A UNIFIED DATA FLOW MODEL FOR
FAULT TOLERANT COMPUTERS

Final Report

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I. INTRODUCTION

We have used the Dataflow Simulation System (DFSS) at USL as the medium on which we have produced a functional simulation of SIFT. DFSS is written in PL/1 and is supported by MULTICS. Within the simulation, all the interprocessor communication, fault simulation, system state data, and monitoring were implemented in dataflow and supported directly by DFSS. The actual processor level computation was carried out by the SIFT code in PASCAL. The interface between DFSS in PL/I and the SIFT code in PASCAL was supported under a mechanism in DFSS called a Node Realization Module (NRM).

There were several reasons for making these choices for this initial simulation. The first reason was that these choices allowed us to effectively use the SIFT code that was available. Also, DFSS supported the addition of appropriate monitoring and fault simulation mechanisms. Another reason involved the fact that this preliminary simulation should point out some of the limitations of the current dataflow simulator and provide useful information in designing the new dataflow simulator in PASCAL. The primary reason for using dataflow only at the highest levels of SIFT was related to the way interprocessor communication took place in the last version of SIFT. Virtually any procedural process can be simulated in dataflow on DFSS. However, as a system simulation medium, dataflow worked best in dealing with parallel, asynchronous, communicating processes.
This report is divided into three sections and each of these sections describes different phases of the simulation of SIFT on DFSS. Section II outlines briefly the changes that have been made to the SIFT code so that the program could be run on the PASCAL compiler at USL. Section III gives the interface mechanism between the SIFT code in PASCAL and the PL/I program. This is necessary to include SIFT code as a node within the dataflow graph. In section IV the simulation of a single processor on the DFSS is described with the basic structure of the node. This section also describes an approach to the simulation of the complete system with \( n (n=5) \) processors. The interprocess communication buffers are concurrent access files with each of the processors having access to them as required by the operating system. This is achieved by means of the PL/I interface program. The details are given in the specific section.

II. SIFT PASCAL CODE

Some functions in SIFT code were realized in the assembly language of BDZ 930. In order to obtain the same kind of accuracy of numerical values computed by these functions, they were translated into PL/I. PL/I was used mainly to utilize the range of options available in obtaining the required accuracy.

The language dependent routines BAND (bitwise 'and') and BOR (bitwise 'or') were written in PL/I. To use these PL/I routines the statements containing the actual functions were modified.
For example: \((\text{framecount} \mod \text{scheds[vp+1]})\) was changed to \(\text{mod(framecount, scheds[vp+1])}\);

\((\text{eofbit band dbx*8})\) was changed to \(\text{band(eofbit,dbx*8)}\);

Another change was made to the code. All the location dependent variables were made independent of the system. The 'at' construct used in the original code was not present in either version of PASCAL compilers available at USL. So these variables were made independent of the locations in memory. In fact, because of the virtual memory system on MULTICS, no construct forcing static memory location is available. This problem is overcome simply by removing the 'at' (location) from the variable declaration part.

For example: \(\text{dbfile at dbloo : integer;}\) is changed to \(\text{dbfile : integer;}\);

The system dependent routine 'gprocessor' is not necessary because the processor id could be initialized at the beginning of the process. The new version of the SIFT code is in Appendix I.
III. INTERFACE PROGRAM

In order to realize the node realization module as described in [1], we used a PL/I program which called the SIFT code as a subroutine and there should be a correspondence between the two. While passing the parameters of type array or structure (record), a pointer to an array or a structure was passed. An array or a structure of same type was declared in the PL/I program with a pointer. This pointer was then equated to the external pointer (PASCAL pointer).

An example to reflect the parameter passing mechanism is given:

PASCAL declaration : dffile : array(0:1023) of integer;
                    dfptrpas :
PL/I declaration : dol dfile(0:1023) fixed bin(35) based(dfptr);
                    dfptr = dfptrpas;

With the above statement, any reference to the PL/I array element was reflected in the corresponding PASCAL array. All the other simple variables were external. This program is in Appendix II.

This PL/I program also realized the interprocessor communication through a procedure which was called whenever the transaction pointer in the "broadcast" or "stobroadcast" routine of the SIFT code was set. The interprocessor buffers were concurrent access files and these could be accessed and checked after every subframe.
IV. SIMULATION OF SIPT ON DPSS

Each individual processor node within the dataflow graph of complete system is given in figure 1. The dataflow program to realize this basic node is given in Appendix - III. With each of these nodes representing a processor, complete simulation with n (5) processors was attempted. Each processor was supposed to execute the current schedule: compute, broadcast, and vote according to schedule and assume that the other processors are also doing the same thing. The behavior of a processor is not immediately changed if communication breaks down or computation faults occur. The only changes in the behavior of the processor, caused by failures in interprocessor communication, are long term. If failures take place, eventually a reconfiguration will occur.

The error buffer data and the data buffer values could be examined through the PL/I interface program at the end of every subframe.

The details of the scheduling tables could not be worked out as expected due to the fact that these were written in assembly language of BDX 930. In effect, the bottleneck in implementing the simulation was the scheduling tables.
ON DATA FLOW SIMULATOR

The major responsibility of the research team at the University of Texas at Arlington was the design of a data flow language and a data flow simulator for this language written in Pascal for VAX/780 system.

DFDLS (pronounced as daffodils) is such a data flow simulator written in Pascal and at present is available on DEC 20 system. It will be available on VAX/780 soon. Simulation of computer systems, both hardware and software, can be performed using data flow concepts. For an introduction to data flow, the reader is referred to [1].

The major features of DFDLS are given below.

1. Tokens on data flow arcs can be structured data items. Existing data flow computers and languages permit only elementary data types like integer, real and characters. DFDLS allows all the Pascal data types. At this time, record data types are not processed, but will be included soon.

2. Firing set semantics can be specified in DFDLS. In the basic data flow, a node is enabled for execution only when all input arcs contain tokens and no tokens are present on the output arcs. This firing semantics are extended in DFDLS by describing alternate firing sets. Each set defines the mandatory input values required for the node to execute.

3. Nodes in DFDLS can be data flow subgraphs. In most of the existing data flow systems only primitive functions such as ADD two numbers are permitted. In our system, a node can be a primitive function defined by the system, a data flow subgraph or a Pascal procedure provided by the user. These Pascal procedures are linked dynamically by the runtime environment.

4. The input language is very simple. DFDLS interprets simulation models expressed in our textual language. There is a one-to-one correspondence between the data flow graphs
and the textual representation. Thus, data flow graphs can
be translated directly into the input language. This also
provides for graphical interface that can be designed at a
later date.

5. Block structures and Recursion: The present
implementation of DFDLS permits a restricted block
structure in that, all names must be unique. Recursion is
not allowed. However, we are in the process of extending
DFDLS to allow more general nesting of blocks and
recursion. Because of our data structures and modular
design of DFDLS, this addition is straightforward.
Separate descriptor tables and node tables will be created
for each block and display stack will be used to implement
recursion and static scopes.

A complete description of DFDLS and a detailed outline of the
design can be found in [3].

We made every attempt to complete the design and testing of
DFDLS on VAX/780 before the end of 1983. However, due to
unforeseen problems, we are only able to complete the design and
test DFDLS on DEC 20. We would like to describe briefly the
technical problems faced by the research team at UTA.

Due to the policies of the board of Regents of the state of
Texas, the acquisition of VAX was delayed by several months. The
hardware had arrived at UTA in December 1983. We are awaiting the
installation of a new air-conditioning equipment before bringing
up the VAX system.

The university and the department of Computer Science and
Engineering have seen significant increases in the enrollment.
The computing facilities are not adequate to handle the increase,
resulting in severe restrictions on the use of disk space, access
to terminals and in general, degraded response time.
The current version of DFDLS is being implemented on DEC 20/60 computer system, awaiting the arrival of VAX 780. Although most of the code for DFDLS is written in Pascal and thus portable, the section that dynamically links user supplied Pascal procedures with the runtime environment of DFDLS is very machine dependent and must be rewritten for VAX.

During the execution of a data flow program, the function of a data flow node can be realized by invoking either system provided Pascal procedures (Library functions) or user provided procedures. This facility enables us to add reliability calculations to the simulator. There is no easy way of linking programs dynamically on DEC 2060 system. Several alternatives have been considered and discarded due to the complexity of implementation.

A dynamic linker could be written with DFDLS to interface with the standard DEC linker provided. This requires significant amount of code in Macro-assembler for DEC 2060. Since DFDLS will be transported to VAX, this solution was discarded. Pascal procedures could be added to the DFDLS and the entire system could be recompiled and linked for each run. This solution was not entertained because of the inefficiency.

Our next choice was to have the NRM (node realization module) to invoke the user supplied procedure as a separate task with the data space mapped into the data space of DFDLS. It was hoped that this option would allow access to parameters similar to call by
reference technique. However, two problems exist with this method. Sharing of data space is not possible because the sub-process (corresponding to the user supplied procedures) would overlay the DFDLS space resulting in the destruction of crucial data belonging to the simulator. The second problem arises from the fact that in order to invoke sub-tasks, it is necessary to make user procedures as independent programs. This would require that the user write programs instead of procedures to link with the runtime environment of DFDLS.

Despite of the restrictions imposed by the last solution, we have decided to pursue this approach in implementing DFDLS on DEC 2060. We will relax these restriction in VAX 780 implementation. In the present solution to the linking problem, user supplied Pascal procedures are made into complete programs and DFDLS will communicate with these programs through standard disk files. The parameters are written into files and read from files by both user programs and DFDLS.
2. REPORT ON RELIABILITY MODELS FOR DATA FLOW

The research team at UTA has also attempted to develop reliability models for data flow graphs, so that the reliability of computer systems modeled as data flow graphs can be predicted. To our knowledge there exists no published reliability studies of data flow systems. A survey of related models can be found in [3].

A recursive algorithmic method can be used to determine the reliability of a data flow graph. The reliability of the output from a node depends on the reliabilities of the inputs to the node and the reliability of the node itself.

\[
R(0) = g( f( R_1, R_2, \ldots, R_N ), R_{node} )
\]

FIG. 1 RELIABILITY OF A DATA FLOW NODE
Here $f$ is a combinatorial function describing the input configuration of the node, $R_1$, $R_2$, ..., $R_N$ are the reliabilities of the inputs and $R_{node}$ is the reliability of the node. The node in the above calculation can be a subgraph, thus providing for a recursive definition.

2.1 Our Approach:

We have developed a method that combines Markov processes with the recursive algorithmic method described above. A path from an input of a data flow graph to an output of the data flow graph is defined as the alternating sequence of arcs and nodes, $a_1$, $n_1$, $a_2$, $n_2$, ..., $a_0$, where $a_1$ is the input arc and $a_0$ is the output arc. The reliability of the path can be determined using Markov methods.

A significant structural property of a data flow system is its capability for parallel processing with split and merge of job streams at various levels. This leads to multiple parallel paths between an input to the data flow graph and an output from the data flow graph. The parallel paths need not be independent. The dependencies will be handled by the algorithmic method.

For example, let there be $M$ parallel paths between a given input and output of the system. Let $R$ be the overall reliability of the output with respect to the given input, which is to be determined. Also, suppose $R_1$, $R_2$, ..., $R_M$ be the corresponding reliabilities of the $M$ parallel paths, obtained using Markov methods. Then $R$ is given by
\[ R = g (R_1, R_2, \ldots, R_M) \]  \hspace{1cm} (2)

where \( g \) is the function describing the inter-relationships between the parallel paths.

The reliability measure of the entire system can be obtained by calculating the reliabilities of all outputs from the system with respect to every input to the system. We are currently working with this method and developing the algorithms required to compute the inter-relationships between the parallel paths.

3. REFERENCES


Appendix - I
program newsift(input, output, datafile01);
  *export clock, dpftrpas *
  *procedure band(var a, b, integer); external, *)
  *procedure bor(var a, b, integer); external; *)

const
  maxtime=71; (* max skew allowed in clock task *)
  maxdata=1015, (* highest address in the datafile *)
  maxtrans=1023, (* highest address in the trans. file *)
  maxb=127, (* highest address in a databuffer *)
  dsize=128, (* size of a databuffer *)
  eofbit=32768, (* end of file bit for transaction *)
  maxprocessors=7, (* highest processor number less 1 *)
  maxstate=128, (* largest number of items in a statevector *)
  maxframe=7; (* Maximum frames in a cycle. *)
  maxsubframe=21, (* last subframe in a frame *)
  maxreconfig=1791, (* Number of elements in reconfig schedules *)
  maxbuf=200, (* maximum for table which tasks broadcast *)
  tpbase=896; (* minimum value of the transaction pointer *)
  magic=769; (* 2*tpbase-1023 *)
  tpclock=1019; (* clock in datafile. *)
  tasks=12; (* number of tasks in the system *)
  maxbufs=119; (* maximum number of buffers *)
  tentrysize=133, (* size of a task entry *)
  tsize=1729; (* tentrysize *(tasks+1); *) (* size of the task table. *)

(* The following constants define scheduling masks *)
  datamask=4097; (* Data portion of a schedule entry *)
  extendmask=8192, (* Extended task entry *)
  contmask=4096, (* Continue prior execution only *)
  suspmask=2048, (* Task may be suspended at clock tick *)

(* the following are constants to be used when referring to buffers. *)
  errerr=33;
  gexecreconf=34;
  gexecmemory=35;
  expected=36;
  lock=37;
  ndr=38;
  xreset=39;

(* The q series is the 1553a input value. The a, b, and c series are the values re-broadcast as part of interactive consistency, corresponding to the 1st, 2nd and 3rd input processors. *)

(* note -- for phase 2 the q buffers have been eliminated. data is now input into a, b or c buffers for p's 1, 2 and 3 respectively *)

astart=40,
  aalpha=40, abeta=41, acmdalt=42; acmdhead=43; adistance=44,
  aglideslope=45, alocalizer=46, ap=47; aphi=48; aphitrn=49,
  apsi=50, aq=51, ar=52; aradius=53; arturn=54; atheta=55,
  au=56; ax3=57; axcntr=58; ay3=59; aycntr=60;
  alast=60;

balpha=61, bbeta=62; bcmdalt=63, bcmdhead=64, bdistance=65,
bg1deslope=66, blocalizer=67; bp=68; bph1=69; bph1trn=70;
bpsi=71; bq=72; br=73; bradius=74; bturn=75; btheta=76;
bu=77; bx3=78; bxcnt=79; by3=80; bycnt=81;
calpha=82; cbeta=83; cmdalt=84; cmdhead=85; cdistance=86;
cglideslope=87; clocalizer=88; cp=89; cphi=90; cph1trn=91;
cpsi=92; cq=93; cr=94; cradius=95; ctturn=96; ctheta=97;
cu=98; cx3=99; cxcnt=100; cy3=101; cycnt=102;

(* The o series are the 1553a output values *)

ostart=103; (* must correspond to first of o series *)
qcmdail=103; qcmdele=104; qcmdrud=105; qcmdth=106;
qdel=107; qdelz=108; qpitmo=109; qlatmo=110; qreconf=111;
olast=111; (* must correspond to last of o series *)

osynch=112;

(* Internal values. *)

phin=113; psin=114; rn=115,
qx=116; qy=117; qz=118; timer=119;

(* 1553a values. *)

appnum = 16; (*timer-ostart+1;*)
onum=103; (*ostart,*); 

num1553a=21; (*last-astart+1,*) (* number of items to read *)
onum1553a=9, (*oastart+1,*) (* number of items to write *)
bas1553a=936; (*tpbase+ostart;*) (* first input location *)
mas1553a=255; (*16#00FF,*) (* status bits *)
out1553a=9; (*oastart+1,*) (* number of items to transmit *)
obas1553a=999; (*tpbase+ostart;*) (* first output location *)

sa0=0;

s1=32, (* subaddress 0 *)

rec1553a=1024; (* Receive *)
tra1553a=0; (* Transmit *)
rt1=2048; (* remote terminal 1 *)
sbas1553a=1008; (*tpbase+osynch,*) (* synch word *)

(* the following constants are to be used when referring to tasks *)
nullt=1, (* the null task *)

(* the following constants specify address of some preconfigured tables *)

floc=16#3400; Address of transaction file *)
tfloc=16#3800; Address of global framecount *)
sfloc=16#3801; Address of subframe count *)

sbloc=16#3802; Address of dbad. *)

sstackloc=16#5000; "Exec Stack" location - start *)

sloc=16#5500; Address of tt. *)

numloc=16#6836; Address of numworking *)

pidloc=16#6837; Address of pid. *)

virloc=16#6838; Address of virtino. *)

pvloc=16#6840; Address of post vote buffer *)

blocl=16#68C0; Address of bt *)

sloc=16#6D00; Address of scheds. *)

dfloc=16#7400; Address of datafile. *)
ploc=16#77FB; Address of pideof. *)
Address of trans pointer *)
Address of stat1553a *)
Address of real time clock *)
Address of cmd1553a *)
Address of ad11553a *)
Address of buffer info. *)
eofbit for loc zero *)
type
  data = file of integer;
  dfindex=0. maxdata,
  dbindex=0. maxdb;
  tpindex=0. maxtrans;
  processor=0. maxprocessors;
  buffer=0. maxbufs,
  task=0 tasks;
  bufint=array[buffer] of integer,
  procint=array[processor] of integer,
  procbool=array[processor] of boolean; (* beware addr *)
  bufrec=record dbx::integer, ad.procint end; (* beware addr *)
  dfarray=record dfindex of integer;
  tfarray=record tpindex of integer;
  statevector=array[0. maxstate] of integer,
  schedcall=(tasktermination, clockinterrupt, systemstartup);
  dfptrty = ^dfarray;
  taskentry=record
    status schedcall; (* cause of the last pause *)
    bufs integer, (* ptr to list of bufs broadcasted. *)
    errors integer, (* Number of transaction overrun errors *)
    stkptr integer; (* last stack pointer *)
    state statevector, (* stack for task *)
end,
var
datafileO1 . data,
  dfptrpas dfptrty;
  datafile : dfarray,
  transfile : tfarray,
  transptr integer; (* transaction pointer *)
  pideof . integer, (* processor ID discrete (read) *)
  scheds : array[0. maxreconfig] of integer;
  (* Precomputed schedules for reconfiguration *)
  postvote bufint; (* post vote buffer *)
  dbad : procint; (* index to start of data buffer for each processor *)
  bt : array[buffer] of bufrec, (* where and who broadcasting *)
  tt : array[task] of taskentry, (* Task Table *)
  binf : array[0. maxbinf] of integer; (* bufs where *)
  clock : integer; (* real time clock (read/write) *)
  clik1 : integer; (* used to prevent optimization *)
  ad11553a integer; (* 1553a address register *)
  cmd1553a : integer; (* 1553a command register *)
  stat1553a : integer; (* 1553a status register *)
  pid : integer; (* My processor number *)
  numworking : integer; (* Number of working processors *)
  virtno : procint; (* Virtual processor numbers. *)
  gframe : integer; (* global frame count *)
  sfcount : integer; (* sub frame count *)
(* p4dec var *)
volatile, votime, wtime, deltat: integer;

working: procbool;

p, v, errors: procint;

p1, p2, p3, p4, p5, v1, v2, v3, v4, v5: integer;  (* more voting *)

state: task;

taskid: integer;

lastconfig: integer;  (* The last configuration *)

pclock, cclock, bclock, aclock,

tp, vp, cptr, 

tpi, vpi, cptri,

framecount: integer;

skew: procint;

teatime: integer,  (* For timing the clktask *)

lines, pages, pagelimit, reason: integer;

fatal: boolean,

hittrue, errtr, vottr, rectr: boolean,

runid, minutes, tsks, tskfn, hltltb, errtrfb, vottrb, rectrb: boolean,

sk array[0..801] of integer;

skptr integer,

stop: integer;

(* include 'p4dec con';
include 'p4dec glo';
include 'p4dec var', *)

(* procedure gprocessor; *)

(* Set the current processor as a number between 0 and maxprocessors. *)

(* begin *)

(* pid := ((pideof div 4000B) band 16#OF)-i*)

(* end, gprocessor *)

function band(a, b: integer): integer,

begin band := a + b;

end;

function bor(a, b: integer) integer,

begin bor := a - b;

end;

procedure dbaddrs;

(* calculate the index of the start of each of the databuffers. This is harder than it seems because it is a function of the processor number. *)

var

i, ad: integer,

begin

ad := 0;

for i := 0 to pid-1 do
begin
dbad[i] := ad; writeln('dbad[i]=', dbad[i]),
ad := ad+dbsize; writeln('ad =', ad);
end;
for i := pid+1 to maxprocessors do
begin
dbad[i] := ad; writeln('dbad[i] = ', dbad[i]);
ad := ad+dbsize; writeln('ad = ', ad);
end;
dbad[pid] := ad; (* there isn’t really one, but *)
end; (* dbaddrs *)

procedure work,
(* At startup, identify which processors are nominally working *)
var
  i integer;
begin
  for i = 0 to maxprocessors do datafile[dbad[i]] = -1,
    writeln('dbad[i]=', dbad[i]);
  (+ wait(1), *)
  datafile[896] := pid,
  transfie[769] := 32768;
  transptr := 896; (* initiate the broadcast. *)
  (+ wait(1), *)
  numworking := 1,
  for i := 0 to maxprocessors do
    if datafile[dbad[i]] = 1 then
      begin working[i] := true; numworking := numworking + 1;
      end
    else working[i] := false;
  working[pid] := true; (* I’m working *)
end; (* work *)

procedure synch,
const
  value = 43690;
var
  i,j integer;
begin (* At startup synchronize the processors *)
  i := 7,
  while not working[i] do i := i-1,
  (* i points to the highest working processor *)
  j := dbad[i];
  datafile[j] := 0;
  if i = pid then
    begin
      (* wait(1); *)
      datafile[896] := value;
      transfie[769] := 32768;
      transptr := 896;
      while pideof<0 do,
    end
procedure fail;
(* All returned values are wrong, so report all processors involved. 
This could be failed inline, but it would take too much room. The 
minor additional time that it takes to call the subroutine is 
probably worthwhile *)
begin
  errors[p1] := errors[p1]+1,
  (*if errtr then pause(43868)*)
end, (* fail *)

procedure err(p integer),
(* Record an error for processor p. *)
begin
  errors[p] := errors[p]+1,
  (* if errtr then pause(43869)*)
end; (* err *)

function vote5(default: integer): integer,
(* This is the five way voter. It assumes that V1 V5 is 
initialized with the 5 values to be voted, and P1 .. P5 
has the corresponding processors. Default is returned in the 
case that there is no majority value. The procedure is basically 
a simple IF tree (pruned where possible) to achieve the quickest 
possible vote *)
begin
  if v1 = v2 then
    if v1 = v3 then
      begin vote5 = v1;
        if v1 <> v4 then err(p4), if v1 <> v5 then err(p5);
      end
    else if v2 = v4 then
      begin err(p3); if v1 <> v5 then err(p5), vote5 := v1;
      end
    else if v1 = v5 then
      begin err(p3); err(p4); vote5 := v1;
      end
    else if v3 = v4 then
      if v3 = v5 then
        begin err(p1), err(p2); vote5 = v3;
        end
    else
begin fail, vote5 := default;
end
else
begin fail, vote5 := default;
end
else if v1 = v3 then
  if v1 = v4 then
    begin err(p2), if v1 <> v5 then err(p5); vote5 := v1;
    end
  else if v1 = v5 then
    begin err(p2); err(p4); vote5 := v1;
    end
else if v2 = v4 then
  if v2 = v5 then
    begin err(p1); err(p3); vote5 := v2;
    end
  else
    begin fail, vote5 := default;
    end
else
begin fail; vote5 := default;
end
else if v4 = v5 then
  if v2 = v4 then
    begin err(p1), if v2 <> v3 then err(p3); vote5 := v2;
    end
  else if v1 = v5 then
    begin err(p2); err(p3); vote5 = v1;
    end
else if v3 = v5 then
    begin err(p1); err(p2), vote5 := v3;
    end
else
begin fail; vote5 := default;
end
else if v2 = v5 then
  if v2 = v3 then
    begin err(p1); err(p4); vote5 := v2;
    end
  else
begin fail, vote5 := default;
end
else if v2 = v3 then
  if v2 = v4 then
    begin err(p1); err(p5); vote5 := v2;
    end
  else
begin fail; vote5 := default;
end
else
begin fail, vote5 := default;
end;
end; (* vote5 *)

function vote3(default::integer) :: integer;
(* This is the 3 way voter. It assumes that V1 . V3 contains*
procedure vote(b buffer; default integer);
var
  i, j, k: integer;
begin
  vtime := clock;
  (* vote buffer b. This involves either five way or three way voting. *)
  (* if vottr then pause(16#ABC2), *)
  j := 0; i := 0;
  repeat
    k := bt[b].ad[1];
    if k >= 0 then
      begin
        j := j+1;
        p[j] := i;
        v[j] := datafile[k]
      end;
    i := i+1;
  until (j=5) or (i>maxprocessors);
  if j < 3 then
    postvote[b] := v[1]
  else
    begin
      v1 := v[1]; v2 := v[2]; v3 := v[3];
      p1 := p[1]; p2 := p[2]; p3 := p[3];
      if j<5 then
        postvote[b] := vote3(default)
      else
        begin
          v4 := v[4]; v5 := v[5];
          p4 := p[4]; p5 := p[5];
          postvote[b] := vote5(default)
        end;
    end,
  datafile[tphase+b] := postvote[b];
end; (* vote *)

• the 3 values to be voted, and that P1 ... P3 contains the
  processors. *)
  begin
    if vl = v2 then
      begin
        if vl<>v3 then err(p3);
        vote3 := vl;
      end
    else if vl = v3 then
      begin err(p2); vote3 = vl;
      end
    else if v2 = v3 then
      begin err(p1), vote3 = v2;
      end
    else
      begin err(p1); err(p2); err(p3);
      vote3 := default
      end,
  end, (* vote3 *)
function getvote(b::buffer): integer;
    (* this phase two module lets us remove the postvote declaration
       from the applications task module *)
begin
    getvote = postvote[b],
end, (* getvote *)

procedure broadcast(b::buffer),
    (* Broadcast buffer b. This is provided for applications tasks, and
       those executive tasks that don't do it themselves. Note: this
       routine does not wait for completion before or after. If that
       is required (for timing reasons) call waitbroadcast. *)
var dbx, tp integer;
begin
    dbx = bt[b].dbx; tp = dbx+tpbase;
    transfile[2*tp-1023] := bor(eofbit, dbx*8);
    transptr := tp;   (* initiate the broadcast. *)
    rewrite(datafile01);
    datafile01^ = b;
    put(datafile01);
end, (* broadcast *)

procedure stobroadcast(b, v::integer);
    (* Store v in buffer b and broadcast it *)
var dbx, tp::integer;
begin
    dbx = bt[b] dbx; tp = dbx+tpbase; datafile[tp] = v;
    transfile[2*tp-1023] := bor(eofbit, dbx*8);
    transptr := tp;   (* initiate the broadcast. *)
end, (* stobroadcast *)

procedure waitbroadcast;
begin
    (* Wait for a broadcast operation to complete. *)
    while pideof<0 do;
end; (* waitbroadcast *)
procedure vschedule;
  (* Vote those items scheduled for this moment. *)
  var
    k: integer;
  begin
    k := scheds[vp];
    while k>0 do
      begin
        if (band(k, extendmask))= 0 then begin vote(k,-1), vp := vp+1 end
        else if (framecount mod scheds[vp+1]+1) = scheds[vp+2] then
          begin
            vote(band(k, datamask),-1);
            vp := vp+3
          end;
        k := scheds[vp]
      end; (* while *)
    if k >= 0 then vp := vp+1;
  end, (* vschedule *)

procedure copschedule;
  (* Copy buffers scheduled for this moment. *)
  var
    c, k: integer,
  begin
    c := scheds[cptr];
    while c >= 0 do
      begin
        if (framecount mod scheds[cptr+2]) = scheds[cptr+3] then
          postvote(band(scheds[cptr+1], datamask)) := postvote[c];
        cptr := cptr+4;
        c := scheds[cptr]
      end;
    if c >= 0 then cptr := cptr+1
  end, (* copschedule *)

procedure tschedule;
  (* Find the next task to schedule *)
  var
    tk, more: integer,
  begin
    more := 0; tk := scheds[tp];
    while more = 0 do
      begin
        if tk = 0 then more := 1
        else if tk = -1 then more := 1
        else if band(tk, extendmask) = 0 then more := 1
        else if (framecount mod scheds[tp+1]+1) = scheds[tp+2] then
          more := 3
        else begin tp := tp+3; tk := scheds[tp] end,
        if tk <= 0 then begin taskid := nullt, taskbits := 0 end
        else
          begin
            taskid := band(tk, datamask);
            taskbits := 1
          end
    end;
  end, (* vschedule *)
taskbits = tk-taskid.

repeat
  tp = tp+more
until scheds[tp] = 0,
end;

if tk >= 0 then tp .-= tp+1
end, (* tschedule *)

procedure builttask(taskname:integer);
/* Initialize a task table entry */
begin
  remit(ttCtaskname, stkptr, ttCtaskname, state);
  ttCtaskname.status = tasktermination
end, (* buildtask *)

function scheduler(ret1, ret2, oldpc:integer,
cause schedcall, state integer).integer;
var
  i: integer;
begin
  (* See large comment in file SCHED.BDX *)
tskfn = clock;
  ttCtaskid.stkptr := state;
  if cause<>tasktermination then
    begin
      if (taskid<>nullt) then
        if taskid<>0 then
          if band(suspmask, taskbits) = 0 then
            begin
              (* pause(16#5500 bor taskid);*)
              ttCtaskid.errors .-= ttCtaskid.errors+1,
              builtas[(taskid)
            end
          else ttCtaskid.status := clockinterrupt,
        if sfcount >= maxsubframe then
          begin
            if framecount >= maxframe then framecount := 0
            else framecount := framecount+1,
            gframe := gframe+1;
            sfcount := 0; vp := vpi; cpwr := cpwr1; tp = tpi
          end
        else sfcount := sfcount+i;
      vschedule,
      (* copschedule; *)
      vschedule, (* changes taskid and taskbits *)
    end
  begin
    taskid := nullt; taskbits .-= 0,
  end;
  tskst = clock;
  scheduler = ttCtaskid stkptr;
function nulltask::integer; *
  (* This is the task that wastes time. It never terminates. In *)
  (* the final system the nulltask will be the diagnostic task. *)
  (* begin *)
  while true do _loop forever _
  (* end, *)
  (*)

function errtask::integer;
  (* Compute and broadcast a word with bits 7 through 0 indicating whether processors 8 through 1 have
    failed (1) or are ok (0). *)
  const
    threshold = 3,
  var
    err, i: integer,
  begin
    err = 0, i = maxprocessors,
    repeat
      err .= err*2,
      if (not working[i]) or (errors[i]>threshold) then err := err+1;
      errors[i] = 0;
      i .= i-1
    until i<0,
    stobroadcast(err, err);
    errtask := 0,
  end, (* errtask *)

function gexectask integer;
  (* Compare values from the errtasks. Those that are reported
    by two or more processors (other than itself) for more than
    one frame, are considered bad. The rest are considered good.
    The report consists of a word, bits 7 through 0 of which
    represent processors 8 through 1. (1 failed, 0 working.)*)
  var
    proc::procbool; err, i, j, count, reconf: integer;
  begin
    i .= 0;
    repeat
      count = 0; j = 0;
      repeat
        if working[j] then
          begin
            err := bt[err, err] ad[j];
            if i<>j then
              if working[i] then
                if odd(datafile[err]) then count := count+1;
          end;
      until j<maxprocessors;
      if count > 2 then
        begin
J := J+1
until J > maxprocessors;
if working[i] then
  if count > 1 then proc[i] := false
  else proc[i] := true
else proc[i] := false,
i := i+1,
until i > maxprocessors;
reconf := 0;
i := maxprocessors;
repeat
  reconf := reconf*2;
  if not proc[i] then reconf := reconf+1;
  i := i+1
until i < 0;
stobroadcast(gexecreconf, band(reconf, postvote[gexecmemory])),
waitbroadcast;
stobroadcast(gexecmemory, reconf);
geexec task := 0
end; (* geexec task *)

procedure clrbufs;
(* Set the buffer table so that no assumptions are made about what processor is computing the value. *)
var i, j. integer,
begin
i := 0;
repeat
  j := 0;
  repeat bt[i] ad[j] := -1; j := j+1 until j > maxprocessors,
i := i+1
  until i > maxbufs,
end, (* clrbufs *)

procedure newvc(s: integer);
(* S points to the vote and copy schedules Copy them into the real schedules. *)
begin
  s := s+3; vi := s,
  while scheds[s] >= 0 do s := s+1,
cptri := s+1
end, (* newvc *)

procedure recbufs(s, p. integer);
(* s points to the task schedule corresponding to real processor p. Figure out what buffers are computed. *)
var
begin
  \( s := s + 3; \)
  while \( \text{scheds}[s] < -1 \) do
    if \( \text{scheds}[s] = 0 \) then \( s := s + 1 \)
    else
      begin
        \( t := \text{band}(\text{scheds}[s], \text{datamask}); \)
        \( 1 := \text{ttttt}.\text{bufs}; b = \text{binf}[i]; \)
        \( t := \text{dbad}[p]; \)
        while \( b > 0 \) do
          begin
            with \( b, t \) do \( \text{ad}[p] := t + \text{dbx}; \)
            \( 1 := i + 1, b := \text{binf}[i]; \)
          end;
        if \( \text{band}(\text{scheds}[s], \text{extendmask}) \) \( \neq 0 \) then \( s := s + 3 \)
        else \( s := s + 1 \),
      end;
  end; (* recbufs *)

function \( \text{xrecf(reconf: integer)} \) : integer;
var
  i, s, nw, integer,
begin
  \( b\text{clock} := \text{clock}; \)
  \( \text{b(able, *)} \)
  \( \text{nw} := -1; i = 0; s = \text{reconf}, \)
  repeat
    if odd(s) then \( \text{working}[i] := \text{false} \)
    else
      begin
        \( \text{working}[i] := \text{true}; \)
        \( \text{nw} := \text{nw} + 1; \)
        \( \text{virtno}[\text{nw}] := 1 \)
      end;
    \( s := s \div 2, \)
    \( i := i + 1; \)
  until \( i > \text{maxprocessors}; \)
  if lastconfig \( \neq \text{reconf} \) then
  begin
    \( \text{(* if rectr then pause(16#ABC4); *)} \)
    \( \text{lastconfig} := \text{reconf}; \)
    \( \text{datafile[tpbase + qreconf]} := \text{reconf}, \)
    \( s := 0; \)
  end;
  \( \text{(* if nw > 5 then nw := 5; phase 1*)} \)
  while \( \text{scheds}[s] \neq \text{nw} \) do
    \( s := s + \text{scheds}[s + 2]; \)
  \( \text{clrbufs}; i := 0, \)
  \( \text{tp1} := 0; \)
  repeat
    \( \text{recbufs}(s, \text{virtno}[i]), \)
    \( \text{if virtno}[i] = \text{pid} \) then \( \text{tp1} := s + 3; \)
    \( s := s + \text{scheds}[s + 2]; \)
    \( i := i + 1 \)
  until \( i > \text{nw}; \)
  \( \text{(* if tp1 = 0 then pause(16#ABC5); *)} \)
  \( \text{newvc}(s), \)
numworking := nw+1;
sfcount := maxsubframe+1;
framecount := maxframe+1
end;
clock := bclock,
xrefc := 0
end;

function recftask(integer,
(* The reconfiguration task calls xrefc to do the real work. *)
begin
  recftask := xrefc(postvote[gexecreconf])
end; (* recftask *)

function clktask: integer;
const
  maxskew = 40,
  commdelay = 24;
  dest = 32768,
  (* Destination 0 *)
var
  1, num, sum, term, x integer,
  delta, epsilon: integer;
  unseen: array[0..maxprocessors] of boolean;
  wksr integer;
beg
  (*disable;*)
  for i := maxprocessors downto 0 do datafile[dbad[i]] := 0; (* dp *)
  bclock := clock; (* begin time *)
  wksr := 0;
  transfile[magic] := dest; (* once is enough *)
  unseen[pid] := false;
  for i := maxprocessors downto 0 do
    begin
      s[eu[1]] := 0,
      while (band (clock, 32))<> 0 do ;
      while (band (clk1, 32))= 0 do ; (* whoa mule *)
      teatime := clock;
      if i = pid then
        repeat (* the Broadcast *)
          if pideof>0 then
            begin
              datafile[tpbase]:=clock;
              transptr:=tpbase,
              end;
          until clock-teatime > maxtime
        else
          begin
            unseen[i] := true;
x:=dbad[i];
            pclock := datafile[x];
repeat
  cclock := datafile[x];
  aclock := clock;
  if cclock <> pclock then
    begin
      skew[i] := cclock + commdelay - aclock;
      unseen[i] := false;
      repeat
        until clock - teatime > maxtime;
      end;
      until clock - teatime > maxtime
    end;
  (* Calculate the clock correction *)
  (* enable, *)
  sum := 0;
  num := 0;
  for i := 0 to maxprocessors do
    begin
      wkset := 2*wkset;
      sk[skptr+i] := skew[i];
      if working[i] then
        begin
          wkset := wkset+1;
          term := skew[i],
          if term > maxskew then
            begin
              term := maxskew;
              reason := reason+1,
            end,
          if term < -maxskew then
            begin
              term := -maxskew;
              reason := reason+1,
            end;
          if unseen[i] then
            begin
              term := 0,
              fatal := true;
              reason := bor(reason, 1024);
            end;
          sum := sum+term;
          num := num+1;
        end;
    end;
  delta := (sum div num),
  (* lets wait for the 1.6 msec interrupt *)
repeat
  cclock := band(clock, 1023),
  until (cclock > 512 + maxskew) OR (cclock < 271),
  cclock := delta+clock,
  clock := cclock;
  (* Adjust the clock value. *)
  pclock := clock;
  epsilon := pclock-cclock,
  if (epsilon > 2) or (epsilon < -2) then
reason := bor(reason, 2048),

sk[skptr+pid] := 43680+pid,
sk[skptr+maxprocessors] := wkset;
sk[skptr+B] := gframe,
sk[skptr+9] := postvote[getexeconf];
sk[skptr+10] := postvote[getexecmemory];
sk[skptr+11] := bclock;
sk[skptr+12] := delta;
sk[skptr+13] := runid;
sk[skptr+14] := pages;
sk[skptr+15] := reason;
skptr = skptr+16;

lines := lines+1,
if fatal then stop:=stop+1;
if hlttrue then
  (* if stop=3 then pause(16#555); *)
if lines > 48 then
  begin
    lines := 1;
    pages := pages+1;
    if hlttrue then
      begin
        (* if reason > 16#FF then pause(16#333); *)
        (* if pages > pagelimit then pause(16#444); *)
        end,
    skptr := 0
  end; (* if lines > 48 *)

clktask := 0;
(* enable dp *)
end; (* clktask *)

(* The following routines have to do with system initialization. *)
(* ------------------------------------------------------------------------- *)

procedure initialize;
  (* initialize the processor numbers and pointers and errors *)
var
  i, j, reconf. integer;
begin
  skptr := 0;  lines := 1;  pages := 1;
  reason := 0;  fatal := false;  stop := 0;
  if (minutes > 1354) or (minutes < 1) then
    minutes := 1354;
  pagelimit := 24*minutes+((6*minutes) div 31);
  sk[800] := pagelimit,  sk[801] := runid;
  votecnt := 0;
  errtr := errtrb;  vottr := vottrb;  rectr := rectrb;
  hlttrue := hlttb;
  (* gprocessor ; *)
  dbaddr, work, synch;
```
taskbits := 0; lastconfig := 0; reconf := 0; gframe := -1;
taskid := 0; sfcount := -1; framecount := 0; clock := 0;
for i := 0 to maxbufs do postvote[i] := 0,
for i := 0 to tasks do
  begin buildtask(i), tt[1] errors := 0
  end;
for i := maxprocessors downto 0 do
  begin
    errors[i] := 0,
    reconf := reconf*2;
    if not working[i] then reconf := reconf+1
  end;
(+ appinit; *)
(> icinit, *)
postvote[gexecmemory] := reconf,
x := xrecf(reconf);
end;
begin
read(pid);
wrriteln(pid),
rewrite(datafile01);
datafile01^ := pid,
put(datafile01);
wrriteln(pid),
doadrs;
work,
synch,
initialize;
end.
```
Appendix - II
siftpl : proc;

dcl sysin file;
dcl sysprint file;
dcl newshift entry options (variable);
dcl dfptr fixed bin (35) based (dfptr);
dcl clk fixed bin external static;
dcl transptr fixed bin external static;
dcl pideof fixed bin(35) external static;
dcl scheds_pl (0:1791) fixed bin(35) external static;
dcl postvote_pl(0:119) fixed bin(35) based(postptr);
dcl postptr ptr;
dcl dbad_pl(0:7) fixed bin(35) based(dbadptr);
dcl dbadptr ptr;
dcl binf_pl(0:200) fixed bin(35) based(binfptr);
dcl binfptr ptr;
dcl binfptrpas ptr external static;
dcl clock fixed bin(35) external static;
dcl cmd fixed bin(35) external static;
dcl sta fixed bin(35) external static;
dcl pid fixed bin(35) external static;
dcl numworking fixed bin(35) external static;
dcl virtno fixed bin(35) external static;
dcl virtnoptr fixed bin(35) external static;
dcl virtnoptrpas ptr external static;
dcl gframe fixed bin(35) external static;
dcl sframe fixed bin(35) external static;
dcl votecnt fixed bin(35) external static;
dcl vtime fixed bin(35) external static;
dcl delta fixed bin(35) external static;
dcl working fixed bin(35) based (workingptr) ;
dcl workingptr ptr;
dcl workptrpas ptr external static;
dcl p_pl fixed bin (35) based (p_pl);
dcl pptrpas ptr external static;
dcl pptr ptr;
dcl v_pl fixed bin(35) based(v_pl);
dcl vplpas ptr external static;
dcl vptr ptr;
dcl errors fixed bin(35) based (errorptr);
dcl errorpas ptr external static;
dcl errorptr ptr;
dcl P1 fixed bin(35) external static;
dcl p2 fixed bin(35) external static;
dcl p3 fixed bin(35) external static;
dcl p4 fixed bin(35) external static;
dcl p5 fixed bin(35) external static;
dcl v1 fixed bin(35) external static;
<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>dcl v2</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl v3</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl v4</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl v5</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl taskid_ol(0:12)</td>
<td>fixed bin(35) based(taskidptr);</td>
</tr>
<tr>
<td>dcl taskidpas</td>
<td>ptr external static;</td>
</tr>
<tr>
<td>dcl taskidptr</td>
<td>ptr;</td>
</tr>
<tr>
<td>dcl skew_pl(0:7)</td>
<td>fixed bin(35) based(skeuotr);</td>
</tr>
<tr>
<td>dcl skewptr</td>
<td>ptr;</td>
</tr>
<tr>
<td>dcl skewptrpas</td>
<td>ptr external static;</td>
</tr>
<tr>
<td>dcl sk_pl</td>
<td>fixed bin(35) based(skptr);</td>
</tr>
<tr>
<td>dcl skptr</td>
<td>ptr;</td>
</tr>
<tr>
<td>dcl skptrpas</td>
<td>ptr external static;</td>
</tr>
<tr>
<td>dcl taskbits</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl lastconfig</td>
<td>fixed bin(35) external static;</td>
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<td>dcl pclock</td>
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<td>dcl cclock</td>
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<td>dcl bclock</td>
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<td>dcl tpi</td>
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<td>dcl vpi</td>
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<td>dcl cptri</td>
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<td>dcl framecount</td>
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<td>dcl teatime</td>
<td>fixed bin(35) external static;</td>
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<td>dcl lines</td>
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<td>dcl pages</td>
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<td>dcl fatal</td>
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<td>dcl hlttrue</td>
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<td>dcl errtrue</td>
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<td>dcl votrtr</td>
<td>bit external static;</td>
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<tr>
<td>dcl rectr</td>
<td>bit external static;</td>
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<tr>
<td>dcl runid</td>
<td>fixed bin(35) external static;</td>
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<td>dcl minutes</td>
<td>fixed bin(35) external static;</td>
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<td>dcl tskst</td>
<td>fixed bin(35) external static;</td>
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<tr>
<td>dcl tskfin</td>
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<tr>
<td>dcl hlttb</td>
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<tr>
<td>dcl errtrtb</td>
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<tr>
<td>dcl vottrtb</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl rectrbb</td>
<td>fixed bin(35) external static;</td>
</tr>
<tr>
<td>dcl stop</td>
<td>fixed bin(35) external static;</td>
</tr>
</tbody>
</table>
bor : proc (a, b) returns (fixed bin(35));

dcl a fixed bin(35);
dcl b fixed bin(35);
dcl c bit (16) init("0000000000000000"b);
dcl temp1 bit (16);
dcl temp2 bit (16);
dcl i fixed bin;

temp1 = substr(unspec(a),21);
temp2 = substr(unspec(b),21);

do i = 1 to 16;
    if substr(temp1,i,1) = "1"b & substr(temp2,i,1) = "1"b
    then substr(c,i,1) = "1"b;
end;

return (fixed (c));
end /* bor */;

band : proc (a, b) returns (fixed bin(35));

dcl a fixed bin(35);
dcl b fixed bin(35);
dcl c bit (16) init("0000000000000000"b);
dcl temp1 bit (16);
dcl temp2 bit (16);
dcl i fixed bin;

temp1 = substr(unspec(a),21);
temp2 = substr(unspec(b),21);

do i = 1 to 16;
    if substr(temp1,i,1) = "1"b & substr(temp2,i,1) = "1"b
    then substr(c,i,1) = "1"b;
end;

return (fixed (c));
end /* band */;
dfptr = dfptrpas;
transptr = transptrpas;
schedsptr = schedsptrpas;
postptr = postptrpas;
dbadptr = dbadptrpas;
binfptr = binfptrpas;
workingptr = workingptrpas;
pptr = pptrpas;
vptr = vptrpas;
errorptr = errorptrpas;
taskidptr = taskidptrpas;
skewptr = skewptrpas;
skptr = skptrpas;
/* call newsift;*/

put skip list ("clock =", clock);
put skip list ("dfile = ", dfptr -> dfile(0), dfotr -> dfile(128));
end;