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ABSTRACT

A paper given at a conference on statistical computation discussed teaching statistics with computers. It concluded that computer-assisted instruction is most appropriately employed in the numerical demonstration of statistical concepts, and for statistical laboratory instruction. The student thus learns simultaneously about the use of computers and those concepts which are best demonstrated through the use of computers--for example, multivariate analysis. In an introductory course on statistical inference, computers are used for weekly laboratory exercises, generating random numbers, empirical theoretical distributions, Monte Carlo studies, means, and the like. However, direct use of the computer in instruction--namely directions and questions included on-line--is at this time too expensive. As cost of computer time decreases it should become more feasible. Future planning centers around more flexible student terminals, and the development of a battery of computer-administered tests to further individual instruction. (BB)

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TECHNICAL REPORT

COMPUTER-ASSISTED INSTRUCTION IN STATISTICS

WILLIAM W. COOLEY

COMPUTER-ASSISTED INSTRUCTION IN STATISTICS

William W. Cooley

Learning Research and Development Center

University of Pittsburgh

1969

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Personnel and Training Branch

Psychological Sciences Division

Office of Naval Research

Computer-Assisted Instruction in Statistics[1]

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I am pleased that the organizers of this Conference on Statistical Computation saw fit to include a session on the teaching of statistics with computers. Certainly most of the statistical-computer effort to date has been directed toward research applications. My thesis is that we can and should provide computer experience as part of instruction in statistical methodology, and that such experiences can be designed to facilitate the learning of basic principles of statistical inference as well as teach how to use the computer in the analysis of data.

The general problem of using the computer as an instructional device has been under investigation for about 10 years. Two recent surveys of this field, readily available to this audience, are the articles in the September, 1968 issue of Datamation by Zinn and others and the Atkinson and Wilson (1968) article in Science. Most generally called computer-assisted instruction (CAI), the field has grown from a vague idea in 1958 to a multimillion dollar research enterprise in 1969.

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A variety of different approaches to CAI has emerged from all this activity. In general they form a spectrum from very rigidly controlled student-computer interactions such as drill and practice, to systems which allow the student to manipulate and operate on aspects of the subject matter through techniques such as simulation and gaming.

The cost of CAI makes it impossible at this time to justify its use for purely instructional purposes. As an object of research CAI is a justifiable enterprise on the assumption that computer costs will continue to go down (relative to instructional alternatives) while its effectiveness will continue to increase, so that someday CAI will be cost-effective for at least some kinds of instruction. There is some disagreement as to how far away that someday is (see, for example, Oettinger and Marks, 1968), but most agree it is coming.

One situation in which CAI is feasible today is where the student must learn how to use the computer anyway, and where such learning is a by-product of his computer-assisted instruction in the primary subject. Certainly an example of such a subject area is data analysis and statistical inference. An example of such an instructional system is the one developed at System Development Corporation (Rosenbaum, 1968; Rosenbaum, Feingold, Frye and Bennik, 1967). Using the PLANIT language, they wrote three types of student exercises:

1) tutorial-dialogue: a programmed instruction mode with computer questions and student answers.

2) exposition: primarily Monte Carlo type experiments where the student-computer "conversations" allow the student to specify the kind of experiment he wishes to perform and then define the parameters for that experiment.

3) computational exercises: data analysis experiences with contrived or randomly generated data.

After two years of studying these three CAI modes the authors concluded that "CAI is most appropriately employed in the numerical demonstration of statistical concepts and for statistical laboratory exercise instruction" (Rosenbaum, et. al., 1967, p. 1).

In the fall of 1967 we[2] began to develop a computer laboratory for statistics instruction which took advantage of the availability of the University of Pittsburgh's time-sharing system. Today we are providing two kinds of experiences in these computer lab sessions. Monte Carlo studies are employed in which the student can examine the sampling distributions of the statistic he is studying in class and note the effects which occur as a result of varying parameters. The other type of laboratory experience is in data analysis. Here the computer takes on the arithmetic chores and frees the student's intelligence for considerations such as the selection of appropriate variables and samples, choice of the statistical program to be applied, and interpretation of the results.

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[2]Colleagues and students who have helped me develop this approach are Paul R. Lohnes, Richard Ferguson, James Carlson, Paul Stieman, and Anthony Nitko. I am also indebted to Robert Glaser, Director of LRDC, for some financial support and personal encouragement.

Before examining these laboratory exercises in detail, it would be useful to describe the time-sharing computer system on which they have been implemented. At the University of Pittsburgh we have the IBM System/360, model 50 with 131K main storage (2 micro-second cycle time), a million byte large capacity storage (8 micro-second cycle time) and the 2314 disc with over two hundred million byte capacity. The Pitt Time Sharing System currently supports up to fifty simultaneous users most of whom operate from 2741's on dedicated lines. One feature of the PTS software which we use most heavily in this work is the time-sharing editor. The editor proves very useful for the initial preparation of source programs and for the continuous creation and editing of data for subsequent analyses. The FORTRAN IV compiler is available on the system, so with the editor we were able to adopt readily our existing statistical FORTRAN batch programs for interactive mode.

Programs and data files are stored on the disc and can be loaded or attached with very simple, typed commands. Additional data for analysis can be entered from the terminal, from cards taken to the Computer Center, or from tapes stored at the Center. When the user logs on, he declares how much core he will need for his current work. Up to 131K bytes can be allocated if core is available. Most applications seem to use 16K or 32K bytes of core.

Introduction to Statistical Inference

Our first course in statistical inference serves about 75 to 100 graduate students in education per trimester. Each student has a weekly laboratory exercise which he does at his convenience by using one of several 2741 terminals on the campus to which he has access on a sign-up basis. The mimeographed directions for each exercise relate the lab to the lectures and the text, provide the necessary direction for terminal operation, and present questions regarding the computer output which the student answers after he has completed his work at the terminal. At first we tried to build directions and questions to be answered on-line into the computer programs, but we have concluded that this is too inefficient of computer time and terminal time. If, someday, computer costs come down and the terminal queue is not a problem, more tutorial-type interactions can be provided. Meanwhile we continue to examine the problem of allocating course content to lecture, tests, mimeographed handouts and computer exercises. Let us turn now to a description of those exercises.

The first lab provides experience with simple data manipulations such as transformations and descriptive statistics using a dataset stored on disc for this purpose. Those data are from a large educational survey conducted at the University of Pittsburgh, called Project TALENT. This provides the student access to a random sample of American high school students. He can select variables and subsamples (e.g., male or female) as he chooses.

Then the student moves through a series of computer experiments designed to familiarize him with:

(1) random number generation;

(2) empirical and theoretical distributions;

(3) sample statistics and population parameters;

(4) Monte Carlo study of sample variances;

(5) symmetric and nonsymmetric binomial distributions;

(6) central limit theorem and the normal distribution;

(7) sampling distribution of the mean;

(8) the t-distribution, power, type I and II errors; and

(9) sampling distribution of the correlation coefficient.

Experience with data analysis is also provided at appropriate points in the sequence. Students either enter their own data or use Project TALENT data for exercises with chi square, t-test, and correlation. A current evaluation of this course ıggests that the data analysis portion should be expanded and some of the initial random number demonstrations be shifted to filmed presentations of dice and other "more concrete" experiments before turning to Monte Carlo experiments on the computer.

Printout 1 illustrates a Monte Carlo study of the t-distribution and Printout 2 illustrates a correlation analysis, where the student centers the data from the terminal. With respect to the computer programs that have been developed for this lab, a batch processing version of them is available in a new Wiley text (Lohnes and Cooley, 1968).

Introduction to Multivariate Analysis

The other statistics course in which we have been using the time-sharing system is a two-semester sequence in multivariate analysis.

Here the emphasis for the computer lab has been on providing data analysis experience for students from many divisions of the University whose interests are very applied. They want to know how to select, compute and interpret multivariate statistics in given research situations.

As each multivariate technique is introduced, the student is responsible for conducting a computer analysis of his own, using either the Project TALENT dataset stored on disc or appropriate data from his own field, if available. Table 1 describes the function of each avaiable program and Figure 1 indicates the input/output compatibility which exists in this system. Printout 3 illustrates the first page of a small discriminant analysis example. As the student moves through an analysis sequence (e.g., EDIT, CORREL, PRINCO, ROTATE), he catalogs and stores intermediate output on disc.

Of course if the objectives of the instruction were more in the direction of mathematical statistics than applied, the building blocks for such a computer lab could be matrix operations rather than specific statistical techniques. However, for the applied course, our approach allows the student to focus on concerns such as selection and interpretation, which are closer to his needs than would be, say, "reinventing" the matrix algebra for canonical correlation every time he was interested in exploring the relationships between two sets of variables.

Plans for the Future

Following extensive use of the CAI laboratory exercises in statistics developed by the project, future efforts will be devoted to further increasing the effectiveness of the laboratory. Two avenues will be explored: (a) One is to investigate the use of a more flexible student terminal. Monte Carlo experiments will be moved to a Sanders CRT terminal in order to see whether they are more effective than they have been with a typewriter-terminal approach. (b) The other is the development of a battery of computer-administered tests which will help to further individualize instruction in statistical inference. At the present time, although students work individually at a terminal, all students take the same laboratory exercise in the same week and have the same lecture and assignment. The long-range intent behind the implementation of a computer testing procedure is to redesign the course into a type of individually prescribed instruction in which the computer does the testing, supplies the laboratory experiences, and indicates suggested readings and paper-and-pencil exercises based on the outcomes of the computer-administered tests.

As I examine systems such as The Augmented Statistician (System Development Corporation, 1967) designed to provide the social scientist with interactive statistical programs, it seems clear that the instructional and interactive production systems are heading toward similar goals. So I shall conclude as I began, with an expression of thanks to our hosts who have brought us together for this exchange of ideas on statistical computation.

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TABLE 1

Multivariate Programs on the System

CANON	Canonical correlation
CLASIF	Multivariate normal classification
COEFF	Factor score coefficients
CORREL	Correlation
COVAR	Covariance analysis
DISCRM	Multiple group discriminant analysis
FACDIS	Factorial discriminant analysis
FACTOR	Extraction of arbitrary factorial analysis
FSCORE	Factor scores
MANOVA	Multivariate analysis of variance
MULTR	Multiple correlation
PARTL	Multiple partial correlation
PRINCO	Principal components
ROTATE	Varimax or quartimax rotation

These programs were adopted from Cooley and Lohnes (1962).

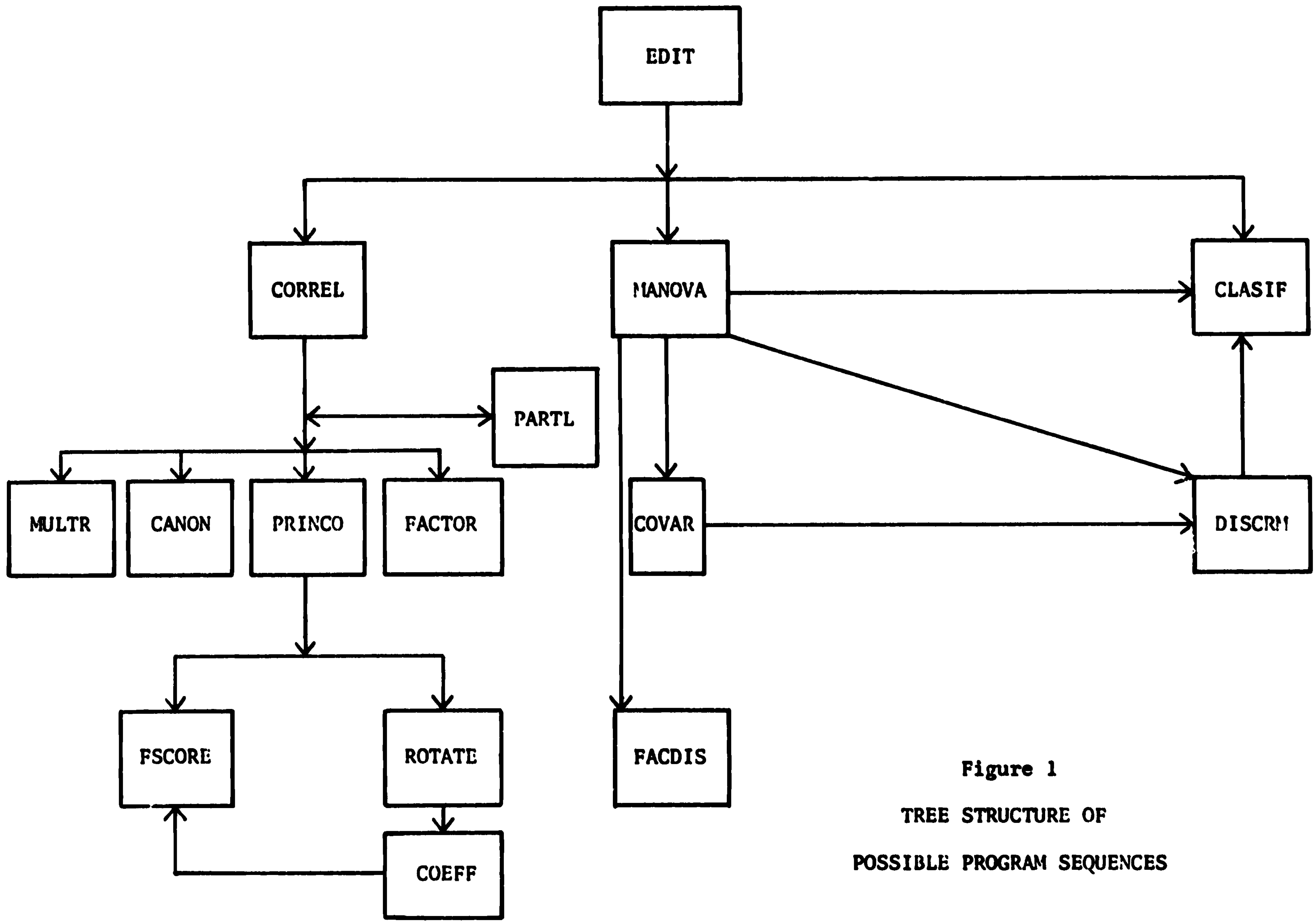

Figure 1

TREE STRUCTURE OF

POSSIBLE PROGRAM SEQUENCES

```
>$$logon 168wwc, size=32000.
M:ENTER PASSWORD

  ACCEPTED
M:  See $$explain schedule about March 13.
Ready:
>$$size = 32000.
>$$load d met.

MONTE CARLO ON T TEST

TYPE A 3 DIGIT NUMBER (200 OR SMALLER) GIVING THE NUMBER OF SAMPLE PAIRS
TO BE DRAWN
>200

TYPE A 2 DIGIT NUMBER (10 OR SMALLER) GIVING THE SIZE OF EACH SAMPLE
>08

BOTH POPULATIONS SAMPLED HAVE UNIT VARIANCE BUT MEANS MAY BE MADE TO DIFFE
TYPE 4 CHARACTERS (WITH DECIMAL) BETWEEN -2.0 AND +2.0, INDICATING DESIRED
DIFFERENCE
>0.0

TYPE IN ANY EIGHT DIGIT "RANDOM" NUMBER TO START THE RANDOM GENERATOR.
>68940215

     ******* DISTRIBUTION OF T'S *******


THE MEAN =      0.0771

THE STANDARD DEVIATION =      1.0330

THE VARIANCE =      1.0671

     FREQUENCY AND CUMULATIVE FREQUENCY DISTRIBUTION
```

INTERVAL	LOWER LIMIT	FREQUENCY	CUM. FREQ.
1	-99.000	0	0
2	-3.333	0	0
3	-3.000	0	0
4	-2.667	2	2
5	-2.333	5	7
6	-2.000	6	13
7	-1.667	7	20
8	-1.333	5	25
9	-1.000	17	42
10	-0.667	24	66
11	-0.333	32	98
12	0.000	16	114
13	0.333	33	147
14	0.667	17	164
15	1.000	12	176
16	1.333	16	192
17	1.667	4	196
18	2.000	1	197
19	2.333	0	197
20	2.667	2	199
21	3.000	0	199
22	3.333	1	200

TRY RUNNING THIS PROGRAM AGAIN WHEN THE NULL HYPOTHESIS IS FALSE

```
>$$det all.
>$$p
>$$list mydata.
 14.       12.
 12.       16.
 11.       15.
 07.       11.
 06.       08.
 05.       10.
 08.       16.
 03.       09.
 09.       13.
>$$det all.
>$$att d mydata as F8.
>$$load d studat.
LOADING STARTS AT LOG 060200
EXTERNAL SYMBOL TABLE


CORRELATION ANALYSIS OF STUDENT'S DATA


SUPPLY THE NUMBER OF SUBJECTS ON THE DATASET YOU HAVE ATTACHED
AS A 3-DIGIT INTEGER.
>009


SUPPLY THE NUMBER OF VARIABLES CONTAINED ON THE DATASET YOU HAVE
ATTACHED AS A 1-DIGIT INTEGER BETWEEN 2 AND 8.
>2


CORRELATION ANALYSIS BETWEEN VARIABLES 1 AND 2 FOR 9 SUBJECTS.

         VARIABLE 1   .                VARIABLE 2

         MEAN      =     8.333         MEAN      =     12.222

         VARIANCE =     12.500         VARIANCE =      8.944

         ST DEV    =     3.5355        ST DEV    =      2.9907
                CORRELATION COEFFICIENT R = 0.654

                R-SQUARED = 0.4279

                Z-SCORE STANDARD ERROR ESTIMATE = 0.7564

                T CALCULATED FROM ABOVE R:

                     T = 2.288 WITH NDF = 7
WOULD YOU LIKE TO TRY THIS PROGRAM AGAIN?

>no

WHEN YOU HAVE COMPLETED YOUR WORK AT THE TERMINAL, BE SURE TO TYPE $$LOGOFF

"SEE YOU NEXT WEEK!"
```

```
>$$att d tandw as F7.
>$$att d means as F8.
>$$att disk as F9.
>$$load d main.
LOADING STARTS AT LOC 088200
EXTERNAL SYMBOL TABLE
  MAIN        0

MULTIPLE DISCRIMINANT ANALYSIS, COMPILED 21 JAN 69


SUPPLY THE NUMBER OF VARIABLES AS A TWO DIGIT INTEGER NOT GREATER THAN 20.
> 2


SUPPLY THE NUMBER OF GROUPS AS A TWO DIGIT INTEGER NOT GREATER THAN 20.
> 3


SUPPLY THE NUMBER OF SUBJECTS AS A 4 DIGIT INTEGER.
> 196


SUPPLY THE NUMBER OF CONTROL VARIABLES PREVIOUSLY PARTIALED OUT BY
COVAR AS A TWO DIGIT INTEGER.
>00


 F-RATIO FOR H2, OVERALL DISCRIMINATION, =      2.15

 NDF1 =      4 AND NDF2 =      384

 CHI-SQUARE TESTS WITH SUCCESSIVE ROOTS REMOVED
```

ROOTS REMOVED	CANONICAL R	R SQUARED	EIGENVALUE	CHI SQUARE	NDF	LAMBDA	PERCENT TRACE
0	0.208	0.043	0.045	8.51	6	0.96	99.87
1	0.008	0.000	0.000	0.01	2	1.00	0.13

```
 ROW COEFFICIENTS VECTORS

 D F   1        0.0043032      0.0494752
 D F   2       -0.0557285      0.0978380

 FACTOR PATTERN FOR DISCRIMINANT FUNCTIONS

TEST

   1     0.888     -0.449
   2     0.992      0.077

COMMUNALITIES FOR       2 DISCRIMINANT FACTORS
   1       0.990      2       0.990

PERCENTAGE OF TRACE OF R ACCOUNTED FOR BY EACH ROOT

   1.88.611       2 10.372
```

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The development of a computer-assisted laboratory in statistical inference is discribed. University of Pittsburgh students work on-line with the Pitt Time-Sharing System on two kinds of laboratory statistics exercises: Monte Carlo exercises for exploring sampling distributions and data analysis exercises. The computer system utilized, the student wxercises, and future plans for evaluation are discussed.

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