ARTIST: A computer system for creating and running psychology experiments

DIANA EUGENIE KORNBROT

The Hatfield Polytechnic, Hatfield, AL109AB, England

A flexible computer system for research and teaching experiments in psychology is described. Special features of the system include (1) separate phases for the generation and running of experiments, (2) facilities to control presentation of stimuli according to any factorial design, and (3) different modes of operation depending on the prior knowledge of the users. The system is evaluated both in terms of the range of experiments that can be performed and in terms of the time and effort required to create new experiments or modify old ones. General principles for designing interactive systems are discussed in the light of experiences with this particular system.

ARTIST is a laboratory computer system for creating and running psychological experiments in cognition and perception. The system is command based. The user communicates with the system by typing a four-letter command followed by parameters. ARTIST is designed to be used by people with very different levels of both computer and psychology knowledge.

The major concern of this paper is to describe how ARTIST actually works as a laboratory tool in a typical British psychology department. The first section sets out the goals that ARTIST was designed to achieve. The following sections describe the workings of the system, details of the implementation, and evaluation of the actual use of the system by groups of different degrees of sophistication. The final section assesses that part of the work on ARTIST that can be used outside our own department and discusses the general lessons to be learned about designing systems for "specialist" users. (The term "specialist" describes computer users who have considerable expertise in some domain—here, psychological experiments—but little knowledge or interest in the details of computer systems.) It is hoped that the discussion of ARTIST may be useful to computer scientists, as well as to psychologists, in that it will give a feel for the problem as seen by actual users.

DESIGN GOALS FOR ARTIST

The main goal is that the system should provide a powerful and usable tool for a very wide range of experiments in perception and cognition. This goal may be loosely divided into experimental subgoals concerned

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with power and range and user subgoals concerned with simplicity of operation.

Experimental Goals

The system should be able to generate as well as control any experiment consisting of a series of trial events in which each trial consists of stimulus presentation, response(s), and outcome or feedback. The stimulus display may be simple, or composite in time or space, and all three factors may be contingent on the results of previous trials. The stimulus and outcome must be selectable from a set of possible events according to an experimental design specified by the investigator.

In the generation phase, the experimenter should be able to create different displays until the final picture is satisfactory. Furthermore, the experimenter should be able to vary the timing of chosen displays and the responses that are available until the best parameters for a particular experiment are found.

In the run phase, a preprepared experiment should be both simple and quick to set up. In practice there are three stages: First, the preprepared data files are read into the computer. Second, information identifying the experiment, condition, subject, and so on, is typed in. Finally, a command is issued to "run" the experiment, that is, to present the stimuli, record the data, and summarize the results.

Goals for Simplicity of Operation by Psychology Specialists

The first goal is that a totally naive user should be able to use the system by following a few lines of instruction. At this level, subjects can be their own experimenter, or nonpsychology students (e.g., linguists) can, for example, play with "drawing" pictures or timing themselves on an arpeggio in which they successively hit up to 10 keys.

At the next level of sophistication, the user will have had some experience of using packages on a timesharing

system (for example, statistical packages). At this level, the user knows how to create data files using an editor and how to copy and combine these files. However, such users typically have written, at most, a 20- to 50-line program in FORTRAN, and many of them will not know any programming language at all. The majority of our users fall into this category, and they should be able to go further than the naive user by modifying existing data files or creating new ones using an editor.

The most sophisticated users are themselves able to program in FORTRAN. For them, the goal is to ensure that they only have to write programs for the part of their experiment that really is unique to their application.

A psychologist well acquainted with the system should be able to set up an experiment in one or two half-day sessions, either by creating data files or by writing relatively few lines of FORTRAN.

THE ARTIST SYSTEM AND ITS USERS

The Physical System

The computer is a Digital Equipment Corporation (DEC) PDP-11/03C laboratory computer with 8-in. floppy disks for storage of data and programs. The system is controlled via a fast visual display unit (4,800 baud), and in addition, there is a line printer to provide a permanent record of results. The current implementation uses a Tektronix 611 oscilloscope to display text and line drawings as stimuli. The 611 can display either in refresh mode with a dot writing time of 3 microsec and a consequent flicker problem for more than 12 characters or 100 lines, or in storage mode, in which the only method of clearing the screen is a 250-msec flash. Onset and offset of the displays, response times, and interresponse times are all measured to within 1 msec.

The minimum time gap between successive displays is also 1 msec. A 16-bit parallel interface is used for responses. The physical response manipulandum has 10 keys that sit comfortably under the fingers of the two hands and an additional two slots into which any switch closure device may be plugged (e.g., voice-operated relay, foot pedal, specially sensitive pairs of keys for forefingers, etc.). The computer may also be linked via a 1,200-baud serial link to the Polytechnic's main timesharing computer, a DEC system 1091, which supports all major statistical packages (SPSS, BMD, etc.).

Users

The users are predominantly members of the Hatfield Polytechnic Psychology Group, consisting of students enrolled in the BSc (Honours) psychology degree (roughly equivalent to American honors majors), postgraduate students reading for MPhil/PhD, and members of staff. All undergraduates attend a compulsory 14-week course on computing in their 1st year, in which they are taught FORTRAN and how to use packages and systems

facilities on the main timesharing system. They are introduced to ARTIST as a demonstration at this stage. At least one of the compulsory 2nd-year laboratory exercises is performed on the ARTIST computer system. Some of the 30 or so final-(3rd-)year students use the system for their independent research projects. The BSc students fall predominantly into the second level of sophistication described above. Postgraduates and staff vary far more widely in their expertise, but anyone who is interested can reach the second level of sophistication quickly by attending short courses or learning in apprenticeship mode from colleagues.

Framework for Describing Experiments

The psychologist, as specialist, thinks of an experiment in terms of stimuli, responses, outcomes, and experimental design, whereas the computer programmer thinks in terms of displaying a specified picture for a specified time with specified response keys active. The command structure of the system has been designed so that psychologists give all the necessary specifications to the system, but, as far as possible, in their own terms. Thus, to set up an experiment the user has to give the following information to ARTIST: (1) a list of all the text stimuli in groups of up to 12 characters, given via the command LIST (characters may be upper- or lowercase letters, numerals, and a few special symbols); (2) a list of the names of all the picture stimuli (line drawings) via the command PILI (picture list); and (3) lists of all other parameters via command TRAN (transformation), including (a) all time settings, which may be either fixed display periods or intervals or random times varying between two given limits, (b) all key settings used in the experiment, (c) all picture transformations used in the experiment (i.e., size, location, and reflection axis), and (d) a specification of the experimental design in terms of how to randomly choose indexes that specify which cell of the design to use on any particular trial. For example, in a 3 by 4 design in which the first factor is picture identity and the second factor is picture size, it may be required that in a block of 15 trials each picture appear five times and that within those five presentations Sizes 1, 2, and 3 appear once but Size 4 appear twice. All the design information needed is specified in a constraint matrix, N_{JI} , via TRAN.

The subroutine SELECT is used to choose indexes according to constraints in N_{JI} without replacement. N_{J1} is the number of levels of Factor J, N_{J2} is the cycle length in which Factor J is randomized, and $N_{J(1+2)}$ is the number of times the Ith level of Factor J is to be chosen within a cycle. Thus, for example, the matrix

3,	15,	5,	5,	5	
4,	15,	3,	3,	3,	6

can be used to choose an integer between 1 and 3 to specify picture identity (Factor 1) and a number

between 1 and 4 to specify picture size (Factor 2). The above matrix gives an unnested design, as picture identity and picture size are chosen independently. The matrix

3,	15,	5,	5,	5	
4,	5,	1,	1,	1,	2
4,	5,	1,	1,	1,	2
4,	5,	1,	1,	1,	2

can be used for a nested design with the first row used to choose a picture identity number, k , and the $k + 1$ th row used to choose size, thus ensuring a separate tally of size presentations for each of the three pictures. In all the above examples, the randomization takes place within a cycle of length 15. Obviously, many designs are possible with such a system.

The graphics routines use a picture store and display buffer for the command STIM. This buffer may be

ARTIST

A package for generating & running experiments in cognition & perception

The program performs the following functions:

1. Prepares picture and text stimuli
2. Stores prepared stimuli on disk & reads back stimuli already stored
3. Activates specified response keys
4. Runs simple experiments & stores data on disk
5. May be used in conjunction with user supplied subroutine to run experiments

THE PROGRAMME ACCEPTS 4 LETTER INSTRUCTIONS

<> encloses material printed by computer
 [] indicates optional input
 * Indicates the program is ready for new instruction
 ^ Indicates that the program is ready for data (parameters)
 within an instruction

In these instructions all integer parameters start with I, J, K, L, M, or N
 & the number input must NOT contain a decimal point (.);
 parameters starting with any other letter are real numbers and
 MUST contain a decimal point (.)

Below is a list of commands according to function
 Detailed instructions for each command are then listed alphabetically

A. GENERAL

DISP Displays current buffer
 PERM Displays buffer in specified mode (storeage or refresh)
 CLER Flash clears screen when in storeage mode
 STOP Terminates program

B. STIMULUS GENERATION

TEXT Accepts alphanumeric characters into display buffer
 DRAW Constructs line drawings
 STOR Stores current picture in main store
 PICL Zeros picture store
 ASEM Assembles numbered picture with specified transformations

C. RESPONSE SPECIFICATION

KEYS Specifies active keys & foreperiod

D. SET UP FOR EXPERIMENT

LIST Accepts list of stimulus words
 PILI Accepts list of pictures
 TRAN Accepts experiment specifications

D. EXPERIMENTS

CHOI Runs experiment according to current subroutine and specifications
 IDEN Specifies identification of current run

E. INTERACTION WITH DISK

SAVE Saves specified picture on disk
 READ Reads back specified picture from disk

Figure 1. Introduction to ARTIST system and functional list of commands. Material that appears on a single index card is delimited by horizontal lines.

changed using TEXT to enter characters or DRAW to create a new picture. It may also be modified by the command ASEM, which brings a numbered picture from the picture store to the buffer with specified transformations as to size, location, and reflection axis, either adding to or replacing the existing display. Thus a composite display of picture segments and/or text may be created. Mixtures of character sizes are also possible. The pictures may be transferred between the computer store and disk using READ and SAVE.

The commands TRAN, PILI, and LIST will all take input either directly from the terminal or from a named file on disk. The files that serve as input to these three commands are called specification files (they have names ending in EXP); they may be easily created and modified using the powerful system editor.

The flexibility of the ARTIST system is achieved by having a constant component common to all users and a short-variable component in a subroutine CHOICE that is specific to a particular paradigm. The paradigm implemented in the training and demonstration version is called AML (for Mueller-Lyer, one of the experiments) and consists of a stimulus presentation (drawing or text), followed by subject response, followed by feedback as to the stimulus presented. A very large range of different experiments may be implemented using this paradigm by simply changing the specification files.

Using the System

Instructions for setting up the computer and operating the ARTIST system, including three simple demonstration experiments, are available on a 5 x 8 in. card index system. The users may obtain copies of the information by printing out a file, ARTIST.DOC. This paper documentation consists of (1) general introduction, including a full list of commands arranged according to their functions (two index cards, as shown in Figure 1), (2) the function of each command and the information (parameters) the user must give for that command, with a separate flagged index card for each command (examples of cards for commands DRAW, STOR, SAVE are shown in Figure 2), (3) instructions for running the demonstration experiment, including one short card for starting the system and one card for each demonstration (the general start card and the card for the Mueller-Lyer illusion demonstration are shown in Figure 3), (4) a list of subroutines and their functions, as in Table 1, and (5) commented program listings.

A naive or first-time user might come on the system and draw a picture of, say, a horizontal line below a vertical line and save the picture on disk for future use. The dialogue is shown in Figure 4, with comments as to the results of each action. Such users might also run themselves on one of the demonstration experiments.

```

DRAW                via subroutine DRAW

Makes line drawing in current buffer

line 1: 1,2048,2048,0
line n: n,IX,IY,IND
line final: 99
      n is any line between initial & final line
      IX,IY are co-ordinate increments
      IND is 0 if line NOT shown (move);
           is 1 if line IS shown (drawn)
      a line may be deleted by typing a new line with the same
      line number, all following lines are also deleted

```

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SAVE                via subroutine SAVE

Saves numbered picture in named file on disk

line 1: N,PNAME
      N is number of picture to be stored
      PNAME name of picture file in format XXXXXX.PIC,
      X are characters to identify picture for future reference

```

```

STOR                via subroutine STORE

Stores current picture in next free slot in computer store
Returns the number assigned to picture in the store

      Maximum number of pictures is 60
      Maximum number of lines in all pictures is 500

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Figure 2. Instructions for commands DRAW, SAVE, STOR. Material that appears on a single index card is delimited by horizontal lines.

The following instructions describe how to use program AML to run a variety of simple experiments.

In all descriptions output from the computer will be enclosed in arrow brackets thus: <....>

When there are 1 or more lines of intervening computer output it will be indicated thus: <:>

General instructions for AML are in file ARTIST.DOC and on the card index

The program responds to 4 letter commands, e.g. KEYS to set the keys active

<*> indicates the program is ready for new 4 letter command

<^> indicates program needs further parameters within a command

In these instructions all parameters starting with I,J,K,L,M or N are integers & must NOT contain a decimal point;

parameters starting with other letters are real & MUST contain a decimal point

To enter the program type:

<.> RUN AML

HI COMRADE will appear on screen & can be erased by pressing any response key

Experiment 1. Size Judgments and the Muller-Lyer illusion

<*>

PICL

<*>

PILI

<^> 4,3,MLPILI.EXP

<:~>

<*>

LIST

<^> 4,8,MLLIST.EXP

<*>

TRAN

<^> 4,MLTRAN.EXP

<*>

KEYS

<^> 8,1

1,2,3,4,7,8,9,10

<*>

IDEN

<^>NT,8,1 (NT is number of trials;8 is number of picture sizes)

DEMO (Subject name)

SIZE (experiment name)

10,11 (condition number and run number)

<^>AAAAAA.RES

<:~>

<*>

CHOI

<*>

Results of the experiment will be in AAAAAA.RES, summary in FTN11.DAT

A new run should be preceded by a further call to IDEN

Figure 3. General demonstration instructions and instructions for Mueller-Lyer experiment. Material that appears on a single index card is delimited by horizontal lines.

The second level of user could go on to change the parameters of a demonstration experiment by getting a copy of the specification files used in the demonstration and making similar files with his own pictures, sizes, and so on. The actual specification files for the Mueller-Lyer experiment are shown in Figure 5.

If the required experiment lies outside the demonstration paradigm (or one of the other existing paradigms), then the user will have to do some FORTRAN programming. Users who wish to have access to the full power of the ARTIST system will construct their own experiment running Subroutine CHOICE. They may use a special file, FRAME.FOR, which contains that part of a

control subroutine common to all experiments, that is, common blocks for entities used in other parts of the system and initiation of disk files for results and summaries (typically, between 50 and 150 lines of FORTRAN will be needed). Alternatively, users may use subroutines of the ARTIST system in programs of their own devising.

IMPLEMENTATION

The ARTIST package is written in FORTRAN and comprises (1) the main program (194 lines), (2) the general subroutines listed in Table 1, (3) a number of experimental control subroutines, including the demon-

stration subroutine in ML.FOR (89 lines) and the effectively empty file FRAME.FOR (28 lines), and (4) a suite of MACRO (machine language) routines,

Table 1
ARTIST Subroutines and Their Functions

Subroutine	Function	L	P
ASSEMB	assembles picture with transformations from computer store to display buffer	53	No
CLEAR	flash clears screen	9	No
DRAW	adds a line to a picture	41	No
LISTER	accepts text from disk or terminal	15	Yes
MOMENT	calculates first four cumulants, skew, and kurtosis of distribution from sums of powers of distribution variable	36	Yes
PILIST	accepts list of pictures	21	Yes
READ	reads picture file from disk	16	No
SAVE	saves picture on disk	19	No
SELECT	chooses design indexes according to preset experimental design	26	Yes
SPECS	accepts list of experimental specifications from disk or terminal	39	Yes
STIM	presents stimulus display	22	No
STOR	stores picture in computer	14	No
TEXT	encodes characters to display buffer	43	No

Note—L = length; P = portable.

written by the Computer Centre, to control the peripherals of our system. FORTRAN was chosen because it is very well supported by the manufacturer (unlike PASCAL at the time) and it is compiled (unlike BASIC), so that we could be completely sure of the timing of all machine language subroutines. These considerations outweighed major disadvantages, namely, that modular construction is very cumbersome since arrays have to be dimensioned in all subroutines and the string handling is ghastly. If we were making the decision today, PASCAL would probably be chosen.

Design decisions were guided by the results of empirical research on the psychology of computer programming and on the using of packages. Recent reviews of such work are given by Cuff (1980), Green (1980), Hammond, Long, Clark, Barnard, and Morton (1980), and Schneiderman (1977). The fundamental decision to make the system interactive and command based was made at the outset. When designing the command structure and details, we paid particular attention to aspects of the system concerned with "defaults" and "coherence," since both these factors have large effects on the usability of any system.

As far as defaults are concerned, every parameter of the system that relates to the generation phase is assigned to a default value on entering the program. Thus,

Computer Dialogue	Display on Screen	Comments
<u>.RUN AML</u>		enter program
<u>16448 0</u>		
<u>268 0</u>		
<u>0 0 0 2379 0</u>	HI COMRADE	introductory message display off from key 4 after 2379 msec clear picture buffer
* FICL		
* DRAW		enter draw routine
<u>1,2048,2048,0</u>		centre the pen
<u>2,0,-200,1</u>		draw vertical line downward
<u>3,-100,-100,0</u>		move invisibly to start of next line
<u>4,200,0,1</u>		draw horizontal line
<u>99</u>		terminate picture
* STOR		
<u>16 0</u>		
<u>FIC 1 STORED</u>		store picture in computer picture number assigned
* SAVE		
<u>1,HORVER.FIC</u>		saves picture 1 under name HORVER.FIC
* STOP		
<u>-- STOP</u>		exit from program

Figure 4. A sample of computer dialogue in the generation phase of ARTIST. Dialogue output by computer is underlined.

implemented are the Mueller-Lyer experiment already described, a word classification task, and a replication of an experiment by Sternberg, Monsell, Knoll, and Wright (1978) on the latency and duration of rapid movement sequences. The demonstrations certainly evoked interest and caused some people to use the system; how effective they were as a training tool is yet to be systematically investigated.

At the next level of complexity, the package was used in spring, 1980, for a 2nd-year laboratory exercise, replicating an experiment of Stanovich and Pachella (1977) on the effect of response modality (voice or key-press) and stimulus frequency on choice reaction time in an eight-choice task (identify the numerals 1-8). As far as implementation was concerned, the experiment took only about 1 h to set up, since it fit the single-interval paradigm of the demonstration subroutine. The experiment was successful with respect to learning psychology, but it was more problematic with respect to learning the system. Only 1 of these 28 students has so far chosen to use the system for his final-year project. The reasons for this limited success probably have to do with both the fact that students had only about 2 h on the system (not enough to satisfy the twin goals of doing the experiment and getting well acquainted with the system) and the fact that the documentation was incomplete at that stage.

Two final-year projects have used the system. The first, in 1979/1980, was actually implemented by the author, according to the specification of the student, and involved a word classification task in which some words were laterally inverted (mirror images). The student was able to use the generation phase to decide on the parameters of stimuli, and she also constructed all her own stimulus files using the editor. The system certainly performed the task and took about 4 h to implement. The second student, who had used the system in the previous year, is investigating visual search time as a function of number of elements and the category of targets and distractors. He successfully wrote his own program, using the ARTIST subroutines SELECT to randomize stimuli and STIM to present them.

The package has also been used by a postgraduate student investigating imagery and memory. This project has not been so successful; the student took an early version of the package and modified it extensively. However, the rather complex line drawings were not really adequate, partly due to the limitations of the display unit.

The author has so far implemented two series of research experiments. The first series comprises arithmetic tasks, in which subjects have to add and compare numbers that include either decimal or fractional parts. The nine numerals in each problem are generated randomly according to rather complicated constraints in a two-factor design. The control subroutine took 10 days to write at a minimum of 10 h/day. The difficulty

occurred because the randomization problem itself was complex and, effectively, the difficulties were being worked out as the program was written. However, once the main control program was written, new conditions could be implemented in about 10 min, using the editor to construct the specification files. The second series of experiments involves signal detectability theory tasks with payoffs for different response-stimulus contingencies and penalties that either are a function of latency or occur whenever the subject exceeds a deadline. The initial experiment took about 1 day to implement, plus a further half-day to implement the deadline conditions. Again, the system was able to perform the task and the time for implementation was small, relative to the time taken to design the experiment.

Projects currently being implemented include an experiment on interresponse times in movement sequences and a general staircase method for thresholds.

All the users described so far had some verbal description and demonstration of the system from the author. The documentation has also been assessed by a single graduate student, who learned the system entirely from the written documentation. Many improvements have been made in the light of his experiences. Nevertheless, he was able to use all the commands for the generation phase and to not only run the demonstrations but also modify them to create new experiments.

DISCUSSION

The ARTIST system is a computer tool within a single psychology department. However, in the discussion of the system, those aspects that may be of use outside the home department will be emphasized.

At the most concrete level, Table 1 indicates which subroutines are directly transportable. SELECT and MOMENT are the ones likely to be of most use to psychologists. SELECT chooses a random order of stimulus presentation for any factorial design; indeed, it may be used to generate such a random order for an experiment not run on a computer. MOMENT is an analysis subroutine. The fact that it operates on sums of observations (Σx , Σx^2 , etc.) means that it is very easy to combine data from different experimental runs.

The entire system should be transportable to any computer with a FORTRAN compiler. Only those routines that control the peripherals would need to be rewritten.¹

At a more general level, ARTIST may be compared with other packages. Any of the teaching experiments with visual stimuli described by Fischler (1980) and White (1980) could be set up within a half-day session, as could most of the visual research experiments described by Poltrock and Carr (1980) (the ones using rotation and projection of three-dimensional figures would take longer).

There are also several similarities between ARTIST and commercially available packages such as word

processors. For example, many word processing packages are, like ARTIST, command based. This gives the advantages of an interactive system, namely, that the result of each user action may be seen immediately and the system is modular in the sense that users need only learn about commands relevant to their own needs.

In another sense, ARTIST is very different from commercial packages, most of which are designed to be completely self-contained so that the user interacts only with the package, never with the main computer-operating system behind it. The ARTIST system, on the other hand, makes maximum use of the powerful system facilities embodied in the editor and file manipulation routines. There are two reasons for this design decision. First, no time is wasted duplicating existing facilities that are already tried and tested. Second, more of what the user learns is generally applicable. Students who move to another department or from the laboratory-control computer to the main timeshared system will certainly need to know about editors, whereas they are unlikely to encounter another ARTIST.

Considerable attention has been paid not only to the system itself, but also to the supporting documentation. The documentation, like the system, is modular, so that users need look at only one command at a time. The relevant information is also much easier to find from a card system than it would be from a booklet. The documentation is designed so that evaluation and improvement constitute an ongoing process. Users are encouraged to clip any comments or suggestions to the relevant instruction card. Because of the modular construction, the programmer may then modify instructions to just one card and try the new version on another user. If more space were available, these features could be implemented on-line. That is, users would be able to ask for help on any command and also write comments on any command.

The system is designed so that the user can "learn by example." Thus, the immediate availability of specification files for all existing experiments is an essential feature of ARTIST. Again, the value of this approach is a matter for future empirical test.

ARTIST is perhaps unusual in that it deliberately allows for users of different levels of sophistication. Nevertheless, before running any experiment, the user must invest some appreciable time in learning the system. It is hoped that the time is small enough that the exercise is worthwhile even for users who use the system only once.

It is important to identify those features of the package that contribute substantially to a reduction in the labor required to implement an experiment. First, the package almost eliminates the need to write input/output routines, which can be as much as a third of a program. Similarly, pictures can be created interactively and without programming. The facility of accessing long lists of parameters from disk as well as terminal also saves time, not only when creating experiments but also

each time they are used. The presence of a laboratory system like ARTIST permits the buildup of a library, so that most new experiments will conform to an existing subroutine. It should be emphasized that if a library routine exists, an experiment can be set up in half a day. Neither alternative equipment (tachistoscopes?) nor an outside systems analyst's help could improve on this time. It is quite impossible to write a package that will cover all possible future experiments, a fact that must be appreciated by psychologists and the computer experts they commission. Hence, the facility to write user programs in a widely available and well supported language that can easily be linked to the package is essential.

Finally, it must be emphasized that techniques for evaluating complex systems or packages are in their infancy. Consequently, the above discussion is based, at best, on empirical field observation, but, more frequently, on the intuition of the author or the users.

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NOTE

1. The following material is available from the author on any computer medium: (a) any subroutine, (b) the entire ARTIST system, and (c) ARTIST documentation. All subroutines marked portable in Table 1 will run on any FORTRAN machine and are fully supported; the rest of the system is guaranteed to work only on systems with hardware configuration identical to ours.