SPURT - A SIMULATION PACKAGE FOR UNIVERSITY RESEARCH AND TEACHING

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One problem facing an academic program in computer and information sciences is how to teach the basic ideas of simulation without being overwhelmed by the requirements of presenting a complex simulation language. It is usually true that the student taking a simulation course has some prior knowledge of computer programming, quite often FORTRAN. Capitalizing on this fact, the Industrial Engineering and Management Sciences Department of Northwestern University has developed SPURT: a Simulation Package for University Research and Teaching. SPURT is written in FORTRAN. It provides the novice with basic subroutines required for simulation, and it provides the more advanced user with considerable capability. SPURT consists of a collection of FORTRAN subroutines and functions providing generators for various probability distributions, matrix and graphical output, list processing, and clock functions for controlling discrete time simulation models. SPURT was developed originally for the CDC 3400 and has been converted to the CDC 6400 and the IBM System/360.

This paper discusses the objectives and design of SPURT and its features for discrete simulation. Examples of the use of SPURT for a typical freshman exercise, an advanced, multiprocessor system simulation and other applications are presented.

Development of SPURT

The development of SPURT was motivated by two factors: the class time consumed in teaching a simulation language and the non-availability at Northwestern a few years ago of the more popular languages. Features from other systems, such as SIMSCRIPT, GPSS, and GASP, were encoded into various SPURT routines. Thus SPURT users are introduced to some of the basic properties found in larger simulation systems. SIMSCRIPT is now available at Northwestern, but the use of SPURT continues in freshman, upperclass and graduate courses. Conversion of SPURT to other computers is simplified because of the adherence to USASI standard FORTRAN in coding SPURT.

Structure of SPURT

SPURT provides several stochastic generators with both pre-defined and user-defined distributions. A few statistical routines are included to calculate basic statistics and to produce associated tables. Output routines for displaying arrays and a simple graphical output to a typical plotter device are included. A group of routines provide a basic set for list-type processing. A special list processing routine is coded to act as a clock for controlling a discrete time simulation model.

Stochastic Generators

The stochastic generating functions enable the user to generate samples from various probability distributions and to calculate sample values.

STOGN1 — permits sampling from a discrete empirical probability distribution defined by the user.

STOGN2 — enables the user to approximate a continuous distribution by means of a piece-wise linear distribution.

UNIFRM — permits the user to sample real values from a uniform distribution in a defined interval.

RANDIN — provides a uniform distribution of integers in a defined interval.

NORMAL — allows the user to obtain a random sample from a normal distribution with given mean and standard deviation.

NEGEXP — permits the user to obtain a random sample from the negative exponential distribution.

POISSN — provides the user with a random sample from the Poisson distribution.

ERLANG — provides a random sample from the Erlang distribution.

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DISCRET permits sampling from a step function describing a discrete cumulative distribution of integer values.

LINEAR provides the user with a random sample from a cumulative distribution which is obtained by linear interpolation in a non-equidistant table of real values.

DRAW provides a boolean value of TRUE or FALSE.

RANPER generates a uniformly distributed, random permutation of the integers 1,2,..., M.

Statistical Computations

A number of subroutines are provided to perform standard statistical computations.

STIX1,2,3 are three interrelated subroutines to accumulate and print out a frequency table and to produce a Calcomp plot of a normalized histogram of the table. Figures 1 and 2 show the frequency table and histogram plot produced by the use of these routines.

STIX4 evaluates the mean, standard deviation, maximum value and minimum value of an array of real numbers.

STIX5 evaluates the correlation coefficient between two arrays of real numbers.

STIX6 ranks an array of real numbers and produces the median and range of the data within the array.

STIX7 produces a statistical description of the data found in an array including the sample size, mean, standard deviation, standard error, minimum and maximum values, range, and a printer histogram plot. Figure 3 shows the histogram printer plot produced by STIX7.

Matrix and Graphical Output

Output is facilitated through matrix printing and graphical output.

OUT prints out a square matrix with column and row headings.

NSOUT prints out a non-square matrix with column and row headings.

GRAPH produces two-dimensional graphs or plots using a Calcomp plotter. Figure 4 shows sample graphs produced by this routine.

Clock Generation

The CLOCK subroutine consists basically of two lists; a Master Time List, and a Master Time Queue. "Events" can be stored on either list. The Master Time List contains events scheduled to happen in the future, while the Master Time Queue contains events which could not take place at the time they were scheduled, and therefore, have been rescheduled, i.e., they have been "blocked" and are waiting in a queue. The purpose of the CLOCK subroutine is to cause events to occur in the proper time sequence.

The CLOCK subroutine, like SIMSCRIPT, recognizes two basic kinds of events; EXOGENOUS and ENDOGENOUS. EXOGENOUS events are those that are "external" to the user's routine. These are read from data cards by the CLOCK. ENDOGENOUS events are those that are "internal" to the user's routine. These are generated dynamically and then maintained by the CLOCK.

List Processing

A number of subroutines are provided for list processing. Lists are n x m arrays. Entries in lists are 1 x m arrays.

ADFIFO adds an entry at the bottom of the list, which can be removed only after all the elements presently on the list are gone (builds first-in, first-out list).

ADLIFO adds an entry at the top of the list which will be removed before any other entry presently on the list (builds last-in, first-out list).

REMOVE removes the top (or first) entry from a list.

PURGE destroys the contents of a list.

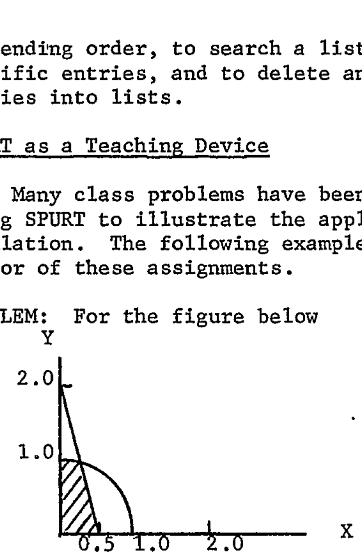
DISPL prints the contents of a list.

Additional subroutines provide the capability to rank lists in ascending or descending order, to search a list for specific entries, and to delete and to insert entries into lists.

SPURT as a Teaching Device

Many class problems have been assigned using SPURT to illustrate the application of simulation. The following example gives the flavor of these assignments.

PROBLEM: For the figure below



find the shaded area by means of a Monte-Carlo computer simulation. Use 500 points for one determination of the area, and calculate the area 20 times. Print out the minimum, maximum and mean values of the area determined.

Presented to freshmen at Northwestern University, this problem is typical of those assigned to engineering students enrolled in a required FORTRAN programming course. Using SPURT the student (1) calls upon a random number generator to provide coordinate data, (2) determines if the coordinate is within the given area, and (3) sums appropriately. Several runs are made and the areas of the different runs are statistically analyzed by a SPURT routine. Thus, the problem for the freshman has been reduced to less than one-third of the total programming effort which would be needed if the entire problem were to be solved using FORTRAN only. The concept of simulation is not lost in the programming effort.

SPURT as a Research Tool

SPURT has been used to facilitate simulation applications and statistical computations for a number of faculty and graduate student research projects. Representative applications are summarized below.

Simulation of Computer Organizations

An example of the more advanced capabilities of SPURT is a model of a complex multiprocessor. The system modeled was described by Aschenbrenner, Flynn and Robinson as "Intrinsic Multiprocessing"[1]. A proposed computer organization consists of N processors sharing the arithmetic and storage resources of the system. This sharing is done to effect a much greater degree of efficiency than in a conventional single processor organization. However, due to sharing, an individual task may be delayed because of resource conflicts. The effects of this were simulated. The model was originally coded in USASI FORTRAN for the IBM System/360-75 and converted, with no trouble, to a CDC 6400. The primary reason for the ease of conversion was the existence of SPURT for both systems. The SPURT routines constituted about 1300 cards of code (comments excluded) and the simulation model comprised about 1200 cards. Thus the bulk of conversion was done before the model was built. The model was able to call upon more than two dozen routines encompassing all major functions provided by SPURT. Thus the job of building and debugging the model was more than halved. The model contained only the logical structure of the system and used SPURT for number distribution generation, event sequencing, list processing, and data collection. Analysis has shown that, at the FORTRAN statement level, FORTRAN statements in SPURT are executed ten times more often than the statements in the model itself. Typical of the output facilities used in the model is Figure 4. This shows average task delay as a function of simulated time in machine cycles. Utilization of the arithmetic control unit (ACU) as a function of time is also shown.

Simulation Report on Children's Memorial Hospital

As a first step toward developing data on occupancy of medical service, bed utilization, hospital population and distribution, etc., a model was developed to simulate admissions to Children's Memorial Hospital. The program was used to:

1. Determine service.
2. Determine period for service.
3. Assign length of stay for each person admitted using an empirical discrete distribution.
4. Determine number discharged.
5. Calculate total population of service and hospital, total admissions for each service, etc.

SPURT was used to provide stochastic generators and graphical output capability for this application.

Spatial Structure of the City and Household Travel

One research project in the Geography Department utilized the statistical summary routine STIX7 to summarize travel data concerned with a study of the relations between household travel and the spatial structure of the city. The relationship between two spatial point patterns defined by the locations of 1) a sample of households and 2) a sample of retail establishments was examined in terms of the frequency distribution of distances between the members of the two point sets. For example, one may wish to utilize, for a specified household, the distribution of distances to all grocery stores in the city. This frequency distribution is generated from a data reduction routine which utilizes STIX7 to create a histogram similar to the one shown in Figure 3.

Implementation of SPURT

SPURT is available as a set of FORTRAN IV subroutines and functions. It has been utilized with the CDC 3400, CDC 6400, and IBM System/360. For the CDC 6400, the routines have been compiled under the RUN and FORTRAN Extended compilers. For the System/360, SPURT routines were compiled using the FORTRAN G and H compilers. A user's manual is available at Vogelback Computing Center that describes the SPURT routines in general and the CDC 6400 version in particular.

Summary

SPURT, like other groups of supporting programs, is designed for a special purpose. It allows a FORTRAN language user to simulate without the need to test and debug most of the routines needed to build a model. The limited diagnostics provide assistance to the programmer in performing this task.

The structure of SPURT is useful as both a simulation teaching tool and as an aid to performing simulations and simple statistical computation. It has served us well as a simulation package for university research and teaching.

Reference

1. "Intrinsic Multiprocessing", R. A. Ashenbrenner, M. J. Flynn, G. A. Robinson, SJCC, April 1967, Atlantic City, New Jersey, Vol. 28, AFIPS Conference Proceedings, pp. 81-86.

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THIS DATA IS ACCOMPANIED BY GRAPH NUMBER 1

DEPTH OF WATER IN TANK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
300	15.000	5.050

	UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN	CUMULATIVE PROBABILITY
UNDERFLOW	0.000	9	3.000	3.000	97.000	0.000	-2.970	.001
	.200	0	0.000	3.000	97.000	.013	-2.931	.002
	.400	0	0.000	3.000	97.000	.027	-2.891	.002
	.600	0	0.000	3.000	97.000	.040	-2.851	.002
	.800	0	0.000	3.000	97.000	.053	-2.812	.002
	1.000	0	0.000	3.000	97.000	.067	-2.772	.003
	1.200	1	.333	3.333	96.667	.080	-2.733	.003
	1.400	0	0.000	3.333	96.667	.093	-2.693	.004
	1.600	0	0.000	3.333	96.667	.107	-2.653	.004
	1.800	0	0.000	3.333	96.667	.120	-2.614	.004
	2.000	1	.333	3.667	96.333	.133	-2.574	.005
	2.200	0	0.000	3.667	96.333	.147	-2.535	.006
	2.400	1	.333	4.000	96.000	.160	-2.495	.006
	2.600	0	0.000	4.000	96.000	.173	-2.455	.007
	2.800	0	0.000	4.000	96.000	.187	-2.416	.008
	3.000	0	0.000	4.000	96.000	.200	-2.376	.009
	3.200	0	0.000	4.000	96.000	.213	-2.337	.010
	3.400	0	0.000	4.000	96.000	.227	-2.297	.011
	3.600	1	.333	4.333	95.667	.240	-2.257	.012
	3.800	0	0.000	4.333	95.667	.253	-2.218	.013
	4.000	1	.333	4.667	95.333	.267	-2.178	.015
	4.200	1	.333	5.000	95.000	.280	-2.139	.016
	4.400	0	0.000	5.000	95.000	.293	-2.099	.018
	4.600	0	0.000	5.000	95.000	.307	-2.059	.020
	4.800	1	.333	5.333	94.667	.320	-2.020	.022
	5.000	0	0.000	5.333	94.667	.333	-1.980	.024
	5.200	1	.333	5.667	94.333	.347	-1.941	.026
	5.400	0	0.000	5.667	94.333	.360	-1.901	.029
	5.600	0	0.000	5.667	94.333	.373	-1.861	.031
	5.800	1	.333	6.000	94.000	.387	-1.822	.034
	6.000	0	0.000	6.000	94.000	.400	-1.782	.037
	6.200	0	0.000	6.000	94.000	.413	-1.743	.041
	6.400	1	.333	6.333	93.667	.427	-1.703	.044
	6.600	2	.667	7.000	93.000	.440	-1.663	.048
	6.800	0	0.000	7.000	93.000	.453	-1.624	.052
	7.000	0	0.000	7.000	93.000	.467	-1.584	.057
	7.200	1	.333	7.333	92.667	.480	-1.545	.061
	7.400	3	1.000	8.333	91.667	.493	-1.505	.066
	7.600	0	0.000	8.333	91.667	.507	-1.465	.071
	7.800	2	.667	9.000	91.000	.520	-1.426	.077
	8.000	0	0.000	9.000	91.000	.533	-1.386	.083
	8.200	3	1.000	10.000	90.000	.547	-1.347	.089
	8.400	1	.333	10.333	89.667	.560	-1.307	.096
	8.600	1	.333	10.667	89.333	.573	-1.267	.103
	8.800	1	.333	11.000	89.000	.587	-1.228	.110

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	9.000	2	.667	11.667	88.333	.600	-1.188	.117
	9.200	1	.333	12.000	88.000	.613	-1.149	.125
	9.400	1	.333	12.333	87.667	.627	-1.109	.134
	9.600	3	1.000	13.333	86.667	.640	-1.069	.142
	9.800	1	.333	13.667	86.333	.653	-1.030	.152
	10.000	1	.333	14.000	86.000	.667	-.990	.161
	10.200	0	0.000	14.000	86.000	.680	-.951	.171
	10.400	2	.667	14.667	85.333	.693	-.911	.181
	10.600	1	.333	15.000	85.000	.707	-.871	.192
	10.800	1	.333	15.333	84.667	.720	-.832	.203
	11.000	0	0.000	15.333	84.667	.733	-.792	.214
	11.200	2	.667	16.000	84.000	.747	-.753	.226
	11.400	3	1.000	17.000	83.000	.760	-.713	.238
	11.600	1	.333	17.333	82.667	.773	-.673	.250
	11.800	1	.333	17.667	82.333	.787	-.634	.263
	12.000	3	1.000	18.667	81.333	.800	-.594	.276
	12.200	1	.333	19.000	81.000	.813	-.555	.290
	12.400	5	1.667	20.667	79.333	.827	-.515	.303
	12.600	1	.333	21.000	79.000	.840	-.475	.317
	12.800	3	1.000	22.000	78.000	.853	-.436	.332
	13.000	6	2.000	24.000	76.000	.867	-.396	.346
	13.200	4	1.333	25.333	74.667	.880	-.356	.361
	13.400	0	0.000	25.333	74.667	.893	-.317	.376
	13.600	3	1.000	26.333	73.667	.907	-.277	.391
	13.800	5	1.667	28.000	72.000	.920	-.238	.406
	14.000	3	1.000	29.000	71.000	.933	-.198	.421
	14.200	4	1.333	30.333	69.667	.947	-.158	.437
	14.400	3	1.000	31.333	68.667	.960	-.119	.453
	14.600	4	1.333	32.667	67.333	.973	-.079	.468
	14.800	5	1.667	34.333	65.667	.987	-.040	.484
	15.000	6	2.000	36.333	63.667	1.000	-.000	.500
	15.200	10	3.333	39.667	60.333	1.013	.040	.516
	15.400	7	2.333	42.000	58.000	1.027	.079	.532
	15.600	5	1.667	43.667	56.333	1.040	.119	.547
	15.800	4	1.333	45.000	55.000	1.053	.158	.563
	16.000	8	2.667	47.667	52.333	1.067	.198	.578
	16.200	3	1.000	48.667	51.333	1.080	.238	.594
	16.400	6	2.000	50.667	49.333	1.093	.277	.609
	16.600	5	1.667	52.333	47.667	1.107	.317	.624
	16.800	5	1.667	54.000	46.000	1.120	.356	.639
	17.000	6	2.000	56.000	44.000	1.133	.396	.654
	17.200	6	2.000	58.000	42.000	1.147	.436	.668
	17.400	5	1.667	59.667	40.333	1.160	.475	.683
	17.600	6	2.000	61.667	38.333	1.173	.515	.697
	17.800	9	3.000	64.667	35.333	1.187	.554	.710
	18.000	3	1.000	65.667	34.333	1.200	.594	.724
	18.200	5	1.667	67.333	32.667	1.213	.634	.737
	18.400	6	2.000	69.333	30.667	1.227	.673	.750
	18.600	9	3.000	72.333	27.667	1.240	.713	.762
	18.800	9	3.000	75.333	24.667	1.253	.752	.774
	19.000	13	4.333	79.667	20.333	1.267	.792	.786
	19.200	9	3.000	82.667	17.333	1.280	.832	.797
	19.400	13	4.333	87.000	13.000	1.293	.871	.808
	19.600	13	4.333	91.333	8.667	1.307	.911	.819
	19.800	19	6.333	97.667	2.333	1.320	.950	.829
	20.000	7	2.333	100.000	.000	1.333	.990	.839
OVERFLOW	XXXXXXXXXXXXX	0	0.000	100.000	.000	1.347	1.030	.848

Figure 1. Output from STIX1,2,3

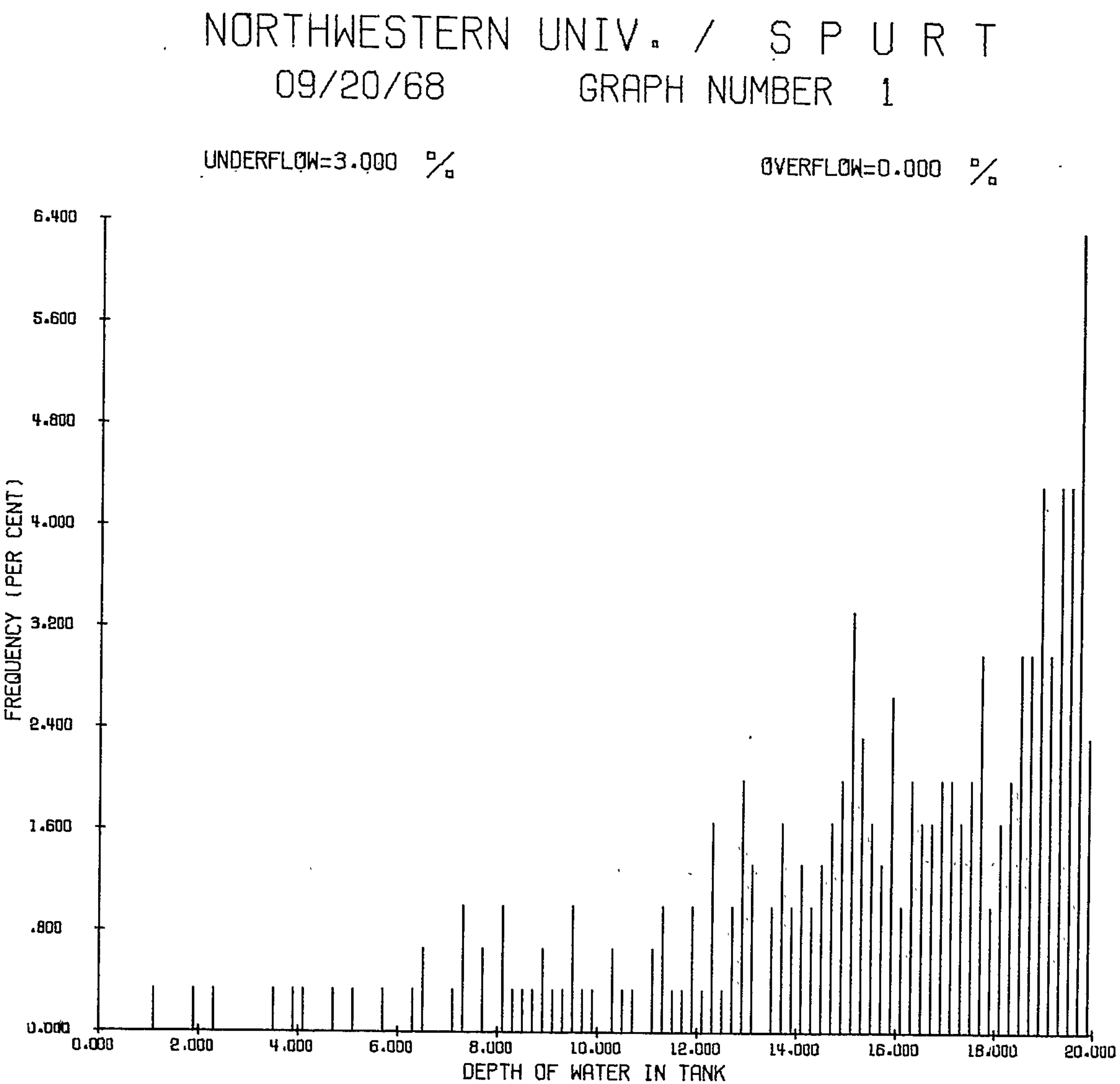

Figure 2. Plotted Output from STIX1,2,3

UNITS ARE SITARS

SAMPLE SIZE	MEAN	STANDARD DEVIATION	STANDARD ERROR
4000	100.12213	19.67703	.31112

30.82351 = MINIMUM VALUE   169.00882 = MAXIMUM VALUE   138.18531 = RANGE

93.50000 = MODE

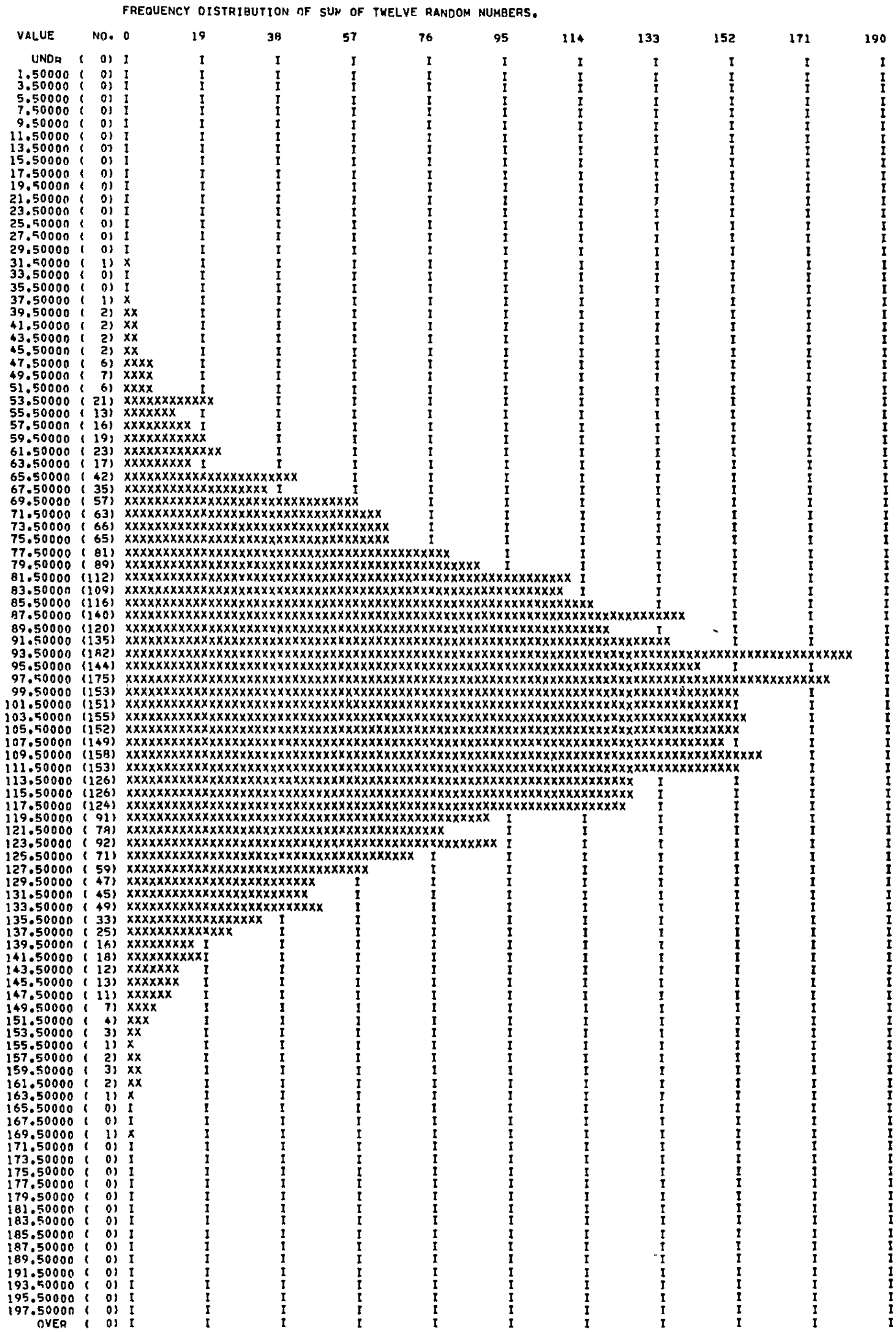

Figure 3. Output from STIX7

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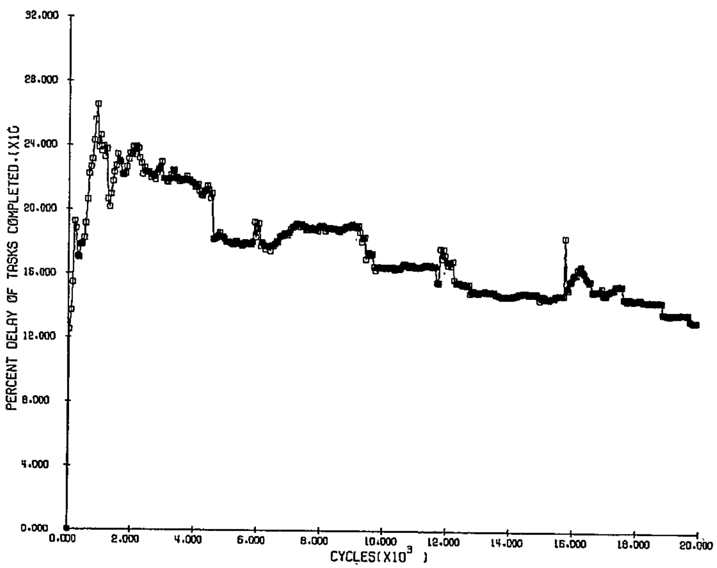

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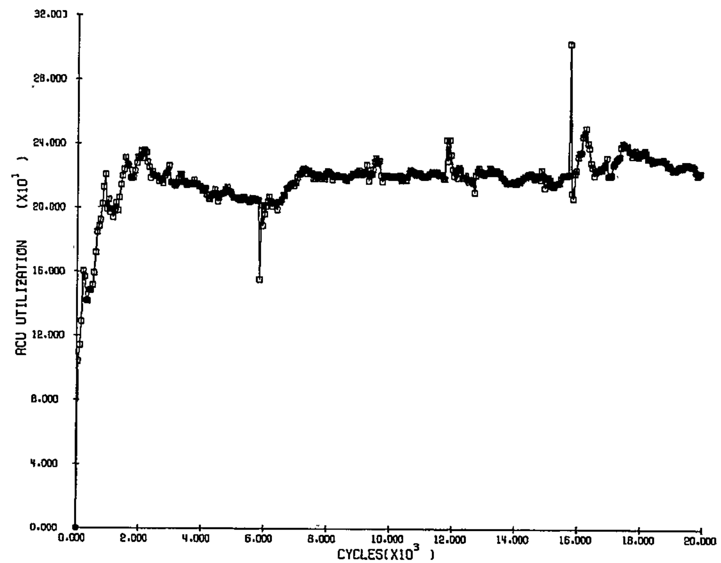

Figure 4. Output from GRAPH