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.... This assumption probably is reasonable in the first example, but the second requires that we assume that the sedimentation rate remained constant through the series. The statistical transformations proposed by John Aitchison to overcome these problems are discussed at length. The chart and standards can be compared only in one position, where intensities at certain angles are compared to intensities of the standards at the same angles. If the number of rows equals the number of columns, the matrix is square. The exchange between Earth scientists and statisticians has been mostly one way, with the notable exception of the expansion of the theory of regionalized variables. If we can determine that our series follows a Poisson distribution, we can use the characteristics of the distribution to make probabilistic forecasts of the series. For centuries, the growers have treated their grapes with "blue galicia," or copper sulfate, to prevent fungus. Both illustrations are reproduced with permission. This is the 2 x 2 matrix: A= ['1 10 30 Repeating the sequence of steps yields the determinant which is then expanded into I 4c; 13: 1 = (4 - A) (30 - A) - 100 = 0 143 Chapter 3 Statistics and Data Analysis in Geology- or h2 - 34h + 20 = 0 There are no obvious factors in the quadratic equation, so we must apply the rule for a general solution: X= - b + J2a =A= - (-34) c J-342 2x1 hi = 33.4 A2 = - 4 x 1 x 20 - 34 + J i D Z 2 0.6 We can check our work by substituting the eigenvalues back into the determinant to see if it is equal to zero, within the error introduced by round-off So, the eigenvalues we have found are correct within two decimal places. Most geologists tend to be pragmatists, and are far more interested in results than in theory. Otherwise, the manner in which you gather your data may predetermine the techniques that can be used for interpretation, and may seriously limit the scope of your investigation. In certain instances these tests may be more appropriate than the procedures described here. Figure 2-25 is copyright by Harcourt Brace Jovanovich, Inc. Rorres, 1994, Elementary Linear Algebra, 7th ed., Applications Version: John Wiley & Sons, Inc., New York, 800 pp. There is no a pn'ori reason why one position of comparison should be better than any other. Also, our thoughts are conditioned by the media in which we express them, and maps, photographs, and cross-sections are printed or drawn on flat sheets of paper. However, you should now have some insight into matrix methods that will enable you to understand the computational basis of techniques we will cover in the remainder of this book. To convert from one matrix to another, we must perform two operations: a multiplication to change the scale, and an addition or subtraction to shift the arbitrary origin. Rowtwois divldedby0.5. So, the (n + 1) column of the augmented matrix contains the solution to the simultaneous equation set, and our original matrix has been replaced by an identity matrix. Results of this experiment follow the binomial distribution, discussed in Chapter 2. As a consequence, the soil is enriched in copper and other metals that are present as impurities in the crude sulfate compound. If we were to compute a transition probability matrix from this frequency matrix and then raise it to an appropriately high power, it would estimate the transition probability matrix of a sequence in which successive states were independent. Second estimate of transition frequency matrix using new diagonal elements calculated by multiplying probabilities on the diagonal by the grand total of 5397. In contrast, rectangular integration will create estimates that are equal to the first observation. These workers are often characterized by a suspicious and iconoclastic attitude toward geological platitudes. Note that each entry C i j in the product matrix results from multiplying and summing the products of elements in the i t h row of matrix A by elements in the j t h column of matrix B . 2 . Chapters 6 and 7 treat matrix algebra and its application to geological problems. From the transition probability matrix we can estimate what the lithology will be 2 ft (that is, two observations) above a given point. The appropriate alternatives are Ho: U r 8 H1: u < u and too few runs will cause rejection off the null hypothesis. The first set of trials contains 13 runs, the second only 2, and the third contains 19. The result you obtain is general. Geologists are trained to see patterns and structure in nature. 1 / 2 = 1/4. A geological sample, such as a "hand sample" of a rock, a "cuttings sample" from a well, or a "grab sample" from a mine face, is a physical specimen and when represented by a quantitative or qualitative value would be called an observation or event by a statistician. The inversion procedure may be illustrated by solving the following pair of simultaneous equations in matrix form. The basic arrangement of topics covered in the book is retained from earlier editions, progressing from background information to the analysis of geological sequences, then maps, and finally to multivariate observations. At every point, the rock type can be categorized and the type immediately above noted. A A D E - 0.208 0.192 B from B to C 0.203 C D 0.200 0.198 E - Row Totals 0.208 0.192 0.203 0.200 0.198 Step 3. The transition probability matrix, computed by dividing each element of the transition frequency matrix by the appropriate row total, shares this same characteristic. The sample mean, for example, is designated X and the population mean is p (mu). Spherical Distributions .... In the quarter-century since the first appearance of this book, computers have progressed from mainframes of ponderous dimensions (but minuscule capacity) to small cubes that perch on the corner of a desk and contain the power of a supercomputer. Many faculty members in the Earth sciences received their formal education prior to the current emphasis on geomathematical methodology, and consequently are untrained in the quantitative subjects their students are required to master. The second eigenvalue represents the length of the minor semiaxis, which is 0.72 units. edge of the ellipse is 1.28 units. The same conditions that govern the binomial distribution may be assumed, except that the number of "trials" is not fixed. 420 Universal kriging .... Once you master the rudiments of matrix algebra, you will be able to see the fundamental structure within the complex procedures we will examine later. Interactive software allows the user to dynamically vary the width of the histogram intervals and move the origin, so alternatives can be easily evaluated. Identification of one 7 Statistics and Data Analysis in Geology - Chapter 1 fossil as a brachiopod and another as a crinoid implies nothing about the relative importance or magnitude of the two. Geologic applications of this test may not be obvious, because we ordinarily must consider more than two states in a succession. Entries in a square matrix whose subscripts are equal (ie., i = j) are called the diagonal elements, and they lie on the principal diagonal or major diagonal of the matrix. A sample is a subset of elements taken from a population. However, we want to reverse these equations, and for given values of P b and At that we read from the well logs, estimate the proportions of the three constituents of the rock. The magnitude of the major semiaxis is equal to 1.85, the first eigenvalue of RC7,,. For example, consider the multiplication A-IA1/2 = A-112 If A is 3 x 3, the product is In some applications, the inverse may not be required, but only the solutions to a set of simultaneous equations. Data for 50 samples are given in Table 4-7 and shown graphically in Figure 4-14. Justification for applying series-of-eventsmodels to spatial data may be tenuous, however, and depends on the assumption that the spatial sequence has been created at a constant rate. To examine these problems, we have created a collection of measurements of a variable and also must know the locations of the measurement points. If we assume that a straight linear relation exists between sample points, intermediate values can be calculated from the geometric relationship Expressed in other words, the difference betweenvalues of two adjacent points is assumed to be a function of the distance separating them. Golub, G.H., and C.F. V a n Loan, 1996, Matrix Computations, 3Tded.: Johns Hopkins Univ. 20 Elementary Statistics The probability of making x discoveries in a drilling program of n holes, when sampling from a population of N prospects of which S are believed to contain reservoirs, is This is the number of combinations of the reservoirs taken by the number of discoveries, times the number of combinations of barren anomalies taken by the number of dry holes, all divided by the number of combinations of all the prospects taken by the total number of holes in the drilling program. Continuous variables, however, must be measured 25 Statistics and Data Analysis in Geology - Chapter 2 Number of heads Figure 2-8. If events occur randomly, the number of intervals that contain exactly 0, 1, 2 , . We may be interested in the geologic features exposed in a deep mine with successive levels, adits, and raises creating a complex three-dimensional net, yet we must reduce this network to flat projections in order to express our ideas concerning the relationships we see. The interval scale is so named because the length of successive intervals is a constant. However, the representation may equally well be a "map" of a thin section or electron photomicrograph, where the relationships between features have been enlarged so they become visible. The value of a point halfway between two observations is exactly intermediate between the values of the two enclosing points. Structural analysis and orthogonal regression .... I would also like to note that I have benefited from the nurturing environment of the Kansas Geological Survey (KGS) at The University of Kansas. Calibration .... Consider the set of equations: a11x1+ alx2 + a z m+mx2 bl = b2 Expressed in matrix form, this becomes and we have discussed how the vector of unknown x's can be solved by matrix inversion. Cross-correlation and stratigraphic correlation .... In other 162 Analysis of Sequences of Data circumstances such as stratigraphic correlation, equivalent thicknesses may not represent equivalent temporal intervals and the problem of cross comparison is much more complex. Data having the characteristic of being arranged along a continuum, either of time or space, often are referred to as forming a series, sequence, string, or chain. Thus, while there may be many excuses for failing to work at computing technology has changed enormously during the 28 years this book has been in print. Acknowledging that to students, not even graduate assistants, like to do drudge work such as data entry, I've provided all of the data for examples and exercises as digital files on the World Wide Web. Statistical problems, whether perceived or not, occur wherever there are elements of chance. 153 Statistics and Data Analysis in Geology - Chapter 3 Exercise 3.4 Coordinates can be rotated by a matrix multiplication in which the premultiplier is a 2 x 2 matrix of sines and cosines of the angle of rotation, [C O S ~ - sine I sine co~e where 8 is the desired angle of rotation. This approach is illustrated in Figure 4-1. The probability also will remain approximately constant if there are a very large number of balls in the urn, even if those selected are not returned, because their removal causes an infinitesimal change in the proportions among those remaining. Rather, there is an infinite continuum of possible results that might be obtained. (1 - 0.110)' - - .5! 1 * 0.90' 5!0! = 1 1 . In this chapter, we will examine methods for analyzing features on what we loosely define as "maps": two-dimensional representations of areas. If the autocorrelation coefficients are not significantly different from zero, as tested by methods that will 183 Statistics and Data Analysis in Geology - Chapter 8 be developed later in this chapter, we can conclude that the events are occurring independently in time or space. A discussion of fractals has been added, not because fractals have demonstrated any particular utility in geological investigations, but because they seem to hold a promise for the future. This unsatisfactory and even dangerous method of education, comparable perhaps to a physician learning by on-the-job training, is one many people seem destined to follow. (Bottom ofsection) 1 2 3 2 3 5 7 9 2 2 1 0 0 2 2 0 10 12 14 22 17 19 14 4 9 11 10 12 7 4 3 3 3 3 4 9 1 0 0 8 9 1 2 2 1 0 0 8 14 16 27 (Topof section) In the study of a silicified shale unit in the Rocky Mountains, it was noted that the calculated number of well-preserved radiolarian tests. The apparent density and the sonic transmission time of a mixture of these three constituents can be calculated as the sum of the products of the densities and transit times for pure constituents times the proportions of the constituents. A matrix with no inverse is called a singular matrix, and presents problems beyond the scope of this chapter. Matrix Multiplication .... Unfortunately, most geologists must collect their Observations where they can. In this procedure, observations are dichotomized by comparing their magnitudes to the preceding observations. For example, if asked to guess whether it will rain tomorrow, most of us would reply with some confidence that rain is likely or unlikely, or perhaps in rare circumstances, that it is certain to rain, or certain not to rain. Of course, there are some applications and some analytical methods that are unique to map analysis. Dividing the data into a small number of categories increases the average number in each and the histogram will be relatively 29 Statistics and Data Analysis in Geology - Chapter 2 reproducible with repeated sampling. Proba bility Although many descriptions and definitions of statistics have been written, it perhaps may be best considered as the determination of the probable from the possible. These may seem obvious or even trivial points to emphasize, but as we shall see, not all geologic sequences have such well-behaved characteristics. The operation is indicated symbolically by XT or by X'. For example, the upward movement of magma in chambers beneath a volcano such as Mt. St. Helens in Washington is believed to cause a harmonic tremor, a particular type of earthquake. Looking at residuals .... Satellite reconnaissance, by its very nature, consists of parallel orbital tracks. Also included is an introduction to probabilistics, a subspecialty that has grown into an entire branch of applied statistics. I especially wish to acknowledge the support and encouragement of two previous directors of the Kansas Geological Survey, Bill Hambleton and Lee Gerhard, who recognized the importance of geology's quantitative aspects. Cox and Lewis (1966) described a variety of graphical tools that are useful in examining series of events. The data in Table 3-3 can be regarded as a 20 x 5 matrix, M. These methods provide answers to the followingbroad categories of questions: Are the observations random, or do they contain evidence of a trend or pattern? (a) Data sequence considered as random, or "rectangular curve." (b) Equally spaced sequence created by rectangular integration. If we wish to create an equally spaced approximation to this distribution, we can generate another step function of rectangles of equal length whose areas equal the total areas of the original rectangles. If the observations X I , X Z , . . Distribution of percent oil saturation (so) measured on cores from a field (a) in northeastern Oklahoma and (b) in west Texas. You should note the similarity of the bellshaped continuous curve drawn in Figure 2-10 to the histogram of the binomial distribution in Figure 2-9. Rather, at specified levels of significance, we can demonstrate that the null hypothesis is incorrect and the sequence is therefore not random. A shear stress is positive if the compressional or tensional component agrees in sign with the direction of force. The final category is concerned with clustering, classification, and the examination of interrelations among variables in which sample locations on a map or traverse are not considered. One is the variance, and the other is the square root of the variance, called the standard deviation. The denominator is the determinant of the coefficients (in our example, the x's). Griffiths, J.C., 1967, Scientific Method in Analysis of Sediments: McGraw-Hill, Inc., New York, 508 pp. The data are contained in file CROATRAD.TXT at the Web sites (see Preface). Individual entries in a matrix, or its elements, are indicated by subscripted italic lowercase letters such as Xij. It includes time series, calculation of semivariograms, analysis of stratigraphic sections, and the interpretation of chart recordings such as well logs. The advantage of matrix manipulation over the "try it and see" approach of ordinary algebra is that it is more amenable to computer programming. As a consequence, the investigator may acquire a closer familiarity with the objects of study than could otherwise be attained. On the first toss, our chances are 1 / 2 of obtaining a head. However, with matrix algebra we can express the basic principles involved in a manner that is succinct and easily understood. At the other extreme, the regular alternation of heads and tails HTHTHTHTHTHTHTHTHTH would also appear very unusual to us, although the probability of the number of heads is calculated from the same distribution. This is done using a x 2 test, first converting the probabilities to expected numbers of occurrences by multiplying each row by the occurrence of harmonic tremors may help predict eruptions. Suppose, for example, an 16 Elementary Statistics Number of discoveries Figure 2-3. We can experimentally create a similar distribution by flipping pennies and noting the occurrence of heads or tails. However, the (n- Y) dry holes and the Y discoveries may be arranged in):combinations or, equivalently, in n!(n- Y) ! Y !different ways. To convert from one ratio scale to another, such as from inches to centimeters, we must only perform the single operation of multiplication. In subsequent chapters, we will not distinguish between the two measurement scales, and they 8 Introduction may occur intermixed in the same problem. Quantitative techniques can reveal the insufficiency of data, the tenuousness of assumptions, the paucity of information contained in most geologic studies. Most values are clustered around some central value, and the frequency of occurrence declines away from this central point. The technique is called rectangular integration. For example, the frequencies along the main diagonal of the transition frequency matrix would be doubled while off-diagonal frequencies remained unchanged if observations were made every half-foot. The quartz-feldspar sequence along the line is listed in Table 4-6. Similarly, the determinant 1 2 3 4 5 6 =O 5 7 9 is zero because the third row is the s u m of rows one and two. Years of eruptions of the volcano Aso for the period 1229-1962. Three major grades of clay were produced: clay for drilling mud; foundry clay; and a miscellaneous category that includes cattle feed binder, drug and cosmetic uses, and pottery clay. Data sets of this type are common in geology, and include measured concentrations of lithologies, geochemical or mineralogical assays along traverses or drill holes, electric logs of oil wells, and chart recordings from instruments. However, they require long strings of data, which has restricted their application to geophysics, well-log analysis, and 167 Statistics and Data Analysis in Geology - Chapter 4 the study of stratigraphic sequences and diamond-drill cores through ore deposits. Using the matrix operations we have already discussed, we will construct a matrix containing correlations between the concentrations of the different metals. to A B C D E Z Z s A - 0 13 B 29 0 from c 35 2 D 29 1 E 26 23 36 5 0 44 9 19 4 45 0 9 52O 12 3 0 120 38 94 77 67 The lithologic states have been coded as (A) unfossiliferous shale and mudstone, (B) shales containing nonmarine bivalves, (C)siltstone, (D) sandstone, and (E) coals and root zones. A modest data set such as 1STRIA.m will present a challenge to those who attempt to analyze the data by hand. In effect, we divide the continuous scale into discrete segments, and can then count the number of events that occur within each segment. Measurements of length are of this type. This is found by first calculating the negative binomial distribution in cumulative form in which each successive probability is added to the preceding probabilities; the cumulative frequency distribution gives the probability that certain lithologies would occur in preferred relations to 173 Statistics and Data Analysis in Geology - Chapter 4 Table 4-4. The manganese values from stream samples listed in Table 4-2 are shown in graphical form in Figure 4-2-a, and interpolated to regular 1000-m intervals in Figure 4-2 b. Suppose our sample contains 300 observations; the three smallest values constitute the first percentile, the WWW addresses are and . We will delay a discussion of this procedure until Chapter 6, where we can provide a motivation for our interest. Usually, eigenvalues are not found by solution of a polynomial equation, but rather by matrix manipulation methods that involve refinement of a successive series of approximations to the eigenvalues. The hybrid Earth sciences of geochemistry, geophysics, and geohydrology require a firm background in mathematics, although their procedures are primarily derived from the non-geological parent. From an analysis of probabilities associated with events, future behavior or past states of the object or event under study may be estimated. Gives procedures and algorithms for matrix operations, especially different methods for inversion, solution of simultaneous equations, and extraction of eigenvalues. In our coin-flipping problem, (y) 3! - 3 - 2 . For example, suppose we wish to develop the probabilities associated with a five-hole exploration program in a virgin basin where the success ratio is anticipated to be about 10%. Demonstrate that for commutative matrices, A - - = (ABP Consider the following two matrices, c= 2 1 0 40 02] [o,3 ..=[: : i] 1 -1 - Compare the determinant, pDl, of these two matrices, or for most part, direct extensions of techniques discussed in Chapter 4. For alla22a33, no transpositions are necessary, so N = 0 and the term is positive. Transpositions for the others and the resulting signs are given below: a1'1'2&2 ='llu32 u23 u12 %&i = '1 a 1 '23 a33 =% % a 3 3 ' protected] a33 = '3'12 '23 ='21'32 '13 u31u 2 a 1 w i k 1 u2a31u2u2u,1a i 1 sigma=31'12 '23 ='21'32 '13 u31u 2 a 1 w i k 1 u2a31u2u2u,1a i 1 sigma= k=1 sigma= k=3 sign = 137 Chapter 3 Statistics and Data Analysis in Geology- Thus, there are three negative and three positive terms in the determinant. Bentonite production in Wyoming, 1964. A more conventional approach (see, for example, Anton and Rorres, 1994) uses what is called the "method of cofactors,"but the two can be shown to be equivalent. These characteristics are known as parameters if they describe populations, and statistics if they refer to samples. It seems reasonable that it also may apply to the series of geological events described at the beginning of this chapter. Summing, we have det A = + 4 8 - 0 + 3 - 18 + 0 - 8 = 25 This method of evaluating a determinant is described by Pettofrezzo (1978). Obviously, an infinite number of measurements of the top of this horizon could be made if we drilled unlimited numbers of holes. Note that O! is defined as being one, not zero. If tests determine that a sequence exhibits partial dependence between successive states, the structure of this dependence may be investigated further. Determinants .... However, the steps between grades do not represent a uniform progression of temperature and pressure. In some situations, an inverse cannot be found because division by zero is encountered during the inversion process. Techniques discussed in this chapter classified by the nature of the variable and its spacing along a line. Probability of intersecting targets with regular search patterns ranging from squares t o parallel lines. Spatial Analysis .... In any problem where points are interpolated between successive observations, we must always remember that you cannot create data by estimation using any method. The term contains one and only one element from each row and each column. The reason for using the average of squared deviations may not be obvious. This equation is not often used for hand calculation, involving as it does n subtractions, n multiplications, and n summations. 131 Statistics and Data Analysis in Geology - Chapter 3 Inversion and Solution of Simultaneous Equations Division of one matrix by another, in the sense of ordinary algebraic division, cannot be performed. Some necessitate reliance on the scale and expressed in real numbers; the variate must be measured on a scale and expressed in real numbers. A symmetric matrix is a square matrix in which all observations X i j = X j i , as for example x33 [::: '1 3 5 6 The variance-covariance matrix of trace elements given above is another example of a square matrix that is symmetrical about the diagonal. Interpolation Procedures Many of the following techniques require data that are equally spaced; the observations must be taken at regular intervals on a traverse or line, or equally spaced through time. Sometimes the measurements we make, such as chemical analyses, require the destruction of the material. This paperback reprint of a classic text covers the traditional material for a one-semester matrix algebra course. Chromium content of an Upper Pennsylvanian shale from Kansas. There are four measurement scales, each more rigorously defined than its predecessor, and each containing greater information. The relationship between conditional and unconditional probabilities can be expressed by Bayes' theorem, named for Thomas Bayes, an eighteenth century English clergyman who investigated the manner in which probabilities change as more information becomes available. The rigor and objectivity required by quantitative methodologies can compensate in part for insight and experience which otherwise must be gained by many years of work. If geology were an experimental science like chemistry or physics-in which observations can be verified by any competent worker-controversy and conflict might disappear. The implications contained in any sequence of probability are discussed in books by von Mises (1981) and Fisher (1973). Large statistical packages implemented almost every procedure described in the text, so program listings were no longer necessary. The event has two states and must occupy one or the other; except for vanishingly small possibility that the coin will stand perpendicularly on edge, it must come up either heads or tails. Call the result U, a 20 x 5 matrix of standardized values; U = DC-' We can calculate the correlation matrix by repeating the procedure we used to find S,substituting U for D: R = (n-1) - I U T U Rw 1 1 -0.312 -0.312 1 0.141 -0.0103 0.33 0.595 -0.28 0.85 0.595 -0.33 -0.28 1 -0.029 0.456 1 0.242 -0.029 0.456 0.242 1 0.141 -0.201 1 To graphically illustrate matrix relationships, we must confine ourselves to 2 x 2 matrices, which we can extract from R. a q&+m 0 0 0 0 0 bc Figure 2-15. Exercises .... Among the topics we will consider that have obvious applications to fields as diverse as geophysics and microscopy is the probability of encountering an object with a systematic search across an area. Using linear interpolation, values will be created which lie on a straight line between two surrounding data points. The vi Preface list of those who provided technical reviews and critical comments over the years reads like a "Who's Who" of mathematical geology and includes, in alphabetical order, Fritz Agterberg, Dave Best, Paul Brockington, Jim Campbell, Ted Chang, Felix Chayes, Frank Ethridge, Je-an Fang, Colin Ferguson, John Griffiths, Jan Harff, Günther Hausberger, Ute Herzfeld, George Koch, Michael McColagh, Gerry Middleton, Vera Pawlowsky, Floyd Preston, Nick Rock, Robert Sampson, Paul Switzer, Keith Turner, Leopold Weber, and Zhou Di. In addition, there have been dozens of others who have called or written to clarify a specific point or to bring an error to my attention, or to suggest ways in which the text could be improved. These are shown in Figure 2-3. Mann-Whitney test .... Examination of the original data shows that there are 1145 cores having saturations within this range, or about 68%of the data. This histogram directly indicates local periods of fluctuation from the average rate of occurrence. The unknown coefficients are x1 = 2 and x2 = 3. Discrete distribution for exactly two successes in a drilling program of n exploratory holes when the probability of a discovery is 25%. Moisture content of core samples of Recent mud in Louisiana estuary. This was a time of transition when personal computers offered the freedom of access and ease of use missing in the centralized mainframe environment, but those PC's lacked the power and speed necessary for many geological applications. 29, no. Figure 2-2 shows the probability for all possible numbers of heads in five flips of a coin. We will also look at ways of describing and comparing more conventional shapes of individual objects, beginning in Chapter 4. For alla22a33, no transpositions are necessary, so N = 0 and the term is positive. Transpositions for the others and the resulting signs are given below: a 1 0 1 0 1 1 I I I I I I I I I I I 1 ' ' ' ' 1 I 0 1 I ' ' I ' 3 0 3 1 2 o l ' 1 * ' ' * ' ' I * * ' * ' I * * ' 6 0 0 ' 500 400 0 25 Y ' * ' 300 200 0 0 0 0 0 0 0 0 0 0 0 15- b 10 ' I r i 1 I I I 1 I I I I 1 I I I I I I 1 I I I I 1 I I I I 1 4 I I I 1 I I I O I O U ' I ' analyzed for iron content by a rapid spectrochemical method. Geology itself is responsible for some of the advances, most notably in the area of mapping and spatial analysis. 18 Elementary Statistics Figure 2-5. That is, p (hit sandstone and drill anticline) = p (hit sandstone) x p (drill anticline). Figure 2-8, for example, gives the probabilities associated with obtaining specified numbers of "successes" (or heads) in ten flips of a coin, and Figure 2-9 shows the probability of heads in these flips of a coin. If, on the other hand, we state that the probability of rain is 1, we are absolutely certain it will. 607 Table A.5. Probabilities of occurrence of specified values of the Mann-Whitney Wx test statistic .... New row totals and grand total are then found A 232 29 B 35 from C 29 D E - 26 A B to C D 13 199 2 1 23 36 5 222 44 9 19 4 45 215 9 E 52 0 12 3 211 How Totals 352 237 316 292 278 1475 Grand Total The process is repeated again and again, until the estimated transition frequencies along the diagonal do not change from time to time. Suppose, for example, we are interested in the porosity of a particular sandstone unit. 603 Table A.4. Critical values of z for v degrees of freedom and selected levels of significance .... The equation given above is solved by finding the inverse of matrix A. Runs in the first sequence shown are underlined: (Start) H T H H T I J T T T H T I J T T H T T H H H 1 1 3 4 5 6 7 8 9 (End) We can calculate the probability that a given sequence of n runs was created by the random occurrence of two states (heads and tails, in this example). The presentation of masses of numbers, all expressed to eight decimal places, overwhelms the minds of many people and numbs their natural skepticism. The critical value of x2 for 11degrees of freedom and an o(= 0.05 level of significance is 19.68, which is far exceeded by the test statistic. For example, a second-order Markov sequence exhibits a significant conditional relationship between points that are two steps apart. The implications contained in this book that will help promote the widening common ground we refer to as geomathematics. The slope of a line drawn from the origin of a graph through a point is defined by the ratio between the two coordinates of the point, and not by the actual magnitudes of the coordinates. 2-6). Equality of two vector means .... Elementary Statistics If observations with certain characteristics are systematically excluded from the sample, deliberately or inadvertently, the sample is said to be biased. Tables A.6 and A.8 are copyright by John Wiley & Sons, Inc. What could be cuter Than to feed a computer With wrong information But naive expectation To obtain with precision A Napoleonic decision? Distribution of Points .... The probabilities calculated are low because they relate to the likelihood of obtaining two successes and exactly x dry holes. The preceding analyses have addressed situations where there are only two possible outcomes: a hole is dry, or oil is discovered. Gould, P., 1967, On the geographic interpretation of eigenvalues: An initial exploration. Trans. Then, the histogram would be a continuous curve, and the horizontal axis would represent a continuous, rather than discrete, variable. Similarly, metamorphic rocks may be ranked along a scale of metamorphic grade, which reflects the intensity of alteration. Blocks contain examples and exercises. This is done, for example, by determining if states tend to be followed an unusual number of times by greater or lesser states on the ordinal scale. If we raise the diagonal matrix H to the onehalf power, the result is a diagonal matrix whose nonzero elements are equal to the square roots of the equivalent elements in A. 346 351 Spectral procedures .... Consider the data in file BAL,TIC.TXT,which gives the weight-percent of sand in five successive size fractions, measured on bottom samples collected in an area of the Baltic Sea. This is usually the variation that is of scientific interest. Although the correspondence may be high, it is meaningless. Increasing the number of categories reveals more details of the distribution, but because each category will contain fewer observations, the histogram will be less stable. Although the ancient monastic records contain an indication of the relative violence and duration of some eruptions, for all practical purposes we must regard the record as one of indistinguishable instantaneous explosive events, a we may define the total area underneath the normal curve as being equal to 1.00 (or if we wish, as loo%),so we can calculate the probability directly from the curve. You will recall from Chapter 2 that the Poisson is a discrete probability distribution that can be regarded as the limiting case of the binomial when n, the number of trials, becomes very large, and p , the probability of success on any one trial, becomes very small. Stratigraphic succession shown in Figure 4-4 coded into four mutually exclusive states of sandstone (A), shale (C), and coal (D);observations taken a t 1-ft intervals. Eigenvalue and eigenvector techniques are directly extendible to larger matrices, even though the operations become tedious. At the same time, the discipline necessary to perform quantitative research will hasten the growth and maturity of the scientist. The Kolmogorov-Smirnov test provides a simple way to test the goodness of fit of a series of events to that expected from a Poisson distribution. The elevation of the top of a horizon measured in one place will not differ from the value in another place unless the holes constitute a single departure. The line on the polished slab may be regarded as a random sample of possible successions through the pegmatite body from which the slab was quarried. Appendix .... Exercise 3.3 File MAGNET1T.m contains the proportions of olivine, magnetite, and anorthite estimated by point-counting thin sections from 15 hand specimens collected at a magnetite deposit in the Laramie Range of Wyoming. However, those to whom I owe the greatest debt of gratitude for help with this 3rd edition are my associates and coworkers at the Kansas Geological Survey, particularly Ricardo Olea, John Doveton, and David Collins, who have provided examples, data, and exercises, and who have patiently reviewed specific topics with me in order to clarify my thoughts and to help me correct my misconceptions and errors. 164 Analysis of Sequences of Data 'I 0 l 08] d 2 0 a 4 0 0 . The resulting x2 statistic is - 2 - (18 - 8.5)' 8.5 + (7 - 7.0)' 7.0 + (5 - 10.4)' 10.4 + (5 - 5.0)' 5.0 + - - - - - (5 - 10.1) 10.1 + - - (18 - 12.3)' 12.3 (5 - 9.8)' 9.8 = 20.99 171 Statistics and Data Analysis in Geology - Chapter 4 The critical value of x2 for nine degrees of freedom and a 5% level of significance is 16.92; the test value comfortably exceeds this, so we may conclude that the hypothesis of independence of successive states is not correct. 53-86. This is not to say that the geologist should unthinkingly bend his interpretation to conform with that of the computer. Testing the Mean .... -0.683- -3 -2 -1 0 1 2 3 Figure 2-18. If the matrix is symmetric (the variety of matrix we will encounter most often),its determinant cannot be negative. Perhaps we have measured the boron content of each lithologic unit in the cyclothem just discussed. 2-11) fallout from the Chernobyl reactor accident in the Soviet Union during April of 1986. This tendency will be used to interpolate between data points, extrapolate beyond the data sequence, infer the presence of trends, or estimate characteristics that may be of interest to the geologist. However, like statistical tests, geomathematical techniques are based on the premise that information about a phenomenon can be deduced from an examination of a small sample collected from a vastly larger set of potential observations on the phenomenon. On a more prosaic topic, the section on regression has been expanded to include several variants that have special significance in the Earth sciences. The relevance of these courses to the geologist's primary field is often obscure. Grid-cell procedure .... These methods of cross comparison superficially resemble the mental process of geologic correlation, but have the limitation that they assume the distance or time scales of the two sequences being compared are the same. An alternative way of expressing our estimate would be to Statistics and Data Analysis in Geology - Chapter 2 use a numerical scale, as for example a percentage scale. However, numbers are used only as identifiers. 4. Finally, even if it were possible to observe an entire population, it might be more efficient to sample. We are interested in the general tendency of the data in most of the examples we will now consider. This is a topic discussed in greater detail elsewhere in this chapter. Heads and tails present two outcomes of a nominal scale, and our data will consist of the number of observations that fall into them. It was. Teaching the techniques of data analysis to engineers and natural scientists, both university students and industry practitioners, would be easier, I reasoned, if I had a suitable textbook. We assume that heads and tails will occur at random; in the two preceding examples, it seems very unlikely that they have. Measurement Systems A quantitative approach to geology requires something more profound than a headlong rush into the field armed with a personal computer. This property is especially important in operations in the following sections. Suppose we want the eigenvalues of the matrix A = [-62 41 3 Expressed as a determinant equal to zero, we have which expands to or h2 - 5 h + 30 = 0 The roots of this equation are But this leads to expressions involving the square roots of negative numbers: hl = A2 = 144 5 5 + m 2 - m 2 = 2.5 + 4.9i = 2.5 - 4.9i Matrix Algebra These are complex numbers, containing both real parts and imaginary parts which Fortunately, a symmetric matrix always include the imaginary number, i - yields real eigenvalues, and most of our computations involving eigenvalues and eigenvectors will utilize covariance, correlation, or similarity matrices which are always symmetrical. Several elaborate statistical distributions have been proposed to account for the variation in mine values, providing a theoretical basis for formal statistical tests. The corresponding transition probability matrix is 174 Analysis of Sequences of Data A - 0.76 from C 0.37 D 0.38 E - 0.40 B 0.11 0.30 0.16 0.43 - 1.00 1.00 0 0.13 0.11 0 0 0.02 0.08 0.13 1.00 0.01 0.57 0 0.04 1.00 1 00 0.34 0.13 0.13 0.79 The marginal probability vector is A D C E 0.30 [.0] 0.19 0.17 A x 2 test, identical to Equation (4.2), can be used to check for the Markov property in an embedded sequence. Selected Readings .... A matrix of trace-element variances and covariances, the variances lie on the diagonal and the off-diagonal elements are the covariances. These are a11a22 and a12a21. This reflects in part the fact that the third dimension, depth, often is accessible to only a fraction of the extent of the other two spatial dimensions. The existence of a significant second-order property can be checked in exactly the same manner as we checked for independence between successive states, by using a x2 test. The eigenvectors of a matrix may be Statistics and Data Analysis in Geology - Chapter 3 measurements of variables, variances or covariances, sums of observations, terms in a series of simultaneous equations, or, in fact, any set of numbers. For example, we might select the ~ 3 3 a 3 x 3 matrix. X contains the eigenvectors of the minor product matrix, XTX, and A is an m x n diagonal matrix whose diagonal elements are the eigenvalues of either XXT or XTX (they will be identical except that XTX will have n - m extra eigenvalues, all equal to zero). 2-7). The mean oil saturation differs in the two fields, but the major difference between the curves reflects the fact that the Texas field has a much greater variation in oil saturation.

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