Discrete Event Simulation
With Pascal

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DISCRETE EVENT SIMULATION WITH PASCAL

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Pascal.SIM is a collection of Pascal constants, types, variables, functions and procedures for developing event, activity, three-phase or process orientated discrete-event simulation models. Facilities are provided for queue processing, time advance and event list maintainence, control of entities and resources, random number generation and streams, sampling from parametric and empirical distributions, statistics collection, and visual displays.

Pascal.SIM has been designed as a minimal simulation tool. It includes less than 50 functions and procedures, and totals less than 800 lines of code. It is a basis for programming simulations in Pascal, where users can alter or extend the facilities provided, rather than a simulation programming language.

The majority of Pascal.SIM conforms to the ISO Pascal standard, enabling high portability to be achieved. It can be used immediately with any Pascal that uses the string type descended from UCSD Pascal, for instance Pro Pascal, Turbo Pascal or Sheffield PRIME Pascal. Alteration of a few lines allows for use with any Pascal that provides a different string type, for instance VAX/VMS Pascal.

Key words: Discrete event simulation, visual, Pascal.

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INTRODUCTION

Discrete event simulation "concerns the modeling of a system as it evolves over time by a representation in which the state variables change only at a countable number of points in time" (1). Normally, the representation is a computer program, and increasingly a program in a Simulation Programming Languages (SPL) such as GPSS (2) or SIMSCRIPT (3). However, recent years have seen some resurgence in interest in the use of general purpose programming languages as vehicles for simulation programs. In part this has been due to the increasing availability of good implementations for strongly-typed block structured languages such as Pascal, Ada, and Modula-2. Further, the use of microcomputers has accelerated such interest, since many SPLs and packages are too large for use on microcomputers, or when available on microcomputers, are highly inefficient.

A number of Pascal based simulation systems have been produced. The majority of these mimic existing SPLs, and do not necessarily make good use of the Pascal that underlies the system. Examples include PASSIM (4), which is based on GPSS, and SIMPAS (5), a SIMSCRIPT-like language which is pre-processed into Pascal.

Pascal.SIM is an attempt to provide the basics of a Simulation Programming Language, taking advantage of the main features of Pascal. Those using Pascal.SIM can then add the facilities they need and change the underlying structure if they wish. A further aim is to provide a means whereby students could learn to write simulations in a familiar language using facilities that are well documented and easy to understand.

WORLD VIEWS

At the heart of any SPL or simulation package is a world view. This is the methodology for viewing a simulation that is enforced upon the programmer. Pascal.SIM provides two worlds views - the three-phase approach and process description. In the three-phase approach, the programmer programs scheduled events, which can be explicitly scheduled to occur at some time in the future, and conditional events, which occur when certain conditions become true. A simulation is driven by an executive which advances the clock to the next scheduled event, executes it, and then scans all conditional events to ascertain which can be executed.

In process description, the list of activities that each object in the simulation can go through is mapped out, and the executive handles the investigation of the conditions whereby an activity can start, and the scheduling of the end of each activity. Whilst conceptually easier to follow than the three-phase approach, complete implementation of process description, where processes are allowed to interact (called process interaction), requires a co-routines facility. Co-routines are not supported in Pascal, although there have been attempts to extend Pascal with co-routines (6). However, simple process description, where processes can be described, but cannot explicitly interact, can be achieved in standard Pascal as is explained later.

VISUAL SIMULATION

Increasingly, the ability to iconically display the ongoing simulation is important (7). Called visual simulation or animation, this aids the programmer in verifying the program, and the model user validating the model. Typically, the amount of effort required to program the
visual display can be as great as that to program the simulation. Thus programming visual displays is supported in Pascal.SIM, and nearly one third of Pascal.SIM is devoted to facilities for producing simple visual displays.

THE STRUCTURE OF A Pascal.SIM PROGRAM

The recommended structure of a three-phase orientated Pascal.SIM program is shown in Figure 1. At the heart of the simulation is the executive, the procedure RUN, which contains the time flow mechanism. Although the structure of this is provided, the user must enter the names of all events into a case statement in this procedure. The number of conditional events MAX.C and the time duration (DURATION) are both arguments. The user must code the events and the procedures INITIALIZE and REPORT; for a visual display DISPLAY and PICTURE must also be coded. INITIALIZE and PICTURE are called once before RUN; they initialize the simulation and the static picture respectively. REPORT should be called after RUN, and should contain any end of run reporting, for example, final statistics prints. DISPLAY is called after every advance of the clock; it should be used to update the visual display as necessary.

The basic object in any simulation is the entity, where entities move through the system engaging in a number of activities. Examples might include patients in a health care simulation, or programs in a computer system simulation. The basis of Pascal.SIM is an entity type, which is a Pascal record thus:-

```
entity="an.entity;
an.entity=packed record
  avail:boolean;
  class:class_num;
  col:colour;
  attr,next_B:cardinal;
  time:real;
end;
```

where the fields of the record represent:-

- **AVAIL**: The availability of the entity
- **CLASS**: The number of the entities class
- **COL**: The colour of the entity
- **ATTR**: The entities attribute number
- **NEXT_B**: The next bound event or block that the entity will enter
- **TIME**: The time that which this will occur

An entity is always either available, entered in the calendar of future events, or is being used by another entity. If entered in the calendar, AVAIL is false, and NEXT_B and TIME will be set to appropriate values. Thus there are no explicit event notices in Pascal.SIM because an entity contains all relevant event information. Entities are generated with the function NEW.ENTITY, and can be disposed of with the procedure DIS.ENTITY.
Access to entities is achieved through the global variable CURRENT, which always points to the entity that has caused the present event, or else by searching queues of entities.

The attribute number ATTR uniquely identifies each entity. If further attributes are required they can either be added to entities by using the attribute number to access another data structure, or else by adding in new fields to the entity record and recompiling Pascal.SIM. In complex models, the developer would establish classes, where a class is a list of entities, and both the class and each entity may have attributes. For visual displays, the developer must enter classes into a class table, which holds information on the letter and colour used to represent an entity in the display.

Most simulations involve passive entities, which only serve other entities. These are commonly called resources, and are said to be acquired and released by entities. Examples might include machines in a factory simulation, or a disc drive in a computer system simulation. A resource type, with associated routines, is provided, where resources are collected into a BIN.

The provided functions and procedures of Pascal.SIM are grouped into 11 groups, respectively:

- queue processing
- entities and classes
- timing and the executive
- facilities for process description
- resources
- error messages
- random number generation and streams
- sampling distributions
- histograms
- screen control
- visual displays

The interface of Pascal.SIM, i.e. all constants, types, global variables and function and procedure heads, is shown in the appendix. A certain excess redundancy is present in the four routines (GIVE.TOP, GIVE.TAIL, TAKE.TOP, TAKE.TAIL) which allow for giving and removing entities to the top and tail of a queue. Use of these allow students to develop First In First Out queueing models without having to explicitly dereference pointers.

AN EXAMPLE - ADMISSION TO HOSPITAL

The example to demonstrate how to program using Pascal SIM is a hospital simulation, shown as an activity diagram in Figure 2. Two types of patient are admitted to hospital. Those not admitted for an operation undergo a short stay, and then return home. Patients admitted for operation undergo a pre-operative stay, an operation (which requires an open and available operating theatre), followed by a post-operative stay and discharge. Such a simulation is somewhat simplistic, but might be used to investigate various policies regarding bed and operating theatre provision.
{ Bound events }

procedure B1;
procedure B2;
    :
    :

{ Conditional events }

procedure C1;
procedure C2;
    :
    :

procedure display;
procedure run(duration:real;max.C:cardinal);
procedure initialize;
procedure picture;
procedure report;

begin
    :
    initialize;
    picture;
    :
    run( ..., ... );
    :
    report;
    :
end.

Figure 1: The structure of a three-phase Pascal.SIM program.
Listing 1 shows a Pascal SIM three-phase orientated program for a visual simulation. An example visual display is shown in Figure 3. In the INITIALIZE procedure, the simulation and random number streams are initialized (via MAKE SIM and MAKE STREAMS), a BIN called bed with 4 resources is created using MAKE BIN, and the queues q1, q2, q3 and q4 are initialized using MAKE QUEUE. The operating theatre is created, and scheduled to close in 8 hours. Note that CAUSE is the scheduling procedure; the first parameter indicates the bound event that will be entered. This has to be entered as an integer, since Pascal does not allow procedure names to be passed as parameters and stored for future calling. Case statements in the executive relate these numbers to procedures calls.

**PROGRAMMING THE SIMULATION**

Producing a three-phase orientated program for the example commences with the identification of all scheduled and conditional events. For the hospital example these are:

**scheduled**

- hospital stay only patient arrives;
- operation patient arrives;
- end hospital stay;
- end pre-operative stay;
- end operation;
- end post-operative stay;
- open theatre;
- close theatre;

**conditional**

- start hospital stay;
- start pre-operative stay;
- start operation;
- start post-operative stay;

As can be seen in Listing 1, the arrival of a patient of each type is modelled in the procedures PATIENT1 ARRIVES and PATIENT2 ARRIVES. An arrival results in another arrival being scheduled with the CAUSE statement. This is the common way to feed arrivals where the inter-arrival distribution is known. The four activities stay, pre-operative stay, post-operative stay and operation, clearly identifyable in Figure 2, are all modelled by a conditional event that starts the activity, and a scheduled event that ends it. Strictly, the starting of a post-operative stay can be a scheduled event, since there are no constraints on its start. However, it is a good idea to model all activities as a pair of conditional and scheduled events, since this aids modularity, and makes the program easier to alter when and if the simulation is extended by introducing further constraints on the start of an activity. Either the closure or opening of the operating theatre is always scheduled. The boolean THEATRE OPEN is used to record whether or not the theatre is open, and similarly THEATRE AVAILABLE is set to false if an operation is in progress.
Figure 2: An activity diagram for the hospital simulation.
program example;

    var  bed:bin;
        q1,q2,q3,q4:queue;
    theatre:entity;
    theatre.open,theatre.available:boolean;
    { true if theatre is open, available }
    old.tim:real;
    operations_queue:record
        measure:histogram;
        last.update:real;
    end;

procedure patient1.arrives; { stay }
    begin
        give.tail(q1,current);
        move.h(12,2,10,current,white);
        write.queue(22,12,white,q1,20);
        cause(1,new.entity(1,1).uniform(60,140,1));
    end;

procedure patient2.arrives; { operation }
    begin
        give.tail(q2,current);
        move.h(14,2,10,current,white);
        write.queue(22,14,white,q2,20);
        cause(2,new.entity(2,1).uniform(24,48,2));
    end;

procedure end.hospital.stay;
    begin
        return(bed,1);
        move.h(12,40,70,current,white);
        dis.entity(current);
    end;

procedure end.pre.operative.stay;
    begin
        current-.col:=yellow;
        give.tail(q3,current);
        move.v(30,14,20,current,white);
        move.h(20,30,50,current,white);
        move.h(20,30,50,current,white);
        write.queue(60,20,white,q3,30);
    end;
procedure end.operation;
  begin
    theatre.available:=true;
    gotoxy(63,21);write('    ');
    move.v(30,4,10,current,white);
    give.tail(qd,current);
  end;

procedure end.post-operative.stay;
  begin
    return(bed,1);
    move.h(12,40,70, current, white);
    dis.entity(current);
  end;

procedure open.theatre;
  begin
    theatre.open:=true;
    gotoxy(63,20);write('OPEN   ');
    cause(8, current, 8);
  end;

procedure close.theatre;
  begin
    theatre.open:=false;
    gotoxy(63,20);write('CLOSED');
    cause(7, current, 40);
  end;

procedure start.hospital.stay;
  begin
    while (bed.num.avail>0)
      and (count(q1,true)>0) do
      begin
        acquire(bed,1);
        cause(3,take.top(q1),uniform(20,40,3));
        write.queue(22,12,white,q1,20);
      end;
  end;

procedure start.pre-operative.stay;
  begin
    while (bed.num.avail>0)
and (count(q2,true)>0) do
begin
acquire(bed,1);
cause(4,take.top(q2),uniform(5,15,4));
write.queue(22,14,white,q2,20);
end;
end;

procedure start.operation;
begin
while theatre.open and theatre.available
and (count(q3,true)>0) do
begin
theatre.available:=false;
cause(6,take.top(q3),1);
gotoxy(63,21);write('IN USE');
write.queue(60,20,white,q3,30);
end;
with operations.queue do
begin
log.histogram(measure,count(q3,true),tim-last.update);
last.update:=tim;
end;
end;

procedure start.postoperative.stay;
begin
while (count(q4,true)>0) do
begin
cause(6,take.top(q4),uniform(5,10,6));
end;
end;

procedure display;
var i:cardinal;
begin
gotoxy(30,12);write(bed.number-bed.num.avail:1);
delay;delay;
for i:=1 to trunc((tim-old.tim)/2) do delay;
old.tim:=tim;
gotoxy(1,1);writeln(tim:7:2);
end { display };

procedure run(duration:real;max.C:cardinal);
var c: cardinal;
begin
running:=true;
repeat
if calendar=calendar^.next then running:=false
else begin
  display;
  tim:=calendar^.next^.item^.time;
  if duration<tim then running:=false
  else begin
    while (calendar<>calendar^.next) and
      (tim=calendar^.next^.item^.time) do
      begin
        calendar.top;
        case current^.next_B of
          0::*;
          1: patient1.arrives;
          2: patient2.arrives;
          3: end.hospital.stay;
          4: end.pre-operative.stay;
          5: end.operation;
          6: end.post-operative.stay;
          7: open.theatre;
          8: close.theatre;
        end;
      end
      for c:=1 to max_C do
      case c of
        1: start.hospital.stay;
        2: start.pre-operative.stay;
        3: start.operation;
        4: start.post-operative.stay;
      end;
    end
  until not running;
end { run };

procedure initialize;
begin
  make.sim;
  makeStreams;
  make.bin(bed,4);
  make.queue(q1); make.queue(q2);
make.queue(q3); make.queue(q4);
with operations.queue do
  begin
    make.histogram(measure, 11);
    last.update := 0;
  end;
{ create theatre }
theatre := new.entity(31);
theatre.open := true;
theatre.available := true;
cause(8, theatre, 8);
end { initialize };
end.

Listing 1: A three-phase Pascal.SIM simulation for the hospital example.

**PROGRAMMING THE VISUAL DISPLAY**

The visual display is composed of two parts - a static background picture which is written to the console once prior to the simulation run, and a dynamic display which moves over the static picture. The dynamic display can be updated either within an event, bound or conditional, or following a time beat (where one or more events will have been executed) in the procedure DISPLAY.

Even with using text to program simple iconic visual displays, a minimum amount of screen control is essential. Cursor addressing must be possible; for colour displays the ability to set both foreground and background colour is necessary. Many terminals provide both of these, and thus the visual display routines are highly portable.

A static picture is created in the procedure PICTURE. Entity classes 1 and 2 (respectively hospital stay only and operation patients) are entered in the CLASS_TABLE with letters 's' and 'o'. Both will appear blue, unless the field COL in the entity record has been set to a colour - this overrides the CLASS_TABLE entry. To provide a background, blocks coloured magenta are entered in the display, and some simple annotation is provided using the GOTOXY procedure in Pascal.SIM and the standard Pascal procedure WRITE.

The procedure DISPLAY provides for updating of the dynamic display after a time beat. The number of BEDs in use (BED_NUMBER-BED.NUM.AVAIL) is written. At this point, the display is completely up to date. The simulation is then delayed relative to the time before the new time beat (TIM-OLD.TIM). If this is not done, the display advances too quickly for comfortable viewing. The new clock time TIM is then written to the display, and the simulation (and thus the part of the picture generated within events) can continue.

Most of the visual display statements are embedded in the events. For instance, when a hospital stay only patient arrives, the following occurs (see procedure PATIENT1.ARRIVES)

```
put patient on a queue for a bed
show the arrival of the patient by horizontal movement
display the hospital stay only queue for beds
cause the arrival of a new hospital stay only patient
```

The procedures MOVE.H (move horizontal) and MOVE.V (move vertical) are the main methods for moving entities across the display. The letter representing the entity is moved on the specified background colour either horizontally or vertically. Note that when ready
Figure 3: An example visual display. A patient, represented by the letter 'o', is waiting for the operating theatre to open. Three beds are in use; the present clock time is 783.06 time units.
mean = 0.45  variance = 0.30  sd = 0.55
min = 0.00  max = 2.00

under
1.00 ****************************
2.00 ****************************
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
over

Figure 4: A histogram for the size of the operating theatre queue.

for an operation, in procedure END.PRE.OPERATIVE.STAY, operation patients have their colour set to yellow, and will thus appear yellow on the screen from that point on.

STATISTICS COLLECTION

Collection of statistics is achieved through a HISTOGRAM type. The programmer must explicitly create histograms with MAKE.HISTOGRAM, arrange to have data logged to them with LOG.HISTOGRAM, and print them to a file with PRINT.HISTOGRAM. A histogram can be one of two types. State histograms record absolute values, whereas time weighted histograms result in the calculation of parameters being weighted by the times that an observation persisted for.

Listing 2 includes the use of a time weighted histogram to record the queue length at the operating theatre. A record called OPERATIONS.QUEUE is declared with two fields MEASURE (the histogram) and LAST_UPDATE (the last time at which an observation was recorded). The queue length is logged in the procedure START.OPERATION, after any change in queue length due to the start of an operation. An example final histogram is shown in Figure 4. As a time weighted histogram, accumulated cell totals represent time duration. Thus, for instance, the queue was empty for 5030.20 time units.

A PROCESS DESCRIPTION VERSION
The hospital example is recoded as three processes for hospital stay only patients, operation patients, and the operating theatre, in Listing 2. Note that DISPLAY, INITIALIZE and PICTURE would be identical to those in Listing 2 and have thus been omitted, as has the statistics collection.

Process orientated simulations in Pascal.SIM are written by splitting up a procedure into a number of different blocks using a case statement. Entities advance from block to block; a procedure can be 'reactivated' by being called and a block (i.e. a branch of the case statement) being attempted. A procedure called BRANCH is used to immediately cause an entity to attempt a new block. Note that the first parameter of a CAUSE statement now specifies a block number rather than an event, and an entities class number identifies its process. The need for the programmer to split a procedure up with a case statement, to explicitly specify when a process must be suspended (this is done here using a repeat until loop with a flag called finished), and to explicitly test if entry to a block is possible, makes the programming fairly ungainly and error prone compared to true process interaction languages. It does, however, allow for process description modelling in Pascal.

In the process description executive, which is modelled on the GPSS executive, an entity is either entered in the calendar or on a chain of suspended entities. Queue priority is implicit, dependent upon an entity's position in the suspended chain. This means that the developer of a visual simulation must introduce dummy queues at various points in a process so that the queues can be written to the picture. This has not been done in Listing 2, therefore the queues displayed using WRITE.QUEUE in Listing 1 would not be present in the picture.

```pascal
program example;

  var  bed:bin;
       q1,q2,q3,q4:queue;
       theatre:entity;
       theatre.open,theatre.available:boolean;
       { true if theatre is open, available }
       old.tim:real;

procedure patient1;
  var finished:boolean;
  begin
    finished:=false;
    repeat
      case current^.next_B of
        1:begin
          move.h(12,2,10,current,white);
          cause(1,new.entity(1,1).uniform(30,60,1));
          branch(2);
        end;
        2:begin
          if (bed.num.avail>0) then
```
begin
  cause(3, current, uniform(20, 40, 3));
  acquire(bed, 1);
end;
finished:=true;
end;
3: begin
  return(bed, 1);
  move_h(12, 40, 70, current, white);
  finished:=true;
  remove_entity;
end;
end;
until finished;
end { process for patient 1 };

procedure patient2;
  var finished: boolean;
begin
  finished:=false;
repeat
  case current^.next.B of
    1: begin
      move_h(14, 2, 10, current, white);
      cause(1, new.entity(2, 1), uniform(12, 20, 2));
      branch(2);
      end;
    2: begin
      if (bed.num.avail>0) then
        begin
          cause(3, current, uniform(5, 15, 4));
          acquire(bed, 1);
        end;
      finished:=true;
    end;
    3: begin
      current^.col:=yellow;
      move_v(30, 14, 20, current, white);
      move_h(20, 30, 50, current, white);
      branch(4);
    end;
    4: begin
      if theatre.open and theatre.available then
        begin

theatre.available:=false;
cause(5,current,1);
gotoxy(63,21);write('IN USE');
end;
finished:=true;
end;
5:begin
theatre.available:=true;
gotoxy(63,21);write('');
movex(30,4,10,current,white);
cause(6,current,uniform(5,10,6));
finished:=true;
end;
6:begin
return(bed,1);
movex(12,40,70,current,white);
finished:=true;
remove.entity;
end;
end;
end { process for patient 2 };

procedure schedule.theatre;
begin
 case current^.next.B of
  1:begin
   theatre.open:=true;
gotoxy(63,20);write('OPEN ');
   cause(2,current,8);
   end;
  2:begin
   theatre.open:=false;
gotoxy(63,20);write('CLOSED');
   cause(1,current,40);
   end;
 end { schedule theatre };
end

procedure display;
begin
:
end { display };

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procedure run(duration: real);
    var c: link;
        remove, changed: boolean;
    e: entity;
    i: cardinal;

procedure reactivate(scanning: boolean);
    var present: cardinal;
begin
    remove := false; on.calendar := false;
    with current do
        begin
            present := next.B;
            case class of
                1: patient1;
                2: patient2;
                3: schedule.theatre;
            end;
            if scanning then
                begin
                    if on.calendar then
                        begin
                            remove := true; changed := true;
                        end
                    else
                        if present <> next.B then
                            begin
                                remove := true; changed := true;
                                give.tail(suspended.chain, current);
                            end;
                        end
                    else begin
                        if next.B <> 0 then
                            if not on.calendar then
                                give.tail(suspended.chain, current);
                            end;
                        if next.B = 0 then dis.entity(current);
                    end;
                end { reactivate };
        begin
            running := true;
            repeat
                if calendar = calendar^ .next then running := false
else begin
  display;
  tim:=calendar^.next^.item^.time;
  if duration<tim then running:=false
  else begin
    while (calendar<>calendar^.next) and
      (tim=calendar^.next^.item^.time) do begin
      calendar.top;
      reactivate(false);
    end;
    repeat
      changed:=false;
      c:=suspended.chain^.next;
      i:=1;
      while c<>suspended.chain do begin
        current:=c^.item;
        reactivate(true);
        c:=c^.next;
        if remove then e:=take(suspended.chain,c^.pre);
      end;
      until not changed;
    end;
  until not running;
end { run };

procedure initialize;
begin
  :
end { initialize };

procedure picture;
begin
  :
end { picture };

procedure report;
begin
  :
end { report };

begin
initialize;
picture;
cause(1,new_entity(1,1),0);
cause(1,new_entity(2,1),0);
old_time:=0;
run(24+30+12);
report;
reset_colours;
end.

Listing 2: A process description version of the hospital simulation.

PORTABILITY AND IMPLEMENTATION

Considerable portability is achieved by close adherence to the ISO Pascal standard. Only two non-standard Pascal facilities are used - the use of an underscore in names (which can easily be edited out), and the use of a string type. However, most Pascal implementations provide a string type, and Pascal.SIM can be implemented without change under any Pascal that uses the string type and associated functions descended from UCSD Pascal. Examples include Turbo Pascal, Pro Pascal, and the Pascal compiler for PRIME systems produced at the University of Sheffield in England. If a string type is defined differently, or different functions are provided, a few alterations are necessary. For instance, in VAX/VMS Pascal, the string type is VARYING ARRAY OF CHAR rather than STRING, and strings are concatenated directly using the addition operator rather than a CONCAT function. If strict ISO Pascal is followed, and a PACKED ARRAY OF CHAR has to be used, then only one procedure is unusable. This is PRINT_HISTOGRAM, which prints histograms to a text file.

Pascal.SIM is normally implemented by some method of prior compilation. Methods include adding the functions and procedures to a library and the variables to a common area (this is the method of implementation in Pro Pascal), production of a unit or module, containing all of Pascal.SIM, that is then put in a library (for instance, UCSD Pascal), or by a similar method (for instance, implementation in VAX/VMS Pascal is achieved by production of an environment file for the constants, types and variables, and an associated module for the functions and procedures). Thus the facilities are available to any Pascal program by simple reference to the library, unit or whatever. Pascal.SIM has been used extensively with Turbo Pascal, which provides no facilities for separate compilation. Here the programmer must recompile Pascal.SIM with the simulation.

To implement Pascal.SIM, it is necessary to set up the screen control codes within a number of procedures. Many terminals can be made to accept ANSI screen control codes (for instance, IBM-PC monitors) or use an extension of ANSI (for instance, DEC VT100 and
VT240). Thus ANSI screen control (and the extended ANSI descended from Telextronix for colour text) is frequently sufficient. Additional copies of some screen control and visual display routines are provided for use with Turbo Pascal, which call the screen control routines built into Turbo Pascal.

CONCLUSIONS

The authors have mainly used Pascal.SIM with Turbo Pascal and VAX/VMS Pascal. Pascal.SIM, Turbo Pascal, a colour monitor, and an IBM-PC/XT or AT allow visual simulations of reasonable display quality to be developed and run. For statistical experimentation, the model can then be ported to a VAX, and the Pascal.SIM statements relating to the visual display replaced by statements for statistics collection using histograms. Shortly, Pascal.SIM will be rewritten in Modula-2, where the built in co-routine facility will allow for proper and neater process interaction simulation.

Programming visual simulations can be time consuming, and typically in the hospital example there are more programmed statements relating to the display than to the logic of the simulation. This is true for other programming language orientated visual simulation systems, for example the FORTRAN based system SEE-WHY (8).

Having both the three-phase approach and process description world views in one package is very useful for teaching. Students can program models using both views, and thus obtain a better understanding of frameworks for simulation model building than when using a single view.

Many simulations are still programmed in FORTRAN (9). Increasingly students of science and engineering subjects are learning Pascal as their main programming language. They will undoubtedly want to write simulations in Pascal. Pascal.SIM provides a structure and the facilities to do this.

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Pro Pascal: Prospero Software Limited
Turbo Pascal: Borland International
VAX/VMS: DEC
IBM-PC: IBM
UCSD Pascal: Regents of the University of California
MS-DOS: Microsoft
Ada: United States Department of Defence
REFERENCES

APPENDIX

```plaintext
const max_cell_num=16;
  max_stream_num=32;
  max_class_num=256;
  max_sample_num=20;
  max_string_length=80;
  delay_num=2000;

type a_string=string[max_string_length];
  cardinal=0..maxint;

colour=(mul,black,red,green,yellow,blue,magenta,cyan,white);

  stream_num=1..max_stream_num;
```
cell_num=0, max_cell_num;
class_num=1..max_class_num;
sample_num=1..max_sample_num;
string_length=1..max_string_length;

entity='an_entity;
link='a_link;
a_link=record
    next,prev:link;
    item:entity;
end;
queue=link;

an_entity=packed record
    avail:boolean;
    class:class_num;
    col:colour;
    attr,next,B:cardinal;
    time:real;
end;

bin=record
    number,num_avail:cardinal;
end;

histogram=record
    cell:array[cell_num] of real;
    count,width,base,total,sosq,min,max:real;
end;

lookup_table=array [1..max_sample_num,1..2] of real;

var tim:real;
current:entity;
calendar:queue;
on_calendar:boolean;
suspended_chain:queue;
running:boolean;
original_seeds,seeds:array [stream_num] of cardinal;
class_table:array [class_num] of
    record
        let:char;col:colour;
    end;
{ queue processing }
procedure make_queue(var l:queue);
procedure give(l:queue;t:link;t:entity);
function take(l:queue;t:link);entity;
procedure give_top(l:queue);entity;
procedure give_tail(l:queue);entity;
function take_top(l:queue);entity;
function take_tail(l:queue);entity;

{ entities and classes }
function new_entity(c:class_num;a:cardinal);entity;
procedure dis_entity(c:entity);
procedure make_class(var c:queue;n:size:cardinal);
function count(var l:queue;a:boolean);cardinal;

{ timing and the executive }
procedure make_sim;
procedure cause(nb:cardinal;e:entity;t:real);
procedure calendar_top;

{ facilities for process executive }
procedure branch(next:cardinal);
procedure remove_entity;

{ resources }
procedure make_bin(var from:bin;n:cardinal);
procedure acquire(var from:bin;m:cardinal);
procedure return(var from:bin;n:cardinal);

{ error messages }
procedure sim_error(s:a.string);

{ random number generator and streams }
procedure make_streams;
procedure rnd(s:stream_num):real;

{ sampling distributions }
function normal(m, sd:real; s:stream_num):real;
function log_normal(m, sd:real; s:stream_num):real;
function poisson(m:real; s:stream_num):cardinal;
function negexp(m:real; s:stream_num):real;
function uniform(l, h:real; s:stream_num):real;
procedure make_sample(var sample_file: text; var table: lookup_table);
function sample(table: lookup_table; s: stream_num):real;
{ histograms }
procedure reset_histogram(var h: histogram);
procedure make_histogram(var h: histogram; cell_base, cell_width: real);
procedure print_histogram(var pr: text; h: histogram; state: boolean; len: cardinal);
procedure log_histogram(var h: histogram; where, what: real);

{ screen control }
procedure make_screen;
procedure gotoxy(x, y: cardinal);
procedure clear_screen;
procedure set_foreground(c: colour);
procedure set_background(c: colour);
procedure reset_colours;

{ visual displays }
procedure delay;
procedure make_class_table;
procedure enter_class(n: class_num; l: char; c: colour);
procedure write_entity(x, y: cardinal; e: entity);
procedure write_queue(x, y: cardinal;
    b: colour; q: queue; max_length: cardinal);
procedure write_block(x1, y1, x2, y2: cardinal; b: colour);
procedure move_v(x, y1, y2: cardinal; e: entity; b: colour);
procedure move_h(y, x1, x2: cardinal; e: entity; b: colour);
procedure write_time;

{ user written routines }
procedure display;
procedure initialize;
procedure picture;
procedure report;

{ simulation executive }
procedure run(duration: real; max_C: cardinal);