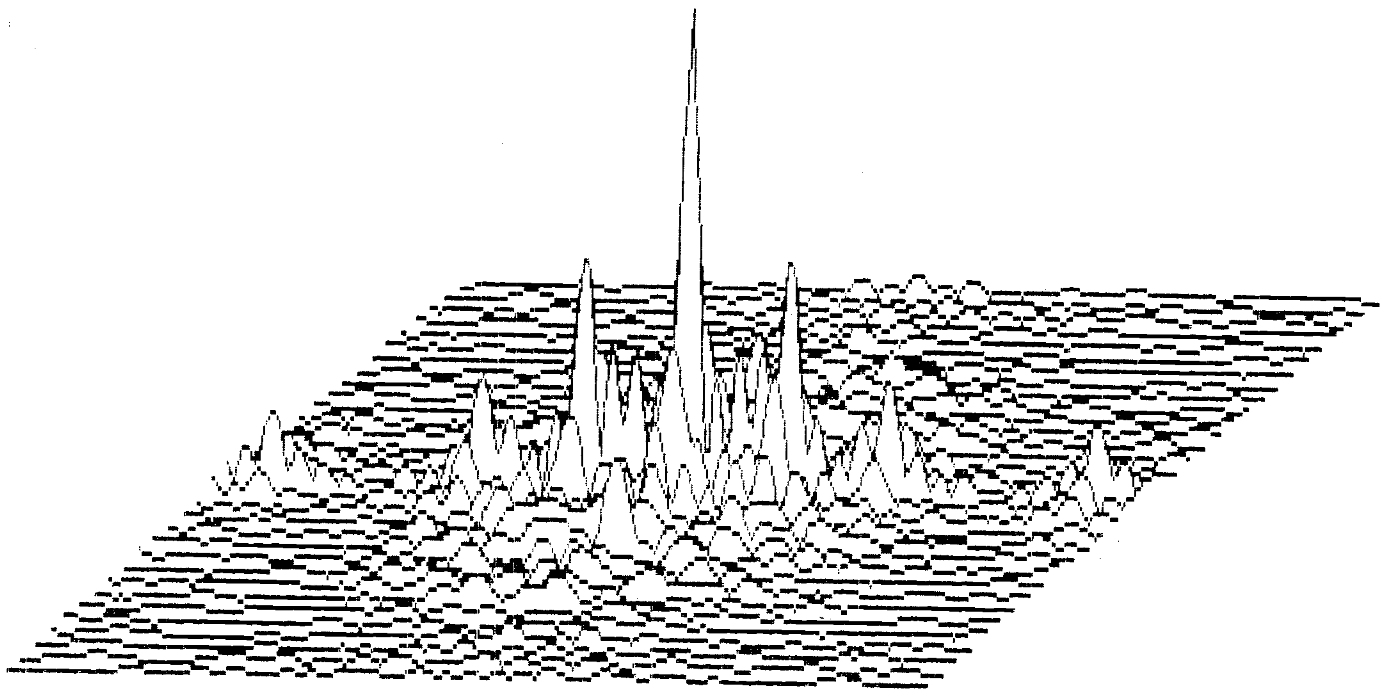
2.3738	2.1708	9.7106	18.1855	611.000	105.328	54.7458	11.9844	23.2412
5689.43	3845.68	9262.75	7123.8418		7654.55	8497.96	4038.35	5368.7329



tail

FOURIER TRANS-
FORM OF WORD:
tail_

1.1551 1.7275 4.8429 7.6788 354.000 112.307 47.1867 11.3387 24.9160
4224.66 3582.40 6313.80 6438.3340 6168.28 6797.29 3707.52 3874.5618

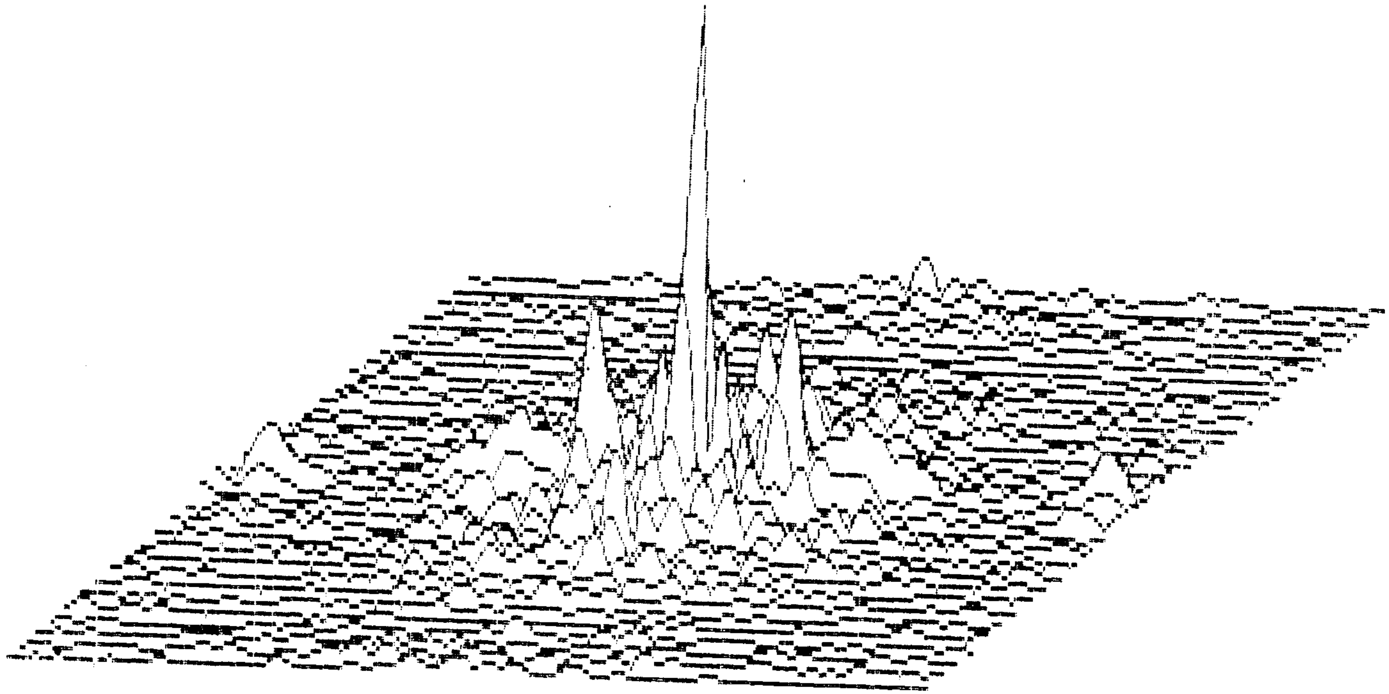


the

FOURIER TRANS-
FORM OF WORD:
the_

1.2346 .9981 5.9175 8.8509
4023.01 3190.20 7205.15 6621.8071

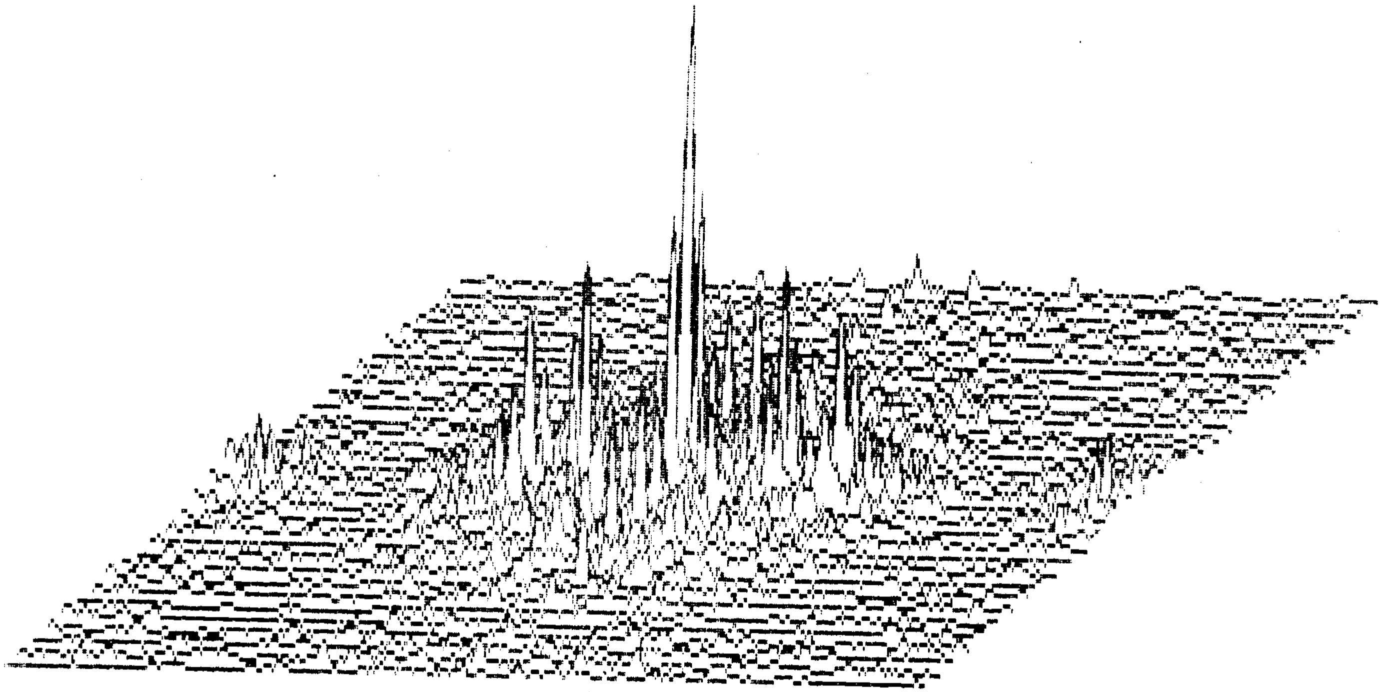
370.000 103.280 48.4968 10.3520 20.0247
6039.52 7110.59 3003.22 3951.2686



thorough

FOURIER TRANS-
FORM OF WORD:
thorough_

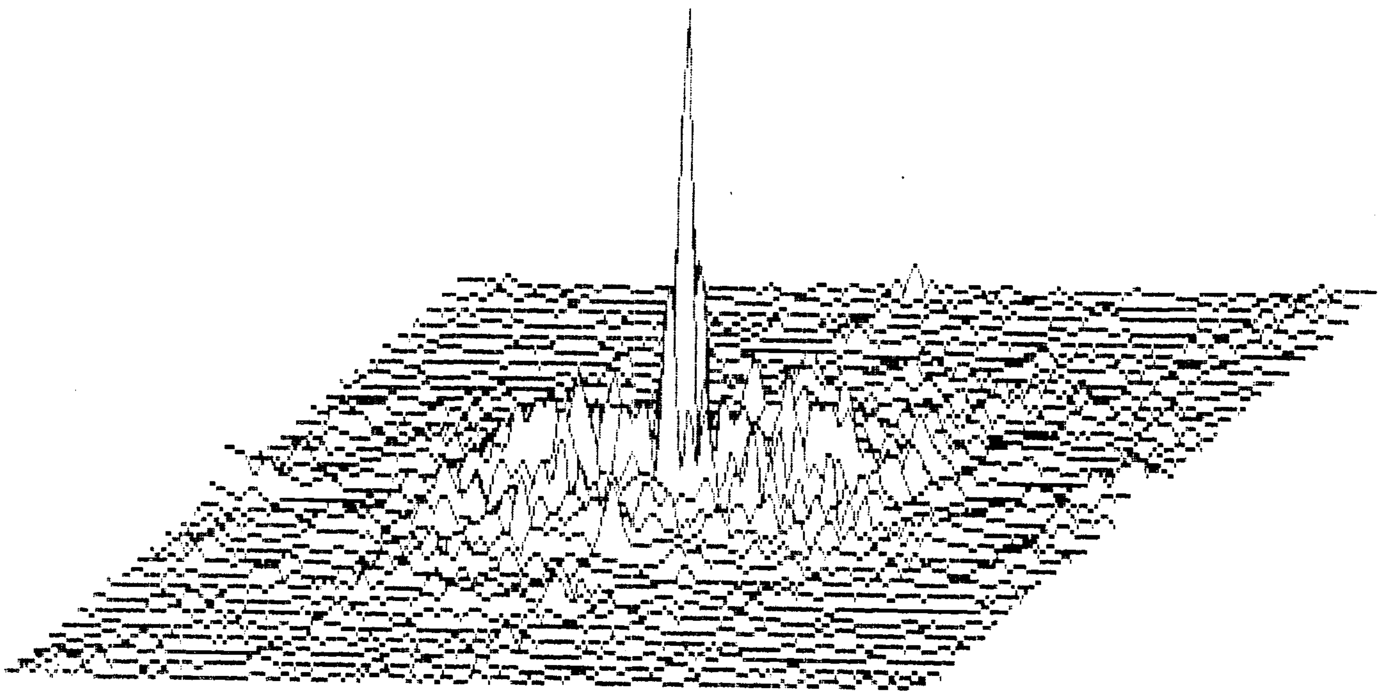
3.4152 2.6337 12.2701 25.5330 980.000 126.324 70.1421 17.5768 30.5889
6330.13 4978.34 10523.6 8871.4658 9476.52 10260.0 5157.15 6294.3481



walk

FOURIER TRANS-
FORM OF WORD:
walk_

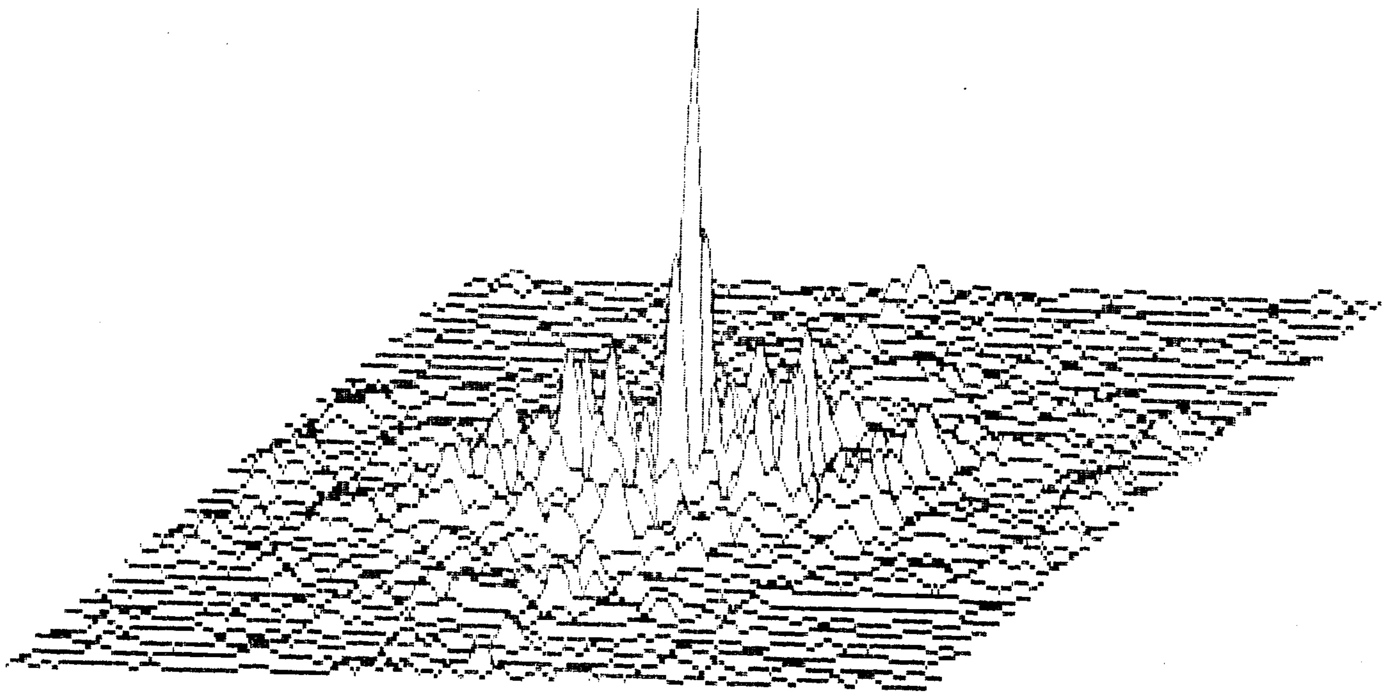
1.3762 2.1002 4.5251 9.9535 469.000 94.2849 60.7677 7.7992 23.2387
4856.82 4839.68 8194.99 6420.3521 6456.38 8750.45 5237.44 5084.7964



war

FOURIER TRANS-
FORM OF WORD:
war_

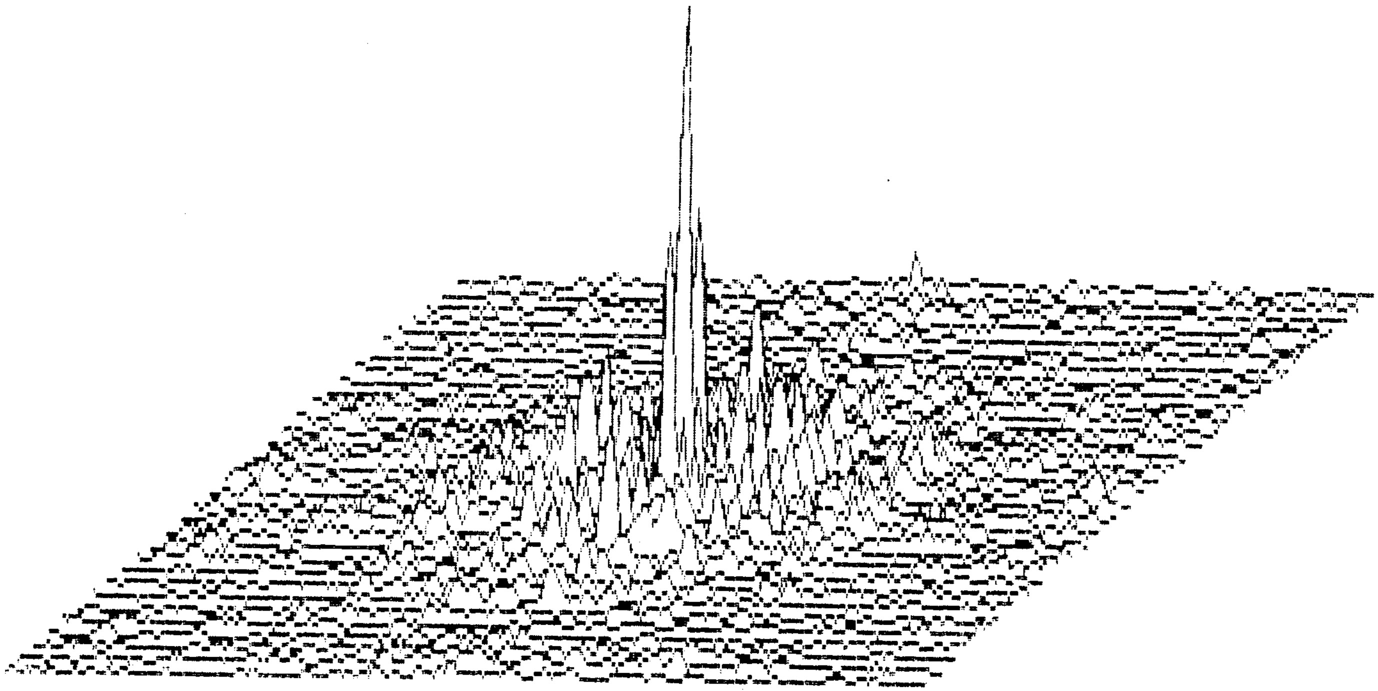
1.5453 1.9705 4.7170 9.0111 332.000 76.7522 31.1455 6.6528 13.1029
4219.09 4349.75 6520.56 5068.1133 5712.10 6930.54 4380.00 4331.0308



waste

FOURIER TRANS-
FORM OF WORD:
waste_

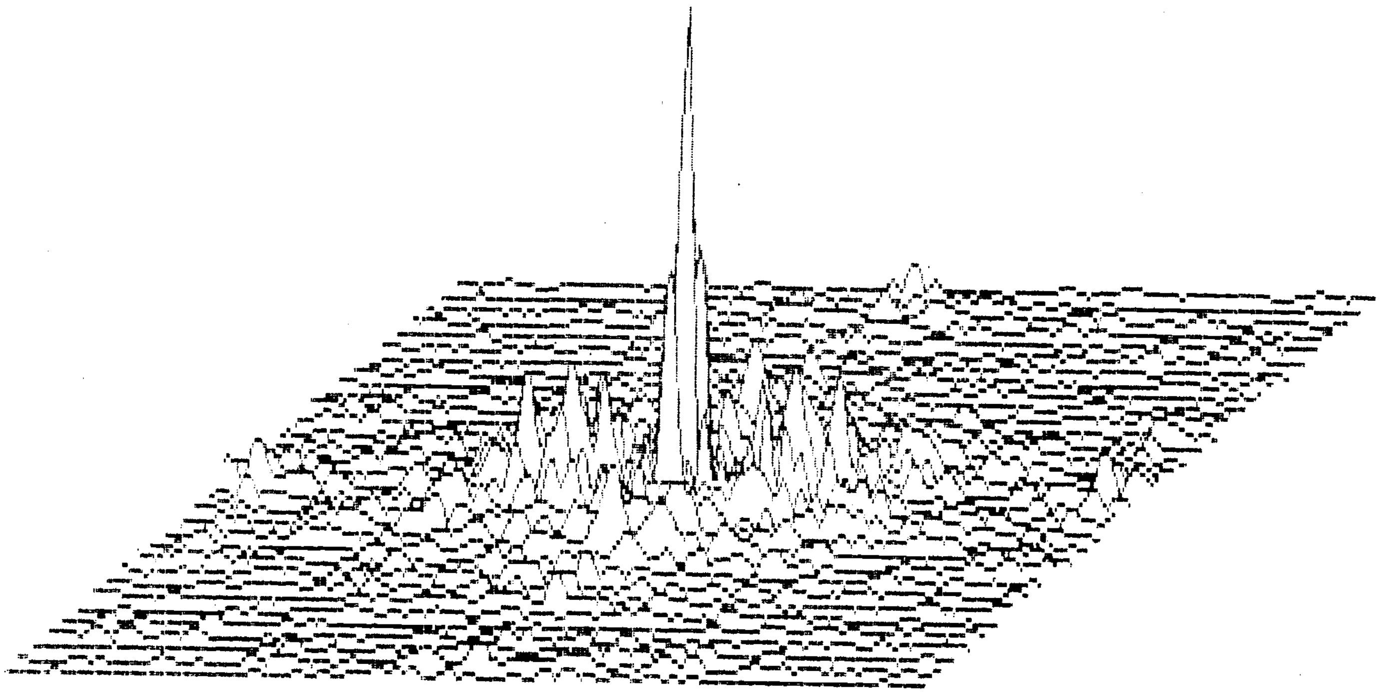
1.8466 2.6869 10.4624 15.6131 631.000 101.995 34.1992 9.1451 16.4054
5950.94 5267.39 9308.88 6996.6514 7023.30 9265.33 5201.48 5715.9766



wish

FOURIER TRANS-
FORM OF WORD:
wish_

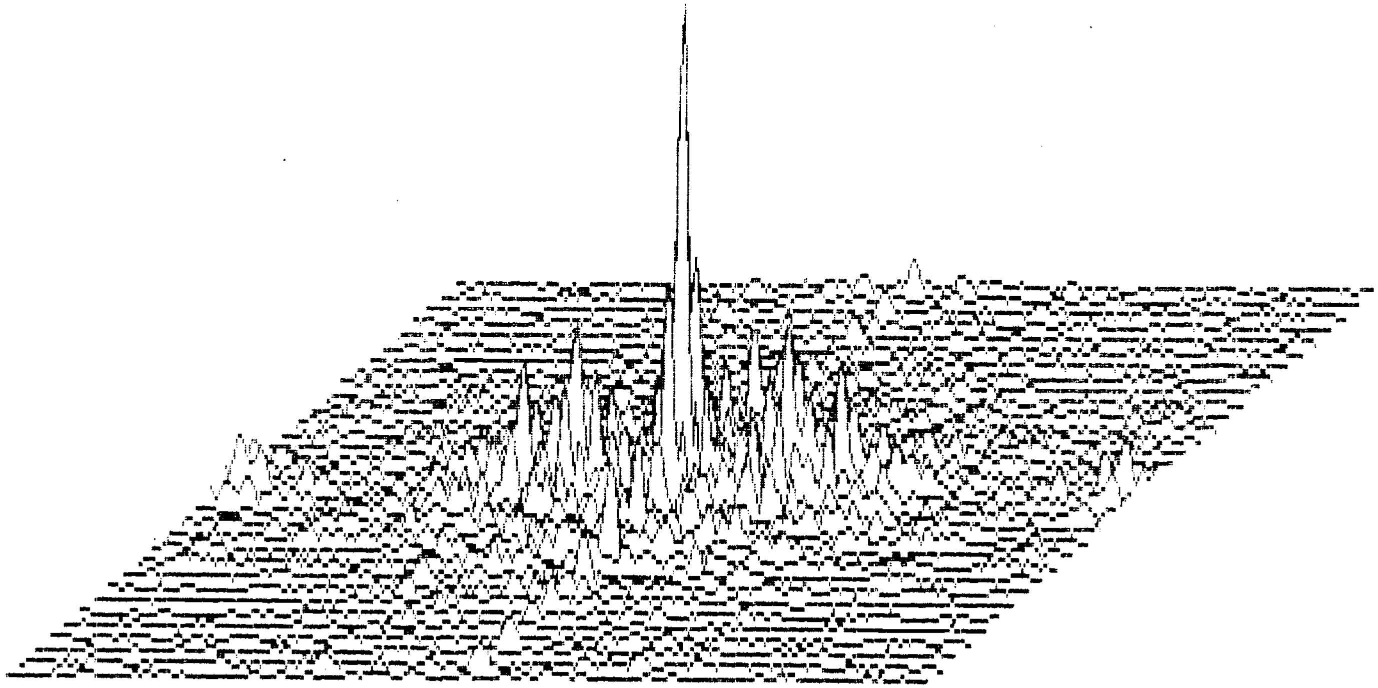
2.0197 2.1442 5.8980 11.3258 476.000 87.2966 54.0079 12.8945 22.4641
5385.93 4328.86 9084.40 6045.2812 6004.11 8159.72 4381.88 5096.9404



writing

FOURIER TRANS-
FORM OF WORD:
writing_

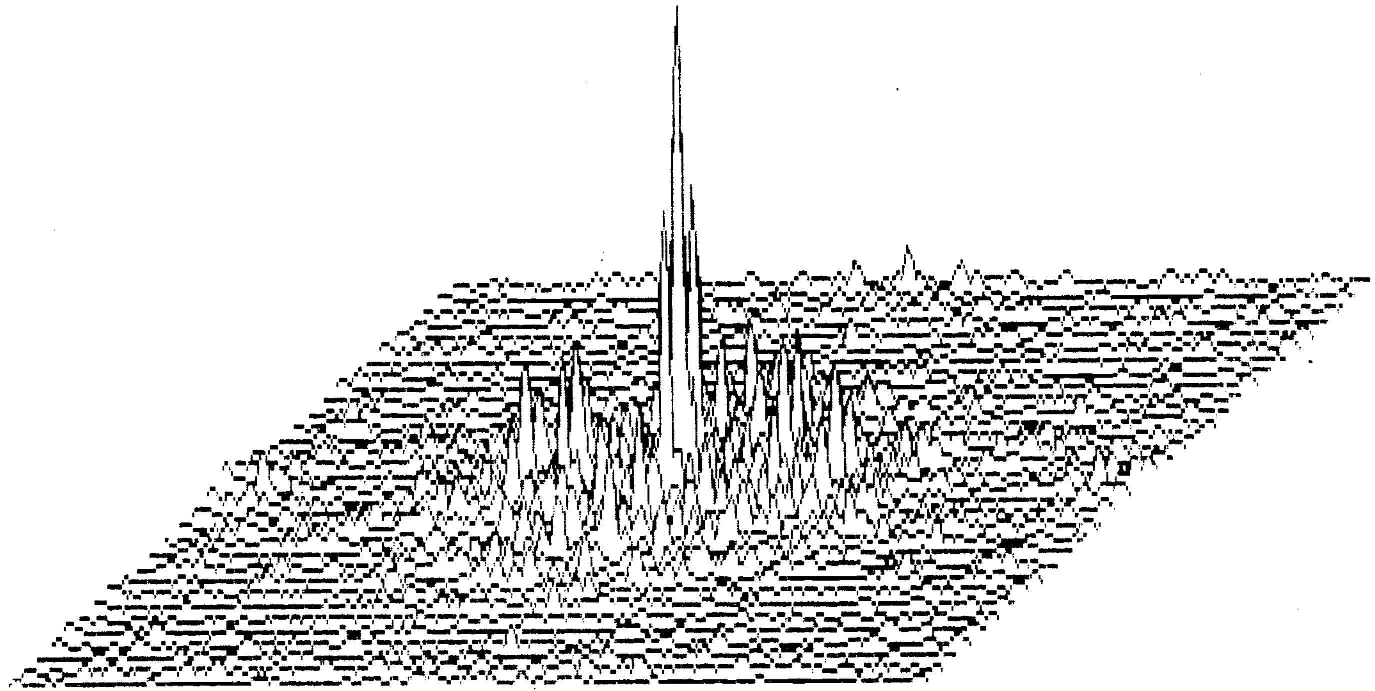
3.1037 3.0529 8.4800 17.3604 726.000 116.223 72.4360 15.2232 29.9655
6004.54 5135.90 9715.05 7664.2725 8219.65 9729.79 5418.51 5970.1055



FOURIER TRANS-
FORM OF WORD:
wonder_

wonder

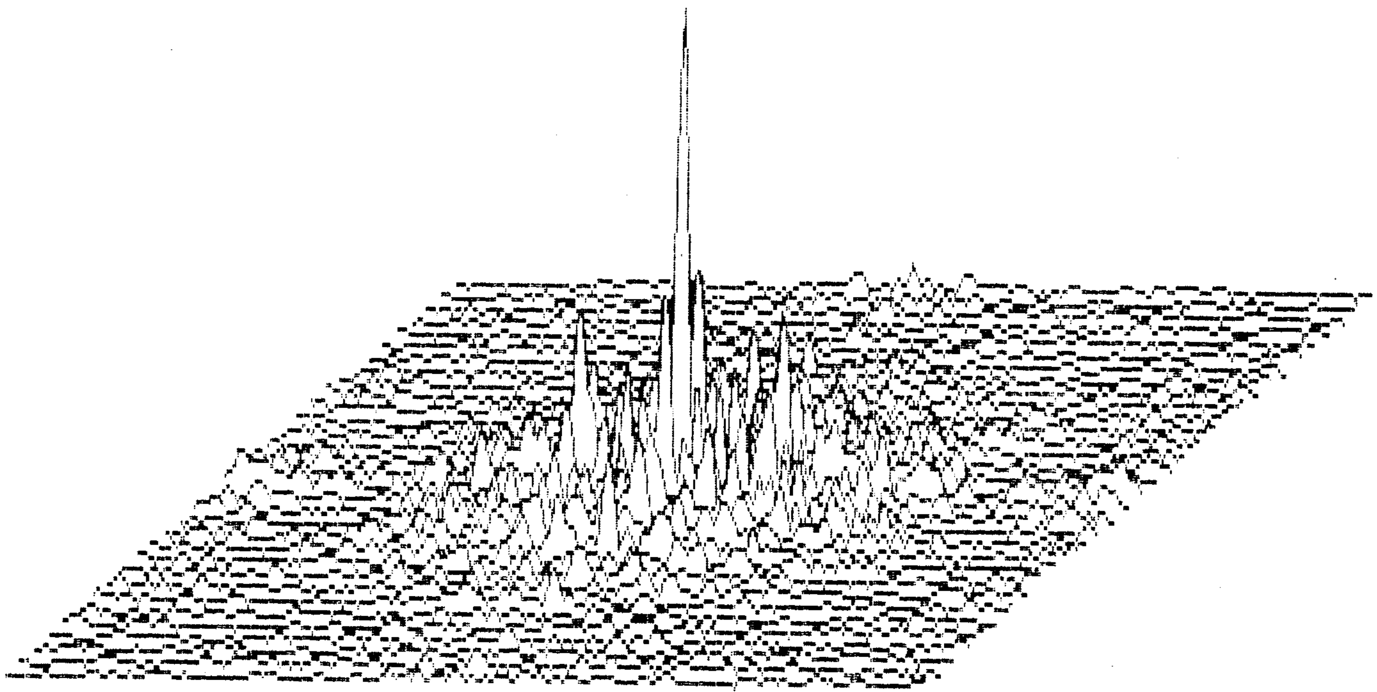
2.4241 1.8562 9.6408 21.2967 749.000 94.1400 48.9565 11.8107 21.6229
5880.59 5011.92 9603.80 7113.0630 8156.42 9488.45 5143.08 6199.1260



yacht

FOURIER TRANS-
FORM OF WORD:
yacht_

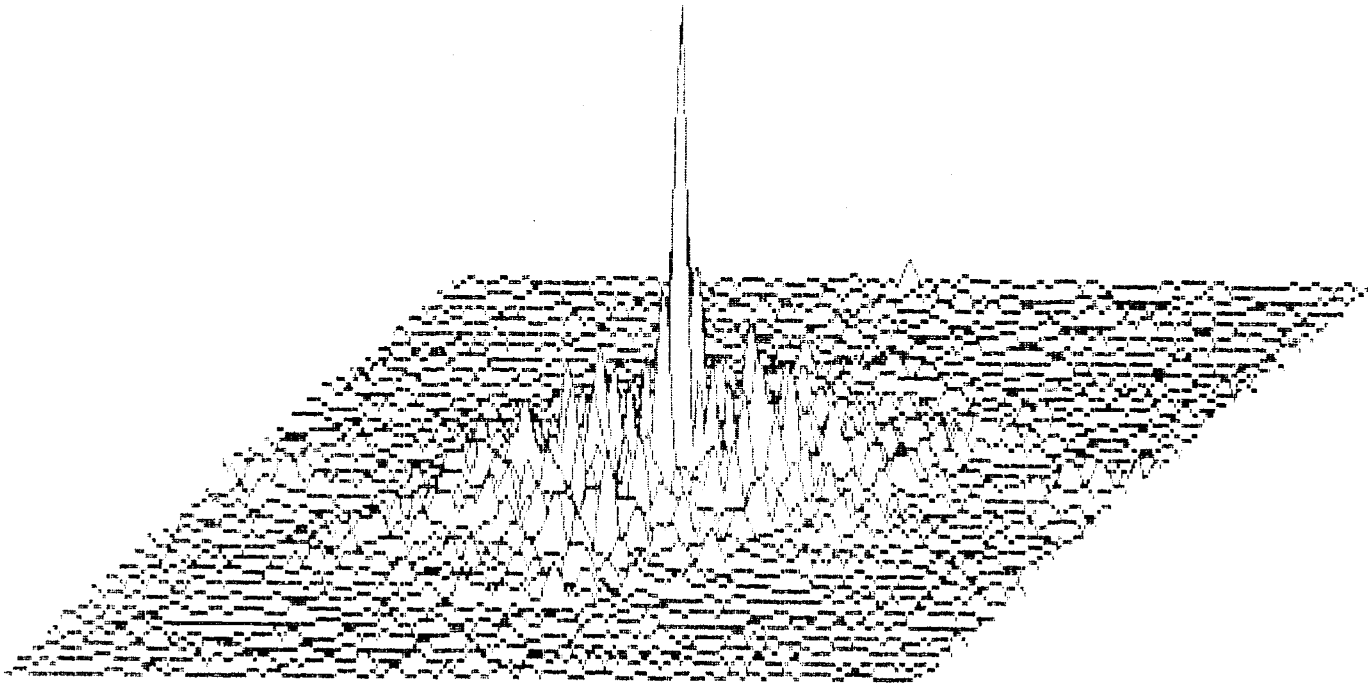
1.8496 1.9745 7.0524 14.0343   564.000 108.560 46.6204 16.2527 23.5210
5398.66 4910.95 8289.96 7329.3228   7730.41 8856.17 5194.69 5229.4604



yard

FOURIER TRANS-
FORM OF WORD:
yard_

1.1732 1.7719 6.1211 11.2275 454.000 99.4726 44.3750 10.8106 18.5557
4698.98 4419.94 7560.51 6360.9463 7533.36 8186.41 4781.43 4726.7378



APPENDIX IV

Fourier Transform

According to the ASYST programming manual (Macmillan Software Company, New York, N. Y., ASYST, Module 2, Analysis, 1985, pp. II-6-2 to II-6-12), the Fourier transform calculates a set of n sinusoidal functions, each of which can be expressed by

$$A(m)\ \sin(2\pi mk/n + T)$$

where A(m) is the amplitude of the sinusoidal function with frequency m/n, and m identifies which of the n sinusoidal functions is being considered. The total number of data points is n (e.g., 256 for the horizontal frequencies in this case), k identifies which of the n points in the original word martix of zeros and ones is being considered, and T is the angle whose tangent is C(m)/B(m). The values of C(m) and B(m) are calculated by the Fourier transform as

$$B(m) = 1/n \sum_{k=0}^{n-1} f(k)\ \cos(-2\pi mk/n)$$

$$C(m) = 1/n \sum_{k=0}^{n-1} f(k)\ \sin(-2\pi mk/n)$$

where f(k) is the k^{th} value in the matrix being transformed (e.g. a zero or one in the original word matrix).

The amplitude A(m) is equal to $(B(m)^2 + C(m)^2)^{1/2}$. The frequency is m/n cycles per data point in the original word matrix, and the frequency in cycles per centimeter is m/n times the number of data points per centimeter (which depends upon the size of the printed word.)

A printed word requires a 2-dimensional Fourier transform. According to the ASYST manual, the 2-dimensional Fourier transform command named "2D.FFT" first calculates individually the Fourier transform for each of the 32 rows of the original word matrix (of zeros and ones) and puts the result in another matrix of the same size (32 rows, 256 columns). It then calculates the Fourier transform for each of the 256 columns in this new matrix, and puts the results in the final matrix (of the same size.)