DIB on the Xerox workstation

Chien-Kuo Chuang

Follow this and additional works at: http://scholarworks.rit.edu/theses

Recommended Citation

This Thesis is brought to you for free and open access by the Thesis/Dissertation Collections at RIT Scholar Works. It has been accepted for inclusion in Theses by an authorized administrator of RIT Scholar Works. For more information, please contact ritscholarworks@rit.edu.
Rochester Institute of Technology  
School of Computer Science and Technology  

DIB On The Xerox Workstation  

by  
Chien-Kuo Eric Chuang  

A thesis, Submitted to  
The Faculty of the School of Computer Science and Technology,  
in partial fulfillment of the requirements for the degree of  
Master of Science in Computer Science  

Approved by:  

Professor John L. Ellis  
Professor Andrew T. Kitchen  
Professor Margaret M. Reek  

November 25, 1986
Title of Thesis: DIB On The Xerox Workstation

I ______________________________ hereby grant permission to the Wallace Memorial Library, of RIT, to reproduce my thesis in whole or in part. Any reproduction will not be for commercial use or profit.

Date: _5/5/87_
ACKNOWLEDGMENTS

I take this opportunity to thank Professor John Ellis for his guidance and encouragement during the course of this thesis work. I also thank Professor Andrew Kitchen and Professor Margaret Reek for their suggestions and criticisms.

I am extremely grateful to Professor Raphael Finkel for his guidance during the implementation of this project. Without his help, this thesis would have been impossible.

Most of all I would like to thank my family, for their support and understanding during the past three years.
ABSTRACT

DIB - A Distributed Implementation of Backtracking is a general-purpose package which allows applications that use tree-traversal algorithms such as backtrack and branch-and-bound to be easily implemented on a multicomputer. The application program needs to specify only the root of the recursion tree, the computation to be performed at each node, and how to generate children at each node. In addition, the application program may optionally specify how to synthesize values of tree nodes from their children’s values and how to disseminate information in the tree. DIB uses a distributed algorithm, transparent to the application programmer, that can divide the problem into subproblems and dynamically allocate them to any number of machines. It can also recover from failures of machines. DIB can now run on the Xerox workstation network at Rochester Institute of Technology. Speedup is achievable for exhaustive traversal and branch-and-bound, with only a small fraction of the time is spent in communication.
# TABLE OF CONTENTS

ACKNOWLEDGMENTS

ABSTRACT

1. INTRODUCTION AND BACKGROUND ........................................... 1
   1.1 General Description .................................................. 1
   1.2 Description Of The General Class Of Problems ................. 2
   1.3 DIB And The Operating System .................................... 3

2. RELATED WORK ....................................................................... 4

3. THE UNDERLYING ALGORITHM .............................................. 6
   3.1 Algorithm For Distribution ........................................... 6
   3.2 Algorithm For Fault Tolerance ...................................... 8

4. IMPLEMENTATION ............................................................... 10
   4.1 Host Implementation .................................................. 10
   4.2 Node Implementation .................................................. 16
   4.3 Communication Interface Implementation ...................... 24

5. USER INTERFACE .............................................................. 27

6. EXPERIMENTS ................................................................. 30
   6.1 Description Of The Applications .................................. 30
   6.2 Results ........................................................................ 36

7. IMPLEMENTATION EXPERIENCES ........................................ 41
   7.1 The Size Of Variables .................................................. 41
1. INTRODUCTION AND BACKGROUND

1.1 General Description

In the next few years, professionals from many areas will have access to advanced workstations connected by networks. A network of workstations is composed of machines that each can act independently but also can cooperate with others through messages. Algorithms that take advantage of these architectures are of great importance. Such algorithms can employ workstations that are frequently idle to help solve computationally intensive problems.

It is apparent from experience that writing distributed programs is significantly more difficult than writing sequential programs. Programmers have to deal with a variety of new issues, such as synchronization, concurrency, communication protocols, and fault tolerance. In the current environment, distributed programming is left mostly to experts.

One way to make distributed programming easier is to develop library packages in specific areas. These packages will be suitable only to specific applications and will lack the generality of a programming language. Because these packages are relatively easy to use, the distributed part of a program can be transparent to the user, and programmers who are unable or unwilling to master the techniques of distributed programming can still use the full power of the workstation network.

DIB A Distributed Implementation of Backtracking is a general-purpose package which allows applications that use tree-traversal algorithms such as backtrack and branch-and-bound to be implemented on a multicomputer. It was presented by Professor Finkel and Professor Manber in the "Proceedings of the 5th International Conference on Distributed Computing Systems" and currently runs on the Crystal multicomputer at the University of Wisconsin-Madison. It is easy to use. The application program needs to specify only the root of the recursion tree, the computation to be
performed at each node, and how to generate children at each node. In addition, the application program may optionally specify how to synthesize values of tree nodes from their children's values and how to disseminate information in the tree. DIB uses a distributed algorithm, transparent to the application programmer, that can divide the problem into subproblems and dynamically allocate them to any number of machines. It can also recover from failures of machines. This thesis will implement DIB on the Xerox workstation network at Rochester Institute of Technology.

1.2 Description Of The General Class Of Problems

The problems that can be supported by DIB are those for which the computation is performed by traversing a tree. The tree is usually built dynamically during the traversal and each tree node gets initial data from its parent. The node may decide to "generate" several children and pass more data to them, or it may decide that it is a leaf, in which case it performs some computation and passes the outcome to its parent. Information flows down the tree as it is built and flows up the tree as subtrees complete. In addition, a node can accept new information from its parent after it is generated and can pass information to its live children. DIB may expand the frontier of the tree in an arbitrary order and may expand the same node twice (to recover from failures). However, it ensures that the information reported back to a node from its children represents exactly one instance of every descendant. The only requirement of the application for using DIB is that each subtree can be correctly searched without any knowledge of the outcome of any other search. The outcome of other searches may affect the efficiency of computation, but it must not affect the correctness.

There are basically two different types or classes of applications that can use DIB. The first class of DIB applications includes exhaustive search of a tree of combinations. In these applications the outcomes of all the leaves have to be collected. Each node is either a solution, a dead end, or an intermediate situation. In the later case, its children represent alternative ways to continue. The outcomes of the computation of all the children of a particular node may have to be combined in some way to produce the outcome for this
node. The number of solutions found can be reported up the tree and the outcome of the computation is then defined as the outcome of the root. The eight-queens problem and knights tour problems are examples of which belong to this class. These problems are described further in section 6.

A second class of applications involves global knowledge that is improved when a search reaches a leaf. This is the situation in applications which use branch and bound, where the global bound is used to prune further development of unsuccessful branches. The traveling salesman problem belongs to this class. In the application program, each node \( v \) computes a function, called the objective function, which depends on values computed along the path from the root to \( v \), and the program intends to find the leaf with the minimum value of this function. If a lower bound on the value of the objective function in a subtree rooted at a given internal node \( v \) exceeds the value already attained by a leaf, there is no need to explore further. A good heuristic is to explore those children with smaller objective function values first in the hope that the other children can be pruned.

1.3 DIB And The Operating System

DIB's requirements from the operating system are minimal: the machines must be connected by a network that supports a message-passing mechanism and each machine must be able to communicate with all other machines directly; each machine may run at a different speed.

There is no need for a clock or a timeout mechanism for DIB. DIB does not require that incoming messages generate interrupts. Instead, incoming messages are buffered; DIB will periodically check to see if new messages have arrived.
2. RELATED WORK

The field of distributed algorithms is growing. Several parallel implementations of specific algorithms and general methods have been reported. Decompositions of alpha-beta search have been the subject of much effort.

Parallel-aspiration search, Baudet [2], gives the entire problem to each machine, with each one constrained to find a solution within a different window. Narrow windows speed up the search.

Mandatory-work-first search, Akl and Barnard [4], distinguishes between those parts of a subtree that must be searched and those parts whose need to be searched is contingent upon search results in other parts of the tree. By searching mandatory nodes first, the algorithm attempts to achieve as many of the cutoffs seen in the serial case as possible.

The tree-splitting algorithm was described by Finkel and Fishburn [3]. The root processor evaluates the root position. Each interior processor evaluates its assigned position by generating the successors and queuing them for parallel assignment to its slave processors. Thus a processor at level N in the processor tree always evaluates positions at level N in the lookahead tree. As an interior processor receives responses from its slaves, it narrows its window and tells working slaves about the improved window. When all successors have been evaluated (or a cutoff has occurred), the interior processor is able to compute the value of its position. Each leaf processor evaluates its assigned position with the serial alpha-beta algorithm. When a processor finishes, it reports the value computed to its master.

These tree-splitting methods require a fixed machine tree. They suffer from machines sitting idle while work is still pending in other parts of the tree. They also allocate identical amounts of processing power to large regions of the tree, even though the left-most region is most likely to yield results quickly.
Moller-Nielsen and Staunstrup [5] have experimented with many different multicomputer algorithms, including branch-and-bound, and found that good speedups are possible when most of the tree has to be traversed.

Another approach to branch-and-bound [6] is to have each processor compute one node of the search tree and then reassign work based on the current bounds and cost functions. The amount of communication needed is very high.

All of these approaches require that a logical problem structure (a tree structure) is mapped in some way onto the physical machines. Under the tree-splitting, the map is dynamic, but the machines must be arranged as a tree and the map respects tree level. In DIB, the work is initially divided arbitrarily among machines. When machine $M_i$ finishes the work it was given, it sends a "request for work" to another machine $M_j$. If $M_j$ is currently working, it divides its work and sends part of it to $M_i$; otherwise, it forwards the request. So, the DIB program allows a highly dynamic mapping between logical subproblems and machines.
3. THE UNDERLYING ALGORITHMS

3.1 Algorithm for Distribution

The algorithm is based on a depth-first search of the tree. If there is only one machine then the computation is straightforward. Suppose there are \( n \) work machines \( M_1, M_2, \ldots, M_n, n > 1 \). Each machine \( M_i \) maintains two tables, WorkGiven and WorkGotten. WorkGotten records problems that were received from other machines. \( M_i \) is said to be responsible for these problems. Finished work is reported to its originator and is removed from WorkGotten. This table therefore allows DIB to pass results back up the tree. WorkGiven records problems that \( M_i \) has given to other machines. It can distinguish problems given to other work machines, and problems that have been generated (or received from elsewhere) but unassigned. When an answer to one of these problems is reported, its parent is notified and the entry is removed from WorkGiven. This table allows DIB to determine which work it is responsible for is still outstanding and to redo it in case of failure.

In the simple case of only one work machine, each table will contain only one entry: the root of the tree. The nodes generated during the search will be stored temporarily in a stack, not in the tables. The tables are only used to keep track of parts of the tree that cross machine boundaries.

When machine \( M_i \) has finished a problem and reported its result, it picks the next problem to attack from WorkGiven. If there are several unassigned problems there, it picks the earliest one, the one that appears first in a symmetric-order traversal of the tree. Unless it needs to subdivide this problem to give some away to another work machine, \( M_i \) uses its stack to record the progress of the search. If WorkGiven has no available work, \( M_i \) sends requests for work to other machines, which are selected by an algorithm that will be described later. WorkGiven might contain unavailable work, that is, work distributed to other machines.
A machine $M_j$ might receive a request for work from $M_i$ while it is engaged in a search. $M_j$ sets the search aside for a moment to try to grant this request by sending $M_i$ some work, the earliest unassigned problems in WorkGiven. If there is no available work in WorkGiven, the current problem $M_j$ is working on is subdivided, and its children are placed in WorkGiven. The child currently being searched by $M_j$ is marked as assigned to $M_j$: its later siblings are marked as unassigned. Some of these later are then sent to $M_i$. This subdivision is repeated until at least one unassigned problem is generated to send to $M_i$. However, if subdivision reaches a trivial problem, or if it reaches the depth at which $M_j$ is currently working, the request is not granted. Instead, it is forwarded to some other work machine. After dealing with $M_i$’s request, $M_j$ returns to its own search. Because the time needed to perform a piece of work and the relative speeds of the machines are not known in advance, they are not used in determining how much work to give away or which machine to ask for work. If $M_i$ receives what turns out to be the bulk of $M_j$’s work or suddenly becomes slow, other machines will finish their work and get $M_i$’s part. Thus, DIB contains an “automatic” load balancing mechanism.

The strategy used to select work to perform or to give away tends to work on the earlier parts of the search tree first. However, it does not guarantee any particular order of search because of the nondeterministic nature of work distribution.

The algorithm for sending request messages is that each machine $M_i$ sends requests for work to $k$ other machines selected at random. The constant $k > 1$ may depend on machine numbers and on the application. If the selected machine $M_j$ can not grant the request then it forwards the request to other machine, if it is forwardable. If the request has already got “Hops = work machines” then $M_j$ will ignore the request. $M_i$ may request for work again if it has been idle some period of time. So if one machine fails, the failed machine will not stop the whole system.
3.2 Algorithm for Fault Tolerance

Fault tolerance is a crucial area in distributed computing. In an environment of personal workstations, hardware or software failures are not the only types of failures. For example, when an application is running on other machines, the machine’s owner may decide at one point to stop all “guest” processes. As a result, the likelihood of failures may be independent of the hardware, and their distribution may be unpredictable.

The fault-tolerance algorithm works as follows. When a machine $M_i$ finishes its work and its WorkGiven table is not empty, some other machine still has work to do or it is likely that the work $M_i$ gave away went to a failing machine. Because $M_i$ can not distinguish between these two possibilities and since $M_i$ has to wait in any case for another machine to grant its request, it can use the waiting time to redo some outstanding work in its WorkGiven table. Redundant work has low priority and is discarded if $M_i$’s request is granted with non-redundant work. If $M_i$ is asked for work while computing redundant work, it grants the request as before, labelling the work it grants as redundant. Even this work may be redone by $M_i$ later, at a higher level of redundancy.

Whenever $M_i$ needs to select work from WorkGiven to perform or give away, it chooses available work at the lowest redundancy level. If there is no available work, it chooses work given away at the lowest redundancy level to redo, raising its redundancy in the process. Within a redundancy level, work earlier in the tree is chosen. Since the same work may be performed by two machines, its result may be received twice. The first result removes the entry from WorkGiven, and the second result is discarded. As long as machine 1 survives, which is responsible for the root, the tree will eventually be searched completely.

One problem called the ancestral-chain problem may happen in a chain of processes ancestral to a failing process. Assume that $M_1$ gave some work to $M_2$, which in turn gave some of it to $M_3$, which failed before reporting the
result back to M₂. When their other work is finished, both M₁ and M₂ will redo the work they gave away. What M₂ is redoing is worth the effort: M₁ however is redoing both work already finished but not yet reported by M₂ and the work being redone by M₂, both of which are unnecessary. This problem becomes more serious with longer chains.

One method which can be used to reduce this unnecessary computation is called “tell child”. When m₁ starts redoing work, it informs m₂ of this fact, m₂ treats this information as a request for work and grants some of its redundant (but necessary) work to its parent m₁. This method often cures the ancestral-chain problem, but it still does not ensure that redundant work is well distributed.

The benefits of the fault tolerance algorithm are that strict timeouts are not needed and this mechanism is independent of the operating system.
4. IMPLEMENTATION

The DIB package produces two executable programs, DIBHost.bcd and DIBNode.bcd. The first program DIBHost.bcd resides on the Host (supervisor) workstation and runs interactively, asking for Node (work) workstation numbers, setting up the working environment, asking for problem sizes, collecting and printing out the execution results. The second program is placed on every Node workstation. It communicates infrequently with the Host program, principally for debugging and statistics collection, and regularly with other Node workstations. Refer to Figure 4.0 DIB’s Working Environment.

4.1 Host Implementation

The data structure for a “message” transmitted between machines is shown on Figure 4.1 and the flow chart for the Host program is shown on Figure 4.2. The Host program works as follow.

1. Set up environment

   a. Host gets Node workstation numbers from user input.
   b. Asks user to input each workstation’s name (including Host), and uses the name to find each workstation’s network address.
   c. According to the workstation input order, stores the network address in an array.
   d. Sends the network address array and workstation’s number, which is their location in the array, to every Node workstation.
   e. After the set up step, each Node knows his number, Host’s network address, and all other workstation’s number and network address.
1. DIBHost runs interactively.

2. DIBNode communicates infrequently with the Host and regularly with other Node workstations.

Figure 4.0 DIB’s Working Environment
StatusSpecification: TYPE = {BatchDone, AnAnswer, Quitting, Reporting, PleaseStop};

MessageType: TYPE = {Request, Work, GlobalInfo, Result, Terminate, Synch, Repeating, Updating};

Message: TYPE = RECORD[
  specifics: SELECT type: MessageClass FROM

  ProblemMessage = > [ Kind: INTEGER, -- 0 means no work; 1 means here is a problem Answer: AnswerSpecification, -- Full, Count Prob: ApplicDfs.ProblemType, PartSize: INTEGER, -- partition size WorkFraction: INTEGER, << how much to give away when asked; 0 means give away none; 10 means give away all work; negative means give away one problem (if possible) >> NumHelp: INTEGER, -- how many to ask when out of work DebugLevel: INTEGER], << higher numbers are more verbose; 0 is silent >>


ENDCASE];

Figure 4.1 Data Structure For Message
Figure 4.2 Flow Chart For Host

1. **Set Up Environment**

2. **Select Execution Choices**

3. **Initialize**

4. **Get Root Problem And Send Message**

5. **Process Message from Nodes And Wait for Job done (Ref Figure 4.3)**

6. **Print Statistics**

7. **Quit**

   - **y** Exit
   - **n**
2. Select execution choices

After "Set up environment", a menu will be shown on the screen. The possible execution choices are " c, f, d, h, n, q ", representing the following:

c: count, only the final result will be reported to Host. The default value is c.
f: full, each possible answer will be reported to Host.
d: debug level; trace the execution of the application program. The possible value are 1, 2, 3, and 6. The bigger the number is, the more details of the execution will be shown on the screen. The default value is 0.
h: helpers, number of helpers when out of work. Due to the number of workstations that can be used, helpers is set to 1 by default.
n: new problem (run the application program with different sizes).
q: quit.

3. After initializing the variables in the Host program and application program, the Host asks the user to input application problem sizes. Using the problem sizes as a parameter, Host calls application program to generate the "Root Problem", the problem to be solved.
Then Host puts the root problem, the selected execution choices into a problem message package, and sends it to each Node workstation.

4. After sending the problem message package, the Host processes each message transmitted back by the Nodes, and waits for the job done message from Node 1. The flow chart for Host wait job done is shown on Figure 4.3. The message transmitted back by each Node has the following meaning.

a. Please Stop: Node 1 tells the Host to stop.
b. Batch Done: The whole problem has been finished, Node 1 tells the updated root to the Host.
c. Reporting: One Node has finished a subproblem; tells the Dewey number (problem ID) of what just finished to the Host.
d. An Answer: A result has been sent back to the Host.
Figure 4.3 Flow Chart For HWaitDone
e. Quitting: Which Node is quitting.

Finally, the Host prints out the statistics results of the execution in each Node, and goes back for the next execution.

4.2 Node Implementation

The data structures for the WorkGotten and WorkGiven Tables is shown on Figure 4.4 and the flow chart for the Node program is shown on Figure 4.5. The Node program works as follow.

1. Node workstations will wait for the set up message from Host. After the message is received, each Node knows his number and each other workstations' number and network address. Until now, workstations could communicate with each other directly.

2. Next, Node workstations wait for the problem message from Host.

3. Using the execution choices part in the problem message, Node workstations initialize their global variables.

4. In order to let Node workstations start the execution at nearly the same time, the Node workstation with the biggest number sends start up message to the other Node workstations.

5. After synchronizing between Node workstations, Node 1 begins to work on the problem given by Host. Other Node workstations will send a "request for work" message to Node 1 to help solve the problem.

6. The algorithms for work distribution and fault tolerance have been given on previous section. The flow charts for the main procedures in the Node program are shown on Figure 4.6 BackTrack, Figure 4.7 AskForHelp, Figure 4.8 CheckIncoming, Figure 4.9 HandleRequest. The following is the descriptions of these procedures.
WorkGottenType: TYPE = RECORD[
    ID: DeweyDfs.Dewey,
    Owner: INTEGER, --who is waiting for the results
    UnsolvedCount: INTEGER, <<how many subproblems
                      are still under computation. >>
    Value: ApplicDfs.ProblemType,
    Next: WorkGottenPtr];

WorkGivenType: TYPE = RECORD[
    ID: DeweyDfs.Dewey,
    Value: ApplicDfs.ProblemType,
    Worker: INTEGER, --who is working on this problem for
             --us
    Available: BOOLEAN, <<may we work on it?
                If not given to anyone, Worker = -1 (Open),
                Available = TRUE
                If given to machine m, Worker = m,
                Available = FALSE
                If given but ready to redo, Worker = m,
                Available = TRUE
                If given and I am redoing, Worker = m,
                Available = FALSE >>
    Parent: WorkGottenPtr,
    Redundancy: INTEGER,
    Next: WorkGivenPtr];

Figure 4.4 Data Structure For WorkGotten
And WorkGiven
Figure 4.5 Flow Chart For Node
a. **BackTrack: PROC[]**
   Recursive backtrack to solve the problem chosen from WorkGiven table. It uses an explicit stack, called CurrentProblem, to store unfinished work. BackTrack uses the Depth-First search to find a child or a sibling of current child. Refer to Figure 4.6.1 Search in BackTrack for detail.

b. **AskForHelp: PROC[FirstTime: BOOLEAN, Begger, Hops: INTEGER]**
   If FirstTime then ask Node 1 for work; afterwards, send a request to other Nodes (equal to the number of helpers) chosen by random. If Begger ≠ MyName, then forward the request. Also tell the number of hops to the helpers.

c. **CheckIncoming: PROC[BusyWait: BOOLEAN]**
   RETURNS[Abort: BOOLEAN]
   Called periodically to see if other Nodes have asked or forwarded a request for some work to do. If it has, call procedure HandleRequest to deal with the request. If BusyWait is set, don’t return if nothing has come in; keep checking. Set Abort to true if work just came in that is less redundant than the current level. The incoming message has the following meaning.

   a. **Synch**: Wait for this message before continuing and set the Start time.
   b. **Request**: Someone is asking me for work. Call HandleRequest to deal with the request.
   c. **Work**: Incoming message was a response to my request, or to my notice that I am repeating work.
   d. **Repeating**: Someone is redoing the work that he gave to me. Try to grant him some useful work.
   e. **Result**: Someone has finished a problem; I need to tell each parent.
   f. **Updating**: The problem in the incoming message has changed, I need to update the problem.
   g. **GlobalInfo**: Incoming message was new global information.
   h. **Terminate**: The whole problem has been finished, Node 1 tells me to stop the work and reports the statistics data.
Figure 4.6 Flow Chart For BackTrack
Typical Depth-First Search

Root

CurrentProblem[0]

Child 1

CurrentProblem[1]
DeweyDelta[Length] = 1

Child 2

Combine Result And Try Generate Siblings

Child 3

A Leaf
Pass Result Up

Child 4

DeweyDelta[3] = 2

Figure 4.6.1 Search In BackTrack
Figure 4.7 Flow Chart For AskForHelp
Figure 4.8 Flow Chart For CheckIncoming
d. HandleRequest: PROC[Who: INTEGER, Hops: INTEGER]
   Called from CheckIncoming. Who has just asked us for work, or we have decide to pass some work to Who. If there is any work to spare, send it; otherwise, forward the request, if it is forwardable. If it has already got Hops = Node Machines, don’t forward it. Refer to Figure 4.9.1 Subdivide Work In HandleRequest about how to subdivide work from CurrentProblem.

4.3 Communication Interface Implementation

The communication between workstations is based on the communication package, NetworkStream. A Network stream is the principal means by which clients of Pilot communicate between machines. NetworkStream provides access to the implementation of the Sequenced Packet Protocol -- a level 2 Internet Transport Protocol which is defined in Xerox Internet Transport Protocols. It is supposed to provide sequenced, duplicate-suppressed, error-free, flow-controlled communication over arbitrarily interconnected communication networks.

A close protocol which is provided by Network streams is also used to implement the communication interface. This method of terminating dialog on a stream is suggested in the NS Internet Protocol Specification. But use of these routines is considered optional.
Try To Subdivide Current Problem
(Ref Fig 4.9.1)

AvailWorkCount = 0

Try To Subdivide Current Problem
(Ref Fig 4.9.1)

AvailWorkCount = 0

Select Work From WorkGiven Table

Forward The Request

Send Work To Requester

Hops < Node Machines

Return

Figure 4.9 Flow Chart For HandleRequest
1. Try to subdivide at GiveAwayDepth (Root)
2. If Root is dividable, Child 1 and his siblings (if any) will store in WorkGiven. All Siblings will be marked available.
3. If Root can not be divided, it will increase GiveAwayDepth, try to subdivide at Child1.

**Figure 4.9.1 Subdivide Work In HandleRequest**
5. USER INTERFACE

To Write an application, the user has to supply the following procedures: ApplicFinish, AcceptRoot, AcceptAnswer, FirstProb, Generate, UseNewInfo, NonTrivial, Combine, Update, ApplicInit, PrintProblem, PrintAnswer. These procedures are similar to what one would need in a sequential program for this application.

The primary procedure is Generate, which DIB calls whenever it needs the next child of a node. DIB indicates whether it is looking for a first child or a later one. The application may respond with a new child or indicate that the node is a leaf, and has no children, or that it has no more children. To start the entire calculation, DIB calls FirstProb to generate the root of the search tree. To print the result of the calculation, DIB calls PrintAnswer on the root node or on the host. The following declarations define DIB's interface to the application program. Appendix B shows two application programs, the eight-queens problem and the traveling-salseman problem.

** Type and Variable

ProblemType: ... the application one wishes to store in a node
InfoType: ... global information format, if any

** The following routines specify initial setup and what to do with results; they are executed on the Host machine (supervisor)

FirstProb: PROCEDURE[Size: INTEGER] RETURNS[P: ProblemType];
Generate the root P of the problem tree, where Size is a parameter selecting which problem of a class is intended. For example, the eight-queens problem can let Size indicate the dimensions of the chessboard.

AcceptAnswer: PROCEDURE[P: ProblemType];
P has information worth recording.
AcceptRoot: PROCEDURE[P: ProblemType];
P contains the result of the entire search.

ApplicFinish: PROCEDURE[];
Used to print final message or do housekeeping.

** DIB calls the following routines on node machines (work)

Generate: PROCEDURE[
    First: BOOLEAN,
    Parent: LONG POINTER TO ProblemType,
    Child: LONG POINTER TO ProblemType]
RETURNS[Done: BOOLEAN];
If First, set Child to first child of Parent. Otherwise, set Child to the next child of Parent. If there are no more children, set Done instead. Generating a child may modify local data within Parent.

UseNewInfo: PROCEDURE[Info: InfoType];
Make use of Info, which was broadcast by a different machine. This information is typically used to improve a bound.

NonTrivial: PROCEDURE[P: ProblemType] RETURNS[BOOLEAN];
Return true if P will take significant computation to complete. DIB will not distribute a problem that the application considers trivial.

Combine: PROCEDURE[
    Child: LONG POINTER TO ProblemType,
    Parent: LONG POINTER TO ProblemType]
RETURNS[Update: BOOLEAN];
Child has just finished; record any information to be passed up the tree in Parent. If Parent’s live children need to be notified asynchronously of Parent’s new situation, set Update to true.

Update: PROCEDURE[
    Child: LONG POINTER TO ProblemType,
    Parent: LONG POINTER TO ProblemType]
RETURNS[Again: BOOLEAN];
Parent has just been modified; Child is already live. Update Child’s information based on the Parent. If Child’s live children must also be notified of its change, set Again to true.

** The following routines are used for initialization, debugging, and printing results. They are invoked both on the Host and work (Node) Machine.

ApplicInit: PROCEDURE[ ];
  Initialize any data structures.

PrintProblem: PROCEDURE[P: ProblemType];
  Print P’s problem description.

PrintAnswer: PROCEDURE[P: ProblemType];
  Print P’s answer values.

** The following routines are provided by DIB on work machines and may be called by the application, for example, during Generate or Combine.

BroadcastInfo: PROCEDURE[Info: InfoType];
  Lets the application in all machines know about this new information. This facility is used in branch and bound.

ReportResult: PROCEDURE[P: ProblemType];
  Causes the work machine to send P to the Host machine, where AcceptResult will be invoked.
6. EXPERIMENTS

Three applications have been implemented and used to test the DIB package. Their execution results are given on Appendix C. The application programs for the eight queens problem and the traveling salesman problem are given on Appendix B. Statistics data for each application is shown in this section and the eight-queens problem is also used as an example to show how to write an application program.

6.1 Description Of The Applications

1. The eight queens problem

Find all possible arrangements of N (chess) queens on an N x N board such that no queen can capture another queen. A count of solutions is passed up the tree.

```
Example Result
(Queens Problem)
N = 4

<table>
<thead>
<tr>
<th></th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td></td>
<td>Q4</td>
</tr>
<tr>
<td>Q1</td>
<td></td>
<td>Q4</td>
</tr>
<tr>
<td>Q2</td>
<td>Q3</td>
<td></td>
</tr>
</tbody>
</table>
```

The most important part in an application program is how to generate children at each node. The comments shown in the step (3) describe the algorithm to attack this problem. To write the application program, the user needs to do the following:
(1) Type and variable declarations

MaxProbSize: INTEGER = 20; -- no more than this many queens
QueenArray: TYPE = ARRAY[1..MaxProbSize] OF INTEGER;
<< store the solution, the number represents the queen's position in each column >>

ProblemType: TYPE = RECORD[
  LeafCount: LONG INTEGER,
  <<It is a synthesized value generated at the leaves of the tree and is passed up as a result of calls to combine. It counts the number of arrangements that the queens can be put on the board.>>
  ProbSize: INTEGER, -- dimensions of the chess board
  Length: INTEGER, -- how many queens have been placed
  Queens: QueenArray]; -- store queen's position

InfoType: TYPE =
  PACKED ARRAY[0..1] OF CHARACTER; -- pseudo data
<< InfoType is not needed in queens application, but it is needed by DIB program. >>

Title: LONG STRING ← "Queens"L;

(2) Code the root problem

FirstProb: PUBLIC PROCEDURE[Size: INTEGER]
  RETURNS[P: ProblemType] =

  BEGIN
    P.LeafCount ← 0;
    P.ProbSize ← Size;
    P.Length ← 0;
  END;

(3) How to generate children at each node

Generate: PUBLIC PROCEDURE[
  First: BOOLEAN,
  Parent: LONG POINTER TO ProblemType,
  Child: LONG POINTER TO ProblemType]
  RETURNS[Done: BOOLEAN] =

  BEGIN
    Seq: INTEGER;
ThisQueen, ThatQueen: INTEGER;
Bad: BOOLEAN;

--what to do during the search

IF First AND (Parent ↑ .Length = Parent ↑ .ProbSize) THEN

{ -- find a leaf
  Done ← TRUE;
  Parent ↑ .LeafCount ← 1; -- set leaf count
  ReportResult[Parent ↑ ]} -- report to Host

ELSE { --not a leaf

  IF First THEN -- expect to find a child
  {Child ↑ ← Parent ↑ ; -- copy parent data to child
   {OPEN Child ↑ ;
    Length ← Length + 1; -- update child's length
    Queens[Length] ← 0}; -- initialize
    First ← FALSE};

  -- search for a reasonable place for current queen

  {OPEN Child ↑ ;
   LeafCount ← 0; -- initialize
   DO
    Queens[Length] ← Queens[Length] + 1;
    ThisQueen ← Queens[Length];
    IF ThisQueen > ProbSize THEN
     {Done ← TRUE;
      EXIT};
    Seq ← 1;
    Bad ← FALSE;
    WHILE Seq < Length

     -- check if Queens[Seq] conflicts with Queens[Length]

     DO
      ThatQueen ← Queens[Seq];
      IF (ThatQueen = ThisQueen) OR --check row

      -- check diagonal position
      (ThatQueen + Seq Length = ThisQueen) OR
      (ThatQueen - Seq + Length = ThisQueen) THEN
       {Bad ← TRUE;
        EXIT};
      Seq ← Seq + 1;
      ENDLOOP;
    IF NOT Bad THEN
     {Done ← FALSE;
      EXIT};
    ENDLOOP};

END;
(4) How to combine the result from children

Combine: PUBLIC PROCEDURE[
  Child: LONG POINTER TO ProblemType,
  Parent: LONG POINTER TO ProblemType]
RETURNS[Update: BOOLEAN] =

BEGIN
  Parent ↑ .LeafCount ← Parent ↑ .LeafCount + Child ↑ .LeafCount;
  Update ← FALSE;
END;

(5) How to print the answer

PrintProblem: PUBLIC PROCEDURE[P: ProblemType] =

BEGIN
  Seq: INTEGER ← 1;
  {OPEN P; -- print the queens' position
    WHILE Seq <= Length
      DO
        WriteChar['];
        WriteDecimal[Queens[Seq]];
        Seq ← Seq + 1;
        ENDLOOP;
    NewLine[];
  END;
END;

PrintAnswer: PUBLIC PROCEDURE[P: ProblemType] =

BEGIN -- print how many arrangements
  WriteLongDecimal[P.LeafCount];
  WriteString[" Leaves "L];
END;

(6) Other useful procedures

ApplicInit: PUBLIC PROCEDURE[] =
BEGIN
  WriteString[Title];
  WriteString[" "];
  NewLine[];
END;

NonTrivial: PUBLIC PROCEDURE[P: ProblemType] RETURNS[BOOLEAN] =

BEGIN
  RETURN[P.Length < P.ProbSize - 2];
END;
AcceptRoot: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  PrintProblem[P];
  PrintAnswer[P];
END;

AcceptAnswer: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  PrintProblem[P];
END;

(7) Refer to Appendix B, put them in Definition and Implementation module.

2. Knights tour

Find all possible tours a (chess) knight can take covering the whole board except k squares without repeating a square. (This is basically a Hamiltonian path problem.)

<table>
<thead>
<tr>
<th>Example Result (Knights Tour)</th>
<th>k = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>K10</td>
<td>K5</td>
</tr>
<tr>
<td>K2</td>
<td>K9</td>
</tr>
<tr>
<td>K8</td>
<td>K11</td>
</tr>
<tr>
<td>K1</td>
<td></td>
</tr>
</tbody>
</table>

3. The traveling-salesman problem

Find a minimal-cost tour of cities. Inter-city costs are initialized from a uniform distribution in [0..1]. The application uses a branch and bound algorithm, broadcasts each newly discovered minimum path cost, and generates children of a node in closest-first order. The best solution found is passed up the tree.
6.2 Results

Table 6.1 collects the running times for the queens problem (queen’s number is changed from 8 to 12) for 1 to 5 workstations. The times were measured by the Host machine. From the table, we can know that if the problem size is small (if queen’s number is less than 10), it is not worth to use more than one machine to run the queens problem. Because the time is needed for synchronization, subdividing problem, and communication
between machines, the running time increases with the number of machines for small problem size.

Figure 6.1 shows timings (in seconds) for the twelve-queens problem. The time curve is measured in seconds. The figure also shows the efficiency, which is defined as

\[
\frac{\text{time for 1 machine}}{n \times \text{time for n machines}}
\]

The efficiency is generally above 90%, and seems to degrade quite slowly as extra machines are added.

Table 6.2 and Figure 6.2 show the statistics data gathered from the knights tours problem and Table 6.3 and Figure 6.3 show the statistics data gathered from the traveling salesman problem.
<table>
<thead>
<tr>
<th>Queen #</th>
<th>Running Times for 1 to 5 workstations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0:2.39</td>
</tr>
<tr>
<td>9</td>
<td>0:12.89</td>
</tr>
<tr>
<td>10</td>
<td>1:3.7</td>
</tr>
<tr>
<td>11</td>
<td>5:45.6</td>
</tr>
<tr>
<td>12</td>
<td>33:51.8</td>
</tr>
</tbody>
</table>

Table 6.1 Queens Problem Testing Result

Figure 6.1 The Queens Problem
<table>
<thead>
<tr>
<th>Board Dimension</th>
<th>Running Times for 1 to 5 workstations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0:0:0.534  0:0:2.15  0:0:2.98  0:0:4.927  0:0:4.335</td>
</tr>
<tr>
<td>4</td>
<td>0:0:6.034  0:0:5.471  0:0:8.036  0:0:9.016  0:0:11.065</td>
</tr>
<tr>
<td>5</td>
<td>1:11:1.0  0:35:38.9  0:24:30.3  0:18:28.5  0:15:18.2</td>
</tr>
</tbody>
</table>

Table 6.2 Knights Tour Testing Result

Figure 6.2 Knights Tour Problem

For Knight on 5 x 5 Board
<table>
<thead>
<tr>
<th>Cities Visited</th>
<th>Running Times for 1 to 4 workstations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>0:0:38.18</td>
</tr>
<tr>
<td>10</td>
<td>0:2:43.37</td>
</tr>
<tr>
<td>11</td>
<td>0:14:13.91</td>
</tr>
<tr>
<td>12</td>
<td>0:19:51.24</td>
</tr>
<tr>
<td>13</td>
<td>0:44:21.37</td>
</tr>
<tr>
<td>14</td>
<td>2:14:1.0</td>
</tr>
</tbody>
</table>

Table 6.3 Traveling Salesman Testing Result

![Figure 6.3 Traveling Salesman Problem](image-url)
During the execution, each Node workstation measures elapsed time in several categories: time spent in communication (generating messages, Processing requests), time spent idly waiting for another work machine to grant a request for work, time spent idly before discovering termination, and time spent computing. The following tables present the computing and communication timings for 5 Node workstations jointly solving a 12-queen problem and for 4 Node workstations jointly solving a 14-city sorted traveling salesman problem. The tables show how equally work is distributed among the workstations and only a small fraction of the time is spent in communication

<table>
<thead>
<tr>
<th>Node</th>
<th>Communication time</th>
<th>Computation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:9.887</td>
<td>6:53.212</td>
</tr>
<tr>
<td>2</td>
<td>0:10.306</td>
<td>6:48.917</td>
</tr>
<tr>
<td>3</td>
<td>0:7.557</td>
<td>6:50.653</td>
</tr>
<tr>
<td>4</td>
<td>0:16.595</td>
<td>6:49.524</td>
</tr>
<tr>
<td>5</td>
<td>0:8.845</td>
<td>6:50.334</td>
</tr>
</tbody>
</table>

Table 6.4 Distribution of work for 12 queens

<table>
<thead>
<tr>
<th>Node</th>
<th>Communication time</th>
<th>Computation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:5.878</td>
<td>36:55.63</td>
</tr>
<tr>
<td>2</td>
<td>0:9.736</td>
<td>36:45.882</td>
</tr>
<tr>
<td>3</td>
<td>0:9.157</td>
<td>36:45.373</td>
</tr>
<tr>
<td>4</td>
<td>0:11.812</td>
<td>36:40.635</td>
</tr>
</tbody>
</table>

Table 6.5 Distribution of work for 14-city visited
7. IMPLEMENTATION EXPERIENCES

There are several issues that are worth mentioning in using the Mesa programming language to implement this project. They are described as follows.

7.1 The Size Of Variables

The maximum size of a variable is around 4000 words; the user may declare a variable as "test: ARRAY[1..4000] OF INTEGER" and will not get any error message from the compiler. If the variable size does exceed this limit, the compiler will print out "variable or field too big" message to the user.

The user may use the Heap which is the primary storage allocator in Mesa to allocate and free blocks of storage of arbitrary size. For example, the user can do the follow to let the variable size exceed 4000 words.

```plaintext
testType: TYPE = ARRAY [1..8000] OF INTEGER; -- declaration
test: LONG POINTER TO testType; -- declaration
test ← zone.NEW[testType]; -- in program
zone.Free[@test]; -- in program
```

7.2 How To Deal With Real Numbers

Users may want to use real numbers in their application programs. The real number operations and functions such as FAdd, FSub, FMul, FDiv, FRem, FComp, Exp, Log, Ln, SqRt, Root and Power can be found in the Real.mesa and RealFns.mesa under the Fiat/XDE/ComSoft/Public directory.

The procedure "InitReals" must be called before any floating point operations are called. It is ok to call InitReals more than once.
7.3 How To Use Variant Records

Users often find it convenient to combine information of different types. The user can use the following steps to declare variant RECORD types, to assign values to variant RECORDs, and to access the fields of variant RECORDs.

1. Declaring variant RECORDs

The declaration for Message is a variant RECORD:

Message: TYPE = RECORD[ -- declaration
    specifics: SELECT type: MessageClass FROM -- no common part
    ProblemMessage = > [
        PartSize: INTEGER,
        DebugLevel: INTEGER],
    InterNodeMessage = > [
        Asker: INTEGER,
        Redundancy: INTEGER],
    ENDCASE];

2. Allocation of variant RECORDs

MsgBuffer: RECORD[
    source: INTEGER,
    dest: INTEGER,
    message: Message];

3. Assignment to variant RECORD variables

    a: ProblemMessage Message; -- declaration
        -- It now is a bound variant
    a.PartSize ← 5;
    a.DebugLevel ← 2;
43

MsgBuffer.message ← a; -- you can do it in this way

4. Accessing the fields of a variant RECORD variable

WITH a: MsgBuffer.message SELECT FROM
  ProblemMessage = > {
    x ← a.PartSize; -- process the data
    y ← a.DebugLevel};
  <<< OR InterNodeMessage = > {
    *** }; >>
ENDCASE;

7.4 About Process.Yield

The Mesa process mechanism does not attempt to allocate processor
time fairly among processes of equal priority. A process itself will yield the
processor to other processes of equal priority whenever it faults, Pauses or
WAITs. In the Node program, the Receiver and the main program run
concurrently. When the problem size is large, as in queen sizes equal 12 or
larger, other Nodes could not connect to Node 1 until Node 1 nearly
finished all the computation. It looks like the Receiver has the problem
getting to the processor.

Process.Yield places the calling process at the rear of the queue of
ready-to-run processes of the same priority. Thus, all other ready
processes of the same priority will run before the calling process next runs.
After using it in the main program to force the scheduling, it did solve the
connection problem but it increased overhead by 5 to 10 percent.
8. FURTHER RESEARCH AND CONCLUSIONS

There are several directions for advancing this software package.

1. Adapting DIB to similar application areas. These applications may be an alpha-beta search problem, or a Petri-net reachability problem.

2. Distributing work not solely by request from underloaded nodes, but also by initiative of overloaded nodes. This facility will help shed load from "hot spots", which occur near the end of computation and when machines have failed.

3. Adapting DIB to be used as an instructional tool in networking and distributed computing courses.

DIB is an attempt at providing an easily used facility for writing distributed programs involving backtracking. The distributed part of DIB is completely hidden from the user, making it especially suitable for programmers without expertise in distributed or parallel programming. The distribution of work in DIB is dynamic, making it suitable for any environments. DIB requires minimal support from the distributed operating system and it is relatively portable.

The experimental results indicate that for simple programs DIB is an efficient and easily used tool for automatically distributing work. Exhaustive search is distributed uniformly with very little performance penalty. Application that uses branch and bound should generate more worthy children first to take advantage of DIB’s search order. The feature of fault tolerance makes DIB very robust.
BIBLIOGRAPHY


9. N. Wirth, Modula: a language for modular multiprogramming, Software Practice and Experience, 1977

10. N. Wirth, Design and Implementation of Modula, Software Practice and Experience, 1977


Appendix A: USER MANUAL

There are certain steps to be followed by the user of this package.

Step 1: Write application program

1. Application program should use "ApplicDfs.mesa" as the name of Definition module, and use "ApplicImpl.mesa" for Implementation module.
2. Follow the description of each procedure in "USER INTERFACE", and use the same procedure name to write each procedure.
3. Refer to the application program examples in Appendix B to get more information.

Step 2: Compile the application program and Bind it with DIB package: retrieve DIB from "Audi/Projects/DIB/Programs" directory

DIB package contains the following Definition modules

1. IO.mesa
2. TimeMeasureDfs.mesa
3. ApplicDfs.mesa (Supplied by user)
4. DeweyDfs.mesa
5. HostDfs.mesa
6. InterfaceDfs.mesa
7. HInterfaceDfs.mesa
8. NodeDfs.mesa
9. NInterfaceDfs.mesa

DIB package contains the following Implementation modules

1. HInterfaceImpl.mesa
2. IOMpl.mesa
3. DeweyImpl.mesa
4. ApplicImpl.mesa (Supplied by user)
5. TimeMeasureImpl.mesa
6. HostImpl.mesa
7. NInterfaceImpl.mesa
8. NIOMImpl.mesa
9. NodeImpl.mesa

DIB package contains two configuration modules

1. DIBHost.config    2. DIBNode.config

DIB package needs the following tool modules: find and retrieve them from the “Fiat/XDE/5.0/...” directory.

1. String.bcd
2. Stream.bcd
3. NetworkStream.bcd
4. Heap.bcd
5. Tool.bcd
6. TTYSW.bcd
7. Process.bcd
8. TTY.bcd
9. System.bcd
10. Put.bcd
11. Exec.bcd
12. FormSW.bcd
13. AddressTranslation.bcd
14. Format.bcd
15. Time.bcd
16. RandomDefs.bcd
17. RandomProg.bcd
18. Real.bcd
19. Reallmpl.bcd
20. Ascii.bcd
21. Window.bcd
22. Environment.bcd
23. UserTerminal.bcd
24. ToolWindow.bcd
User should compile and bind these modules in the following steps

1. Active "CommandCentral" window if it is in tiny or inactive state. Otherwise, get it from "Executive" window.
2. Enter those Definition modules in the following order to the "compile:" field on the CommandCentral window; IO TimeMeasureDfs ApplicDfs DeweyDfs HostDfs InterfaceDfs HInterfaceDfs NodeDfs NIInterfaceDfs, and invoke "Compile!" command.
3. Enter those Implementation modules to the "Compile:" field, the order is not important, and invoke "Compile!" command.
4. Enter DIBHost and DIBNode to the "Bind:" field, and invoke "Bind!" command. Ignore if the Binder gives the message "BroadcastInfo or ReportResult" are not bindable when Binder tried to bind DIBHost.config.
5. If everything is OK, the Binder will generate two executable programs, DIBHost.bcd and DIBNode.bcd.
6. If there are compiling errors from ApplicDfs.mesa, then redo steps 2-4.
7. If there are compiling errors from ApplicImpl.mesa, then only ApplicImpl.mesa needs to be recompile and redo step 4.

Step 3: Run application program

1. Load DIBHost.bcd or DIBNode.bcd (via FileTool) onto those workstations which are going to be used.
2. Enter DIBHost to the "Run:" field of CommandCentral window, and invoke "Run!" command at only one workstation.
3. Enter DIBNode to the "Run:" field of CommandCentral window, and invoke "Run!" command at other workstations.
4. Set Node (work) workstations
   Enter the workstation's name shown on the monitor upper left corner to the "I am:" field and invoke "Assert!" command.
5. Set Host (supervisor) workstation

(1) Enter the workstation’s name shown on the monitor upper left corner to the “I am:” field and invoke “Assert!” command.

(2) Follow the instructions on the monitor screen to input data or to make a selection. For example,
   a. “Please input Node Number”
      Enter the number of node (work) workstations (exclude the host).
   b. “Please input the name of each node - First is Host”
      Enter the Host name first, then enter each node workstation’s name.
   c. Selection
      c: count, only the final result will be reported to Host.
      f: full, each possible answer will be reported to Host.
      d: debug level; trace the execution of the application program. The possible value is 1, 2, 3, and 6. The bigger the number is, the more details of the execution will be shown on the screen.
      h: helpers, number of helpers when out of work. Due to the number of workstations that can be used, helpers is set to 1 by default.
      n: new problem, run the application program with different problem sizes.
      q: quit

Step 4: Back to Copilot

1. From Host, enter ‘q’ then deactivate the window and press the SHIFT-STOP keys.
2. From Node, deactivate the window and press the SHIFT-STOP keys.
NOTE:

1. DIB can only use these workstations: ALVIS, LIT, GALAR, FJALAR, ANDVARI, EITRI, BROKK, MODSOGNIR, DURIN.

2. These workstations use fixed network addresses to communicate with each other. These addresses are set in the HInterfaceImpl.mesa and NInterfaceImpl.mesa programs. If workstations are moved to another place or are connected to other sockets, users need to find the new network addresses and to revise them in the HInterfaceImpl.mesa and NInterfaceImpl.mesa programs.

3. If the “Sender ConnectionFail” message occurs during the “Set up environment” step, the user may need to check the network addresses.
Appendix B: Sample Application Programs

B.1 Application Example 1 (Eight-Queens Problem)

Part 1 Definition Part -- File name: ApplicDfs.mesa

ApplicDfs: DEFINITIONS =

BEGIN
MaxProbSize: INTEGER = 20;
QueenArray: TYPE = ARRAY[1..MaxProbSize] OF INTEGER;
ProblemType: TYPE = RECORD[
  LeafCount: LONG INTEGER,
  ProbSize: INTEGER,
  Length: INTEGER,
  Queens: QueenArray];
InfoType: TYPE = PACKED ARRAY[0..1] OF CHARACTER; -- pseudo data
ApplicFinish: PROCEDURE[];
AcceptRoot: PROCEDURE[P: ProblemType];
AcceptAnswer: PROCEDURE[P: ProblemType];
FirstProb: PROCEDURE[Size: INTEGER] RETURNS[P: ProblemType];
Generate: PROCEDURE[First: BOOLEAN,
  Child: LONG POINTER TO ProblemType,
  Parent: LONG POINTER TO ProblemType]
  RETURNS[Done: BOOLEAN];
UseNewInfo: PROCEDURE[Info: InfoType];
NonTrivial: PROCEDURE[P: ProblemType] RETURNS[BOOLEAN];
Combine: PROCEDURE[Child: LONG POINTER TO ProblemType,
  Parent: LONG POINTER TO ProblemType]
  RETURNS[Update: BOOLEAN];
Update: PROCEDURE[Child: LONG POINTER TO ProblemType,
  Parent: LONG POINTER TO ProblemType]
  RETURNS[Again: BOOLEAN];
ApplicInit: PROCEDURE[];
PrintProblem: PROCEDURE[P: ProblemType];
PrintAnswer: PROCEDURE[P: ProblemType];
Part 2 Implementation Part -- File name: ApplicImpl.mesa

DIRECTORY
   ApplicDfs,
   NodeDfs,
   IO;

ApplicImpl: PROGRAM
IMPORTS NodeDfs, IO
EXPORTS ApplicDfs =

BEGIN
   OPEN NodeDfs, ApplicDfs, IO;
   Title: LONG STRING ← "Queens"L;

   PrintProblem: PUBLIC PROCEDURE[P: ProblemType] =
   BEGIN
      Seq: INTEGER ← 1;

      {OPEN P;
      WHILE Seq <= Length
      DO
         WriteChar[ ];
         WriteDecimal[Queens[Seq]];
         Seq ← Seq + 1;
      ENDLOOP;
      NewLine[]};
   END;

   PrintAnswer: PUBLIC PROCEDURE[P: ProblemType] =
   BEGIN
      WriteLongDecimal[P.LeafCount];
      WriteString[" Leaves "L];
   END;

   Generate: PUBLIC PROCEDURE[First: BOOLEAN,
                                 Parent: LONG POINTER TO ProblemType,
                                 Child: LONG POINTER TO ProblemType]
   RETURNS[Done: BOOLEAN] =

   BEGIN
      Seq: INTEGER;
      ThisQueen, ThatQueen: INTEGER;
      Bad: BOOLEAN;

      IF First AND (Parent ↑ .Length = Parent ↑ .ProbSize) THEN
      {Done ← TRUE;
      Parent ↑ .LeafCount ← 1;
      ReportResult[Parent ↑ ]}
      ELSE { --not a leaf
IF First THEN
{Child ↝ Parent ↝;
 {OPEN Child ↝;
   Length ↝ Length + 1;
   Queens[Length] ↝ 0;
   First ↝ FALSE};
{OPEN Child ↝;
 LeafCount ↝ 0;
 DO
   Queens[Length] ↝ Queens[Length] + 1;
   ThisQueen ↝ Queens[Length];
   IF ThisQueen > ProbSize THEN
     {Done ↝ TRUE;
     EXIT};
   Seq ↝ 1;
   Bad ↝ FALSE;
   WHILE Seq < Length
   DO
     ThatQueen ↝ Queens[Seq];
     IF (ThatQueen = ThisQueen) OR
        (ThatQueen + Seq • Length = ThisQueen) OR
        (ThatQueen - Seq + Length = ThisQueen) THEN
       {Bad ↝ TRUE;
       EXIT};
     Seq ↝ Seq + 1;
   ENDLOOP;
   IF NOT Bad THEN
     {Done ↝ FALSE;
     EXIT};
   ENDLOOP};
END;

FirstProb: PUBLIC PROCEDURE[Size: INTEGER] RETURNS[P: ProblemType] =
BEGIN
  P.LeafCount ↝ 0;
  P.ProbSize ↝ Size;
  P.Length ↝ 0;
END;

Combine: PUBLIC PROCEDURE[Child: LONG POINTER TO ProblemType,
Parent: LONG POINTER TO ProblemType]
RETURNS[Update: BOOLEAN] =
BEGIN
  Parent ↑ .LeafCount ↝ Parent ↑ .LeafCount + Child ↑ .LeafCount;
  Update ↝ FALSE;
END;

NonTrivial: PUBLIC PROCEDURE[P: ProblemType] RETURNS[BOOLEAN] =
BEGIN
  RETURN[P.Length < P.ProbSize - 2];
END;
ApplicInit: PUBLIC PROCEDURE[] =
BEGIN
  WriteString[Title];
  WriteString[" - "];
  NewLine[];
END;

ApplicFinish: PUBLIC PROCEDURE[] =
BEGIN
END;

UseNewInfo: PUBLIC PROCEDURE[P: InfoType] =
BEGIN
END;

AcceptRoot: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  PrintProblem[P];
  PrintAnswer[P];
END;

AcceptAnswer: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  PrintProblem[P];
END;

Update: PUBLIC PROCEDURE[Child: LONG POINTER TO ProblemType,
                          Parent: LONG POINTER TO ProblemType]
          RETURNS[Again: BOOLEAN] =
BEGIN
  Again ← FALSE;
END;

END.
B.2 Application Example 2 (Traveling Salesman Problem)

Part 1 Definition Part -- File name: ApplicDfs.mesa

ApplicDfs: DEFINITIONS =

BEGIN
   MaxProbSize: INTEGER = 20;
   Infinity: REAL = 1.0e30;
   PermArray: TYPE = ARRAY[0..MaxProbSize - 1] OF INTEGER;
   ProblemType: TYPE = RECORD[
      ProbSize: INTEGER,
      Length: INTEGER,
      Perm: PermArray,
      Children: PermArray,
      Cost: REAL,
      LeafCount: LONG INTEGER,
      BestCost: REAL,
      BestPerm: PermArray];
   InfoType: TYPE = RECORD[Estimate: REAL];

   ApplicFinish: PROCEDURE[];
   AcceptRoot: PROCEDURE[P: ProblemType];
   AcceptAnswer: PROCEDURE[P: ProblemType];
   FirstProb: PROCEDURE[Size: INTEGER] RETURNS[P: ProblemType];
   Generate: PROCEDURE[First: BOOLEAN,
                     Parent: LONG POINTER TO ProblemType,
                     Child: LONG POINTER TO ProblemType] RETURNS[Done: BOOLEAN];
   UseNewInfo: PROCEDURE[Info: InfoType];
   NonTrivial: PROCEDURE[P: ProblemType] RETURNS[BOOLEAN];
   Combine: PROCEDURE[Child: LONG POINTER TO ProblemType,
                     Parent: LONG POINTER TO ProblemType] RETURNS[Update: BOOLEAN];
   Update: PROCEDURE[Child: LONG POINTER TO ProblemType,
                      Parent: LONG POINTER TO ProblemType] RETURNS[Again: BOOLEAN];

   ApplicInit: PROCEDURE[];
   PrintProblem: PROCEDURE[P: ProblemType];
   PrintAnswer: PROCEDURE[P: ProblemType];

END.
Part 2 Implementation Part -- File name: ApplicImpl.mesa

DIRECTORY
ApplicDfs,
NodeDfs,
IO,
Real;

ApplicImpl: PROGRAM
IMPORTS NodeDfs,IO,Real
EXPORTS ApplicDfs =

BEGIN
OPEN NodeDfs,ApplicDfs,IO,Real;
InitialDataType: TYPE = ARRAY[0..MaxProbSize 1] OF
   ARRAY[0..MaxProbSize - 1] OF REAL;

   BestInfo: InfoType ← [Infinity];
   Title: LONG STRING ← "Sorted Travel"L;
   InitialData: InitialDataType ←

   [[0.51387,0.17574,0.30865,0.53453,0.94763,0.17174,0.70223,0.22643,0.49477,0.12472,0.08390,0.38965,0.27723,0.36807,0.98344,0.53540,0.76568,0.64647,0.76714,0.78024],
   [0.82295,0.15193,0.62548,0.31468,0.34690,0.91720,0.51976,0.40115,0.60676,0.78540,0.93152,0.86652,0.67452,0.75840,0.58189,0.38925,0.35563,0.20023,0.82693],
   [0.41450,0.46352,0.97916,0.12644,0.21264,0.95845,0.73746,0.40906,0.78011,0.75790,0.95684,0.02810,0.31873,0.75693,0.24299,0.58954,0.04342,0.95602,0.31913,0.05936],
   [0.44188,0.91502,0.57225,0.11884,0.56977,0.25205,0.95845,0.73746,0.40906,0.78011,0.40609,0.87300,0.42696,0.35822,0.38199,0.04318,0.16059,0.52235,0.69658,0.09710,0.40085],
   [0.77343,0.24483,0.34282,0.22999,0.29788,0.30455,0.88721,0.03667,0.65115,0.39861,0.67630,0.73258,0.93780,0.23328,0.83848,0.96721,0.77864,0.43152,0.67410,0.80936],
   [0.15877,0.27990,0.13532,0.86419,0.75018,0.20800,0.13996,0.29459,0.80281,0.21893,0.56308,0.71560,0.19754,0.98982,0.25004,0.43061,0.75527,0.86093,0.89478,0.97809],
   [0.39541,0.43220,0.12714,0.45767,0.23783,0.98603,0.65283,0.60425,0.24191,
0.00994, 0.38707, 0.47714, 0.19295, 0.50789, 0.77501, 0.35440, 0.69776, 0.91279, 0.67096, 0.70578,

[0.42689, 0.02091, 0.21296, 0.94759, 0.50282, 0.19426, 0.64472, 0.12799, 0.26495, 0.33603, 0.70369, 0.03814, 0.95359, 0.75474, 0.87435, 0.63400, 0.24353, 0.63580, 0.85049, 0.23738],

[0.72095, 0.33922, 0.05023, 0.48501, 0.89747, 0.24299, 0.52751, 0.49445, 0.85505, 0.34589, 0.12384, 0.21552, 0.11548, 0.36322, 0.20400, 0.43607, 0.82828, 0.50973, 0.81951, 0.41071];

PrintChildren: PROCEDURE[P: ProblemType] =
BEGIN
  Seq: INTEGER ← 0;

  {OPEN P;
   WriteChar('{};
   WHILE Seq < ProbSize - Length
     DO
       WriteDecimal[Children[Seq]];
       WriteString(" ", L];
       Seq ← Seq + 1;
       ENDLOOP;
   WriteString{" } "L];
  END;

PrintProblem: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  Seq: INTEGER ← 0;

  {OPEN P;
   WHILE Seq < Length
     DO
       WriteChar(' ];
       WriteDecimal[Perm[Seq]];
       Seq ← Seq + 1;
     ENDLOOP;
   WriteString(" (L];
   WriteFloat[Cost];
   WriteString(" )L];
   IF LeafCount > 0 THEN
     {WriteString", "L];
     WriteLongDecimal[LeafCount];
     WriteString(" Leaves "L])};
   PrintChildren[P];
  END;

SortChildren: PROCEDURE[Ptr: LONG POINTER TO ProblemType] =
BEGIN
  PrevNode: INTEGER;
  ThisChild: INTEGER;
ThisDistance: REAL;
Seq, Seq1: INTEGER;

{OPEN Ptr ↑;
  PrevNode ← Perm[Length 1];
  Seq ← 1;
  WHILE Seq ≤ ProbSize - Length - 1
    DO
      ThisChild ← Children[Seq];
      ThisDistance ← InitialData[PrevNode][ThisChild];
      Seq1 ← Seq - 1;
      WHILE (Seq1 > -1) AND
        (FComp[ThisDistance, InitialData[PrevNode][Children[Seq1]]] = -1)
        DO
          Children[Seq1 + 1] ← Children[Seq1];
          Seq1 ← Seq1 - 1;
        ENDLOOP;
      Children[Seq1 + 1] ← ThisChild;
      Seq ← Seq + 1;
    ENDLOOP;
  END;

Generate: PUBLIC PROCEDURE[First: BOOLEAN,
                           Parent: LONG POINTER TO ProblemType,
                           Child: LONG POINTER TO ProblemType]
                     RETURNS[Done: BOOLEAN] =

BEGIN
  Seq: INTEGER;
  OldNext: INTEGER;

  IF Parent ↑ .Length = Parent ↑ .ProbSize THEN
    {OPEN Parent ↑;
      Length ← Length + 1;
      Perm[Length - 1] ← 0;
      Cost ← FAdd[Cost, InitialData[Perm[Length-2]][Perm[Length-1]]];
      IF FComp[Cost, BestInfo.Estimate] = -1 THEN
        {BestInfo.Estimate ← Cost;
         BestCost ← Cost;
         BestPerm ← Perm;
         ReportResult[Parent ↑ ];
         BroadcastInfo[BestInfo]}
      ELSE BestCost ← Infinity;
      Length ← Length - 1;
      Done ← TRUE;
      LeafCount ← 1}
  ELSE { -- not a leaf
    Done ← FALSE;
    IF First THEN
      {Child ↑ ← Parent ↑;
       Child ↑ .Length ← Child ↑ .Length + 1};
      {OPEN Child ↑;
       Children ← Parent ↑ .Children;
       IF First THEN
        Seq ← 0
ELSE {
    OldNext ← Perm[Length - 1];
    Seq ← 0;
    WHILE Children[Seq] ≠ OldNext
        DO
            Seq ← Seq + 1;
            ENDLOOP;
    Seq ← Seq + 1;
    Perm ← Parent ↑ .Perm;
    DO
        IF Seq = ProbSize - Length + 1 THEN
            {Done ← TRUE;
                 EXIT};
        Perm[Length - 1] ← Children[Seq];
        Cost ← FAdd[Parent ↑ .Cost,
                     InitialData[Perm[Length - 2]][Perm[Length - 1]]];
        IF FComp[Cost, BestInfo.Estimate] = -1 THEN
            EXIT;
        Seq ← Seq + 1;
        ENDLOOP;
    WHILE Seq < ProbSize - Length + 1
        DO
            Children[Seq] ← Children[Seq + 1];
            Seq ← Seq + 1;
            ENDLOOP};
    IF NOT Done THEN
        {SortChildren[Child];
         Child ↑ .LeafCount ← 0}];
    END;
}

UseNewInfo: PUBLIC PROCEDURE[Info: InfoType] =
BEGIN
    IF FComp[Info.Estimate, BestInfo.Estimate] = 1 THEN
        BestInfo.Estimate ← Info.Estimate;
    END;
END;

FirstProb: PUBLIC PROCEDURE[Size: INTEGER] RETURNS[P: ProblemType] =
BEGIN
    Seq: INTEGER ← 0;

    {OPEN P;
     LeafCount ← 0;
     ProbSize ← Size;
     Length ← 1;
     Perm[0] ← 0;
     Cost ← 0.0;
     BestCost ← Infinity;
     WHILE Seq < ProbSize
         DO
             Children[Seq] ← Seq + 1;
             Seq ← Seq + 1;
             ENDLOOP};
    SortChildren[@P];
    END;
Combine: PUBLIC PROCEDURE[Child: LONG POINTER TO ProblemType, 
Parent: LONG POINTER TO ProblemType] 
RETURNS[Update: BOOLEAN] =

BEGIN
  OPEN Parent ↑;
  LeafCount ← LeafCount + Child ↑.LeafCount;
  IF FComp[Child ↑.BestCost, BestCost] = -1 THEN
    {BestCost ← Child ↑.BestCost;
     BestPerm ← Child ↑.BestPerm};
  Update ← FALSE;
END;

NonTrivial: PUBLIC PROCEDURE[P: ProblemType] RETURNS[BOOLEAN] =
BEGIN
  RETURN[P.ProbSize - P.Length > 2];
END;

ApplicInit: PUBLIC PROCEDURE[] =
BEGIN
  WriteString[Title];
  WriteString(" ");
  NewLine[];
  BestInfo.Estimate ← Infinity;
  InitReals[];
END;

ApplicFinish: PUBLIC PROCEDURE[] =
BEGIN
END;

AcceptRoot: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  Seq: INTEGER ← 0;

  WriteString("Best path ");
  {OPEN P;
   WHILE Seq < ProbSize
     DO
     WriteString(" ");
     WriteDecimal[BestPerm[Seq]];
     Seq ← Seq + 1;
   ENDLOOP;
  WriteString(" ");
  WriteFloat[BestCost];
  WriteString(" ");
  WriteLongDecimal[LeafCount];
  WriteString(" Leaves Searched");
  NewLine[]};
END;

AcceptAnswer: PUBLIC PROCEDURE[P: ProblemType] =
BEGIN
  Seq: INTEGER ← 0;
WriteString["New Path "L];
{OPEN P;
WHILE Seq < Length
  DO
    WriteString[" "L];
    WriteDecimal[Perm[Seq]];  
    Seq ← Seq + 1;
  ENDLOOP;
  WriteString[" ("L];
  WriteFloat[Cost];
  WriteString[" )"L];
  NewLine[]};

END;

Update: PUBLIC PROCEDURE[Child: LONG POINTER TO ProblemType,
    Parent: LONG POINTER TO ProblemType]
    RETURNS[Again: BOOLEAN] =

BEGIN
  Again ← FALSE;
END;

PrintAnswer: PUBLIC PROCEDURE[P: ProblemType] =

BEGIN
END;

END.
### Appendix C: Execution Results

#### C.1 Queens Problem Results

<table>
<thead>
<tr>
<th>Queens</th>
<th>Execution Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 4</td>
<td>3164275 25713864</td>
</tr>
<tr>
<td>2413</td>
<td>3572461 25741863</td>
</tr>
<tr>
<td>3142</td>
<td>3625147 26174835</td>
</tr>
<tr>
<td>- 5</td>
<td>3724615 26831475</td>
</tr>
<tr>
<td>13524</td>
<td>4136275 27581463</td>
</tr>
<tr>
<td>14253</td>
<td>4152637 28613574</td>
</tr>
<tr>
<td>24135</td>
<td>4275316 31758246</td>
</tr>
<tr>
<td>25314</td>
<td>4613572 35281746</td>
</tr>
<tr>
<td>31425</td>
<td>4736251 35286471</td>
</tr>
<tr>
<td>35241</td>
<td>4752613 35714286</td>
</tr>
<tr>
<td>41352</td>
<td>5147362 35841726</td>
</tr>
<tr>
<td>42531</td>
<td>5164273 36258174</td>
</tr>
<tr>
<td>52413</td>
<td>5263741 36271485</td>
</tr>
<tr>
<td>53142</td>
<td>5316427 36275184</td>
</tr>
<tr>
<td>- 6</td>
<td>5724613 36418572</td>
</tr>
<tr>
<td>246135</td>
<td>5726314 36428571</td>
</tr>
<tr>
<td>362514</td>
<td>6135724 36814752</td>
</tr>
<tr>
<td>415263</td>
<td>6251473 36815724</td>
</tr>
<tr>
<td>531642</td>
<td>6314752 36824175</td>
</tr>
<tr>
<td>- 7</td>
<td>6357142 37285146</td>
</tr>
<tr>
<td>135724</td>
<td>6374152 37286415</td>
</tr>
<tr>
<td>147362</td>
<td>6427531 38471625</td>
</tr>
<tr>
<td>152637</td>
<td>6471352 41582736</td>
</tr>
<tr>
<td>164275</td>
<td>7246135 41586372</td>
</tr>
<tr>
<td>241753</td>
<td>7362514 42586137</td>
</tr>
<tr>
<td>246135</td>
<td>7415263 42736815</td>
</tr>
<tr>
<td>251473</td>
<td>7531642 42736851</td>
</tr>
<tr>
<td>253174</td>
<td>7582463 42751863</td>
</tr>
<tr>
<td>257413</td>
<td>24683175 42857136</td>
</tr>
<tr>
<td>263741</td>
<td>15863724 42861357</td>
</tr>
<tr>
<td>275316</td>
<td>16837425 46152837</td>
</tr>
<tr>
<td>316257</td>
<td>17468253 46827135</td>
</tr>
<tr>
<td></td>
<td>17582463 46831752</td>
</tr>
<tr>
<td></td>
<td>3162574  47185263</td>
</tr>
<tr>
<td></td>
<td>24683175 47382516</td>
</tr>
</tbody>
</table>
C.2 Knights Problem Result

Knights - 3

(1,1) (2,3) (3,1) (1,2) (3,3) (2,1).
(1,1) (3,2) (1,3) (2,1) (3,3) (1,2).

Knights - 4

(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (1,4) (2,2) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (1,4) (2,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (4,1) (2,2) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (4,1) (2,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (2,1) (4,2) (3,4) (2,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (2,1) (4,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (2,1) (1,3) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (3,1) (1,2) (3,3) (2,1) (1,3) (3,4) (2,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (3,4) (4,2) (2,1) (3,3) (1,2) (3,1).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (3,4) (1,3) (2,1) (3,3) (1,2) (3,1).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (4,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (1,3) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (1,3) (3,4) (2,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (4,1) (3,3) (2,1) (4,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (4,1) (3,3) (2,1) (1,3) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (4,1) (3,3) (2,1) (1,3) (3,4) (2,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (4,2) (3,4) (1,3).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (1,3) (3,4) (4,2).
(1,1) (2,3) (4,4) (3,2) (2,4) (4,3) (2,2) (1,4) (3,3) (2,1) (1,3) (3,4) (2,2).
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (4,1) \ (2,2) \ (3,4) \ (1,3).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (4,2) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (4,2) \ (3,4) \ (1,3).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
\[
(1,1) \ (3,2) \ (4,4) \ (2,3) \ (3,1) \ (4,3) \ (2,4) \ (1,2) \ (3,3) \ (2,1) \ (1,3) \ (3,4) \ (2,2).
\]
<table>
<thead>
<tr>
<th>(1,1)</th>
<th>(3,2)</th>
<th>(4,4)</th>
<th>(2,3)</th>
<th>(4,2)</th>
<th>(3,4)</th>
<th>(1,3)</th>
<th>(2,1)</th>
<th>(3,3)</th>
<th>(1,2)</th>
<th>(2,4)</th>
<th>(4,3)</th>
<th>(2,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(3,4)</td>
<td>(1,3)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,2)</td>
<td>(3,1)</td>
<td>(4,3)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(3,4)</td>
<td>(1,3)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,2)</td>
<td>(3,1)</td>
<td>(4,3)</td>
<td>(2,2)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(2,4)</td>
<td>(1,2)</td>
<td>(3,1)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
<tr>
<td>(1,1)</td>
<td>(3,2)</td>
<td>(4,4)</td>
<td>(2,3)</td>
<td>(4,2)</td>
<td>(2,1)</td>
<td>(3,3)</td>
<td>(1,4)</td>
<td>(2,2)</td>
<td>(4,3)</td>
<td>(3,1)</td>
<td>(2,1)</td>
<td>(2,4)</td>
</tr>
</tbody>
</table>
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (4, 1) (2, 2) (4, 3) (2, 4) (1, 2) (3, 1) (2, 3) (4, 2).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1) (2, 3) (4, 2) (3, 4) (2, 2).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (1, 2) (2, 4) (4, 3) (2, 2) (3, 4) (4, 2) (2, 3) (4, 4).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (1, 2) (2, 3) (4, 2) (2, 2) (3, 4) (4, 2) (2, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (1, 2) (3, 1) (4, 2) (2, 3) (4, 2) (2, 3) (4, 4).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 3) (2, 3) (2, 3) (4, 2) (4, 3) (2, 4) (3, 1) (2, 3) (4, 4).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (1, 2) (2, 2) (4, 3) (2, 4) (1, 2) (3, 1) (2, 3) (4, 4).
(1, 1) (3, 2) (1, 3) (2, 1) (3, 1) (4, 2) (2, 3) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).
(1, 1) (3, 2) (1, 3) (2, 1) (4, 2) (3, 4) (2, 2) (1, 4) (3, 3) (1, 2) (2, 4) (4, 3) (3, 1).

336 Leaves.
C.3 Traveling Salesman Problem Results

Sorted Travel - 4
Best path 0 1 2 3 (1.36954)

Sorted Travel - 5
Best path 0 1 4 2 3 (1.43378)

Sorted Travel - 6
Best path 0 1 4 2 3 5 (1.40272)

Sorted Travel - 7
Best path 0 5 6 2 4 1 3 (1.65287)

Sorted Travel - 8
Best path 0 1 4 7 6 2 3 5 (1.57089)

Sorted Travel - 9
Best path 0 1 3 5 2 4 7 6 8 (2.01829)

Sorted Travel - 10
Best path 0 9 8 1 4 7 6 2 3 5 (2.09491)

Sorted Travel - 11
Best path 0 10 1 4 7 6 2 3 5 9 8 (2.3249)

Sorted Travel - 12
Best path 0 10 7 4 1 3 5 9 6 2 11 8 (2.08736)

Sorted Travel - 13
Best path 0 10 5 6 2 11 8 1 3 9 4 7 12 (1.90502)

Sorted Travel - 14
Best path 0 10 1 3 5 9 6 2 11 8 13 4 7 12 (1.87925)
Appendix D: DIB SOURCE CODES

File name: DIBHost.config
DIBHost: CONFIGURATION
   IMPORTS String,Stream,NetworkStream,Heap,Tool,TTYSW,Process,
           TTY, System, Put, Exec, FormSW, AddressTranslation, Format
   CONTROL HInterfaceImpl, HostImpl =

   BEGIN
      HInterfaceImpl;
      RealImpl;
      IOImpl;
      TimeMeasureImpl;
      DeweyImpl;
      ApplicImpl;
      HostImpl;
   END.

File name: DIBNode.config
DIBNode: CONFIGURATION
   IMPORTS String, Stream, NetworkStream, Heap, Tool, TTYSW, Process,
           TTY, System, Put, Exec, FormSW, AddressTranslation,
           Format, Time
   CONTROL NInterfaceImpl, NodeImpl =

   BEGIN
      NInterfaceImpl;
      RealImpl;
      NOIImpl;
      TimeMeasureImpl;
      RandomProg;
      DeweyImpl;
      ApplicImpl;
      NodeImpl;
   END.
File name: DeweyDfs.mesa

DeweyDfs : DEFINITIONS =
BEGIN
MaxDepth : INTEGER = 25; --depth of recursion allowed
Comparison : TYPE = {Smaller, Bigger, Equal, Indeterminate};
Dewey : TYPE = RECORD[
    DNums : ARRAY [1..MaxDepth] OF INTEGER,
    Length : INTEGER];
DeweyCompare : PROCEDURE[A,B : Dewey]
    RETURNS[Answer: Comparison];
DeweySubsumes : PROCEDURE[Higher,Lower: Dewey]
    RETURNS[Answer: BOOLEAN];
PrintDewey : PROCEDURE[D : Dewey];
END. --Dewey

File name: TimemeasureDfs.mesa

DIRECTORY
System USING[GreenwichMeanTime, Pulses];
TimeMeasureDfs: DEFINITIONS =
BEGIN
OPEN System;
TimeMeasure: TYPE = RECORD[
    gmt: GreenwichMeanTime,
    pulses: Pulses];
Millisecs: TYPE = LONG CARDINAL;

Get: PROC[] RETURNS [TimeMeasure];
ElapsedTime: PROC[time: TimeMeasure] RETURNS [Millisecs];
WriteMillisecs: PROC [m: Millisecs];
END.
File name: HInterfaceDfs.mesa

DIRECTORY
    InterfaceDfs;

HInterfaceDfs: DEFINITIONS =
    BEGIN
        OPEN InterfaceDfs;
        GetWindowHandle: PROCEDURE [] RETURNS [DataHandle];
        SetUp: PROCEDURE[partit: INTEGER];
        GetInData: PROCEDURE[] RETURNS[MsgBufferPtr];
        Sender: PROCEDURE[outMsgPtr: MsgBufferPtr];
        ClearInQueue: PROCEDURE[];
        << HostDolt: PROCEDURE[]; >>
    END.

File name: NInterfaceDfs.mesa

DIRECTORY
    InterfaceDfs;

NInterfaceDfs: DEFINITIONS =
    BEGIN
        OPEN InterfaceDfs;
        GetWindowHandle: PROCEDURE [] RETURNS [DataHandle];
        InQueueEmptyCheck: PROCEDURE [] RETURNS [BOOLEAN];
        GetInData: PROCEDURE[] RETURNS[MsgBufferPtr];
        Sender: PROCEDURE[outMsgPtr: MsgBufferPtr];
        ClearInQueue: PROCEDURE[];
    END.
DIRECTORY
DeweyDfs, IO;

END. "– DeweyImpl

DeweyImpl : PROGRAM
IMPORTS IO
EXPORTS DeweyDfs =

BEGIN OPEN DeweyDfs, IO;

PrintDewey : PUBLIC PROCEDURE[D : Dewey] =
BEGIN
Seq : INTEGER;
BEGIN
WriteChar['<'];
OPEN D;
Seq + 1;
WHILE Seq < Length DO
WriteDecimal[DNums[Seq]];
WriteString["."];
Seq + Seq + 1;
ENDLOOP;
WriteString[">"];
END;

DeweyCompare : PUBLIC PROCEDURE[A,B : Dewey] RETURNS[Answer: Comparison] =
<<Equal means identical, Smaller means A is shorter than
B (higher in the tree) or to the left if sibling. >>
BEGIN
Seq : INTEGER;
Answer = Indeterminate;
OPEN A;
SELECT TRUE FROM
Length < B.Length => Answer = Bigger;
Length = B.Length => Answer = Equal;
ENDCASE = >> { = A.Length = B.Length, non-trivial
Seq + 0;
DNums[Length + 1] + 0; = pseudo-data
B.DNums[Length + 1] + 1; = pseudo-data
WHILE Answer = Indeterminate DO
Seq + Seq + 1;
SELECT TRUE FROM
DNums[Seq] < B.DNums[Seq] => Answer = Smaller;
DNums[Seq] > B.DNums[Seq] => Answer = Bigger;
ENDCASE;
ENDLOOP;
IF Seq = Length + 1 THEN
Answer = Equal;
END;

<<return True if the Higher is a prefix of Lower >>
BEGIN
Seq : INTEGER;
Answer = FALSE;
OPEN Higher;
IF Lower.Length <= Lower.Length THEN
BEGIN
Seq + 1;
WHILE Seq <= Lower THEN
DO
DNums[Seq] ≠ Lower.DNums[Seq] EXIT;
Seq + Seq + 1;
ENDLOOP;
Answer = Seq > Length);
END; "– DeweySubsumes
Hinterfaceimpl.MESAT 1 Apr 20 06:13 EST

DIRECTORY
Ascii USING[SP],
(, interfaceDs,
HinterfaceDs,
Exec,
Format,
Form$W,
Tool,
ToolWindow USING [TransitionProcType],
TTY USING[Char$Available, Handler],
TTYUSWUSING[GetTTYHandle],
NetworkStream,
Stream,
System USING[NetworkAddress, nullNetworkAddress],
Process,
Put USING [LongString, NetworkAddress],
String USING[Equal],
Heap USING[systemZone],
Window USING[Handle],
AddressTranslation;
Hinterfaceimpl.MONITOR
IMPORTS String, Stream, NetworkStream, Heap, AddressTranslation, Exec, Format,
Form$W, Tool, Process, Put, IO, TTYSW, TTY < < HinterfaceDs > >
EXPORTS HinterfaceDs =
BEGIN
OPEN interfaceDs, HinterfaceDs, AddressTranslation, IO,
zone: UNCOUNTED ZONE = Heap, systemZone;
data: DataHandle = Nil;
wh Window Handle = Nil;
dataAvailable CONDITION,
receiver: PROCESS = Nil;
< < problemSolver: PROCESS = Nil; > >
FrontinBuffers: MsgBufferPtr = Nil;
RearinBuffers: MsgBufferPtr = Nil;
AllNodeInList: ARRAY[1, 14] OF NodeData = ALL, [Nil, System, nullNetworkAddress],
NodeInUse: NodeInUseType = ALL, [System, nullNetworkAddress],

-- Command from Form Subwindow
Assert: Form$W.ProcType = (ProcessDetach(FOUR, DOAssert));
DOAssert: PROCEDURE() =
BEGIN
  if receiver # NIL THEN
    (Process: Abort(receiver);
     JOIN receiver;
     receiver = Nil;
    ) < < if problem Solver: # NIL THEN
      (Process: Abort(problemSolver);
       JOIN problem Solver;
       problem Solver = Nil;
      ) > >
data address + Find(data myName),
Put.LongString(data msg$W, data myName);
Put.LongString(data msg$W, " ");
if data address # System, nullNetworkAddress THEN
  (Put.NetworkAddress(data msg$W, data address, octal);
   receiver = FORK Receiver)
else
  PUT.LongString(data msg$W, "This workstation can not be used. Please check the user manual.");
END;

-- Executive interface procedures
WindowInit PROCEDURE() =
BEGIN
  wh + Tool Create
make5WSProc: Make5WS, initialState: default,
clientTransition: ClientTransition, name: "DIBHost",
cmSection: "DIBHost";
END:
Null: Exec: ExecProc =
  (Format:Line (Exec: OutputProc(h),
    "A nothing burger.in"));
Help: Exec: ExecProc =
  (Format:Line (Exec: OutputProc(h),
    "Use Y DIBHost... to unload the tool."));
Unload: Exec: ExecProc =
  (Exec: RemoveCommand(h, "DIBHost... ");
   if wh # NIL THEN
     Tool: Destroy(wh)
   ELSE Format:Line
     (Exec: OutputProc(h), "No DIBHost tool to delete.");

-- Tool interface procedures
ClientTransition: ToolWindow.TransitionProcType =
  SELECT TRUE FROM
    old = inactive =>
      if data # NIL THEN data + zone.NEW(Data + []),
    new = inactive =>
      if receiver # NIL THEN
        (Process: Abort(receiver);
         JOIN receiver;
         receiver = Nil;
        ) < < if problem Solver: # NIL THEN
          (Process: Abort(problem Solver);
           JOIN problem Solver;
           problem Solver = Nil;
          ) > >
      if data # nil THEN zone.FREE(@data));
ENDCASE;

Make5WS. Tool: Make5WSProc =
  (root: LONG STRING = "DIBHost Log");
logName: LONG STRING = "DIBHost Log.XXX";
data.msg$W + Tool: Make5WSWindow: window, lines, 4, 48;
data.msg$W + Tool: Make5WSWindow: window, window, lines, 4, 48;
window, formProc: MakeForm;
Tool: Unused globalization(unused, logName, root: root);
data msg$W = Tool: MakeTTYS]
window, window, name: logName, h: 96),

MakeForm: Form$W: ClientItemsProcType =
  OPEN Form$W;
nitens: CARDINAL = (Form: Items: LAST: ORD + Form: Items: FIRST: ORD) + 1;
items = AllocatItemDescriptor(nitens);
items[Form: Items: assert: ORD] = CommandItem
  tag: "Assert", place: [6, line], proc: Assert;
items[Form: Items: iam: ORD] = StringItem
  tag: "1", type: [66, line], string: @data.myName);
RETURN(items: items, freeDesc: TRUE)

GetWindowHandle: PUBLIC PROCEDURE() RETURNS(DataHandle) =
BEGIN
RETURN(data);
END;

GetInData: PUBLIC ENTRY PROCEDURE() RETURNS(MsgBufferPtr) =
BEGIN
  tmpPtr. MsgBufferPtr = Nil.
WHILE FrontinBuffers = Nil OR FrontinBuffers: status = 0 DO
  WAIT dataAvailable,
  ENDLOOP;
  tmpPtr. FrontinBuffers;
  FrontinBuffers + FrontinBuffers: next,
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = NIL THEN
    RearinBuffers + FrontinBuffers;
  IF FrontinBuffers = N
RETURN([tmpPtr];
ENO;

ClearinQueue: PUBLIC PROCEDURE] =
BEGIN
next: MsgBufferPtr = NIL;
WHILE FrontinBuffers ≠ NIL DO
next ← FrontinBuffers;
FrontinBuffers ← FrontinBuffers↑next;
zone.FREE[next];
ENDLOOP;
RearinBuffers ← FrontinBuffers;
ENO;

StoreinData: ENTRY PROCEDURE(tmpPtr: MsgBufferPtr] =
BEGIN
IF FrontinBuffers ≠ NIL THEN
{"FrontinBuffers ← tmpPtr;
RearinBuffers ← FrontinBuffers}
ELSE {RearinBuffers↑next ← tmpPtr;
RearinBuffers ← tmpPtr};
RearinBuffers↑status = 1;
NOTIFY dataAvailable;
END;

SetUp: PUBLIC PROCEDURE(partid: INTEGER] =
BEGIN
tty: TTY.Handle ← TTYSW.GetTTYHandle(data ttySw);
realMsg: MACHINE DEPENDENT RECORD {
length, maxlength: CARDINAL;
text: PACKED ARRAY[0, 10] OF CHARACTER] ←
[0, 10, ALL[AscI, 52]];
nodeName: LONG STRING ← LOOPHOLE[LONG][realMsg]];
stream: Stream.Handle ← NIL;
Seq: INTEGER;
b: MACHINE DEPENDENT RECORD {
prefix: PACKED ARRAY[0, 0] OF Stream.Byte,
mcnum: INTEGER,
usedNode: NodeUseType};

Seq ← 0;
WHILE Seq < = partid DO
WriteString("Please input the name of each node - first is the Host ");
NewLine();
WHILE TTY.ChasAvailable(tty) = 0 DO
Process.Pause[25]
ENDLOOP;
nodeName.length ← 0;
ReadLine[ nodeName];
NodeUse[Seq] ← Find [nodeName];
Seq ← Seq + 1;
ENDLOOP;
Seq ← 1;
WHILE Seq < = partid DO
ENABLE
NetworkStream.ConnectionFailed, 
NetworkStream.ConnectionSuspended = > {
IF stream # NIL THEN
{stream.delete[stream];
stream ← NIL};
WriteString("Sender = ConnectionFailed or 
ConnectionSuspended.RETRY...");
WriteDecimal[outMsgPtr↑dest];
NewLine[];
RETRY};
END: 
stream ← NetworkStream.Create[
remote: NodeUse[outMsgPtr↑dest],
timeout: 200000,
classOfService: transactional];
Stream.SetInputOptions[stream, [terminateOnEndRecord: TRUE]]; 
Stream.PutBlock[
sh: stream,
block: {[outMsgPtr↑prefix,
0, BytesInMsgBuffer]},
endRecord: TRUE];
IF NetworkStream.Close[stream] # good THEN 
SIGNAL Retry,

b.mcnum ← Seq;
b.usedNode ← NodeUse;
Stream.SetSST[stream, NodeNameSST];
Stream.PutBlock[
sh: stream,
block: {[b.mcnum, BytesInNodeUse]},
endRecord: TRUE];
stream.deleteStream();
stream = nil;
zone.FREE@OutMsgPtr;
END;
END;

Receiver: PROCEDURE[] =
BEGIN
stream: StreamHandle = nil;
listener: NetworkStream.ListenHandle =
    NetworkStream.CreateListener(data.address);
DO
    ENABLE BEGIN
        ABOarded = > EXIT;
        NetworkStream.ConnectionFailed,
            NetworkStream.ConnectionFailed = > {
                if stream # nil THEN
                    (stream.deleteStream);
                    stream = nil;
                    WriteString("Receiver - ConnectionFailed or Connection Suspended, LOOP ");
                    LOOP);
                END
                (sIGNAL ENAbled);
            [1] = > NetworkStream.Listen(listenerH: listener);
            stream = NetworkStream.ApproveConnection
                listenerH: listener,
                classOfService: transactional);
            Process.DetachFORK(Receiveinstance(stream)),
            ENdLoOP;
            NetworkStream.DeleteListener(listener ! ABOarded = > CONTINUE);
            END;

Receiveinstance: PROCEDURE [stream: StreamHandle] =
BEGIN
tmpPtr: MsgBufferPtr = nil;
EmptyBlock: MACHINE DEPENDENT RECORD
    prefix: PACKED ARRAY [0..0] OF StreamByte
    pseudo: MsgBuffer;
    size: CARDINAL = 0;
why: StreamCompletionCode + normal;
sst, dummy: Stream.SubSequenceType = 0;
BEGIN
    ENABLE BEGIN
        NetworkStream.ConnectionFailed,
            NetworkStream.ConnectionFailed = > {
                if stream # nil THEN
                    (stream.deleteStream);
                    stream = nil;
                    WriteString("Receiver - ConnectionFailed or Connection Suspended,
                        CONTINUE ");
                    CONTINUE);
                END;
                stream.setTimeout(H: stream, waitTime: 200000);
                Stream.SetInputOptions(stream, [terminateOnEndRecord: TRUE],
                    tmpPtr = zone.NEW(MsgBuffer),
                    size = 0; dummy = 0; why = sstChange,
                    WHILE size = 0 DO
                        if why = sstChange THEN sst = dummy,
                            [size, why, dummy] = Stream.GetBlock
                                stream, [tmpPtr => prefix, 0, bytesInMsgBuffer]
                                | Stream_TIMEOUT = > RESUME]
                        ENDLOOP;
                    IF (why # endRecord) OR (size < bytesInMsgBuffer) THEN
                        (zone.FREE[tmpPtr],
                        GO TO EXIT);
                        StoreInData[tmpPtr],
                    [size, why, sst] = Stream.GetBlock
                        stream,
                        [@EmptyBlock.prefix, bytesInMsgBuffer]
                        | Stream_TIMEOUT = > RESUME]
                    IF (size = 0) OR (sst # NetworkStream.closeSST) THEN
                        GO TO Exit;
                    IF NetworkStream.CloseReply(stream) # good THEN
                        GO TO exit;
                    EXITs Exit = > NULL;
                    END;
                    IF stream # nil THEN
                        (stream.deleteStream);
                        stream = nil;
                        END;
                    = = main
                    Exec.AddCommand(name: "DBHost = ",
                        proc: null, help: Help, unload: Unload);
                    WindowInit();
                    Process.EnableAborts(dataAvailable);
                    AllNodeList[1].name = "ALVIS",
                    AllNodeList[1].addr =
                        StringToNetworkAddress("5772.25200121351.71525", nil, nil, addr);
                    AllNodeList[2].name = "Lit",
                    AllNodeList[2].addr =
                        StringToNetworkAddress("5772.25200121602.16756", nil, nil, addr);
                    AllNodeList[3].name = "FJALAR",
                    AllNodeList[3].addr =
                        StringToNetworkAddress("5772.25200121213.13160", nil, nil, addr);
                    AllNodeList[4].name = "ANDVARU",
                    AllNodeList[4].addr =
                        StringToNetworkAddress("5771.25200122706.22011", nil, nil, addr);
                    AllNodeList[5].name = "GALAR",
                    AllNodeList[5].addr =
                        StringToNetworkAddress("5771.25200121527.120223", nil, nil, addr);
                    AllNodeList[6].name = "BROKK",
                    AllNodeList[6].addr =
                        StringToNetworkAddress("5771.25200115272.26065", nil, nil, addr);
                    AllNodeList[7].name = "MODSOGNIR",
                    AllNodeList[7].addr =
                        StringToNetworkAddress("5771.25200120764.65150", nil, nil, addr);
                    AllNodeList[8].name = "DURIN",
                    AllNodeList[8].addr =
                        StringToNetworkAddress("5771.25200113474.50653", nil, nil, addr);
                    AllNodeList[9].name = "EITIR",
                    AllNodeList[9].addr =
                        StringToNetworkAddress("5771.25200123657.35367", nil, nil, addr);
HOSTDOFS: DEFINITIONS =
BEGIN
MaxProbSize: INTEGER = 20;
MaxRedundancy: INTEGER = 5;
TimeMeasures: INTEGER = 4;
CommTime: INTEGER = 0;
TossTime: INTEGER = 1;
TermTime: INTEGER = 2;
IdleTime: INTEGER = 3;
AnswerSpecification: TYPE = {Full, Count};
StatusSpecification: TYPE = {BatchDone, AnAnswer, Quitting, Reporting, PleaseStop};
TimeType: TYPE = ARRAY[0..TimeMeasures + MaxRedundancy] OF TimeMeasureDS.Milliseconds,
< < calculating waiting for work/helping peer, printing messages on console, waiting for termination message. > >
MessageType: TYPE = {Request, Work, GlobalInfo, Result, Terminate, Synch, Repeating, Updating};
MessageClass: TYPE = {AnswerMessage, ProblemMessage, InterNodeMessage};
Message: TYPE = RECORD
specifies: SELECT type: MessageClass FROM
AnswerMessage = [ ]
Status: StatusSpecification,
Prob: ApplDOFs.ProblemType,
Times: TimeType,
Sequence: LONG INTEGER,
AnswerDewey: DeweyDOFs.Dewey),
ProblemMessage = [ ]
Kind: INTEGER, -- 0 means no work; 1 means here is a problem
Answer: AnswerSpecification,
Prob: ApplDOFs.ProblemType,
PartSize: INTEGER, -- partition size
WorkFraction: INTEGER, < < how much to give away when asked;
0 means give away none; 10 means give away all work; negative means give away one problem (if possible) > >
NumHelp: INTEGER, -- how many to ask when out of work
DebugLevel: INTEGER, < < higher numbers are more verbose; 0 is silent > >
InterNodeMessage = [ ]
Kind: MessageType,
Asker: INTEGER,
Child: ApplDOFs.ProblemType,
ChildDewey: DeweyDOFs.Dewey,
Count: INTEGER,
SomeInfo: ApplDOFs.InfoType,
Redundancy: INTEGER),
ENDCASE;}
END. -- HOSTDOFS
WriteString(" Total ");
PrintRow[AllTotal];
NewLine[];
  — AllTotal + AllTotal / PartitionSize
Category += 0;
WHILE Category <= TimeMeasures + MaxRedundancy
  DO
    AllTotal.Time[Category] += AllTotal.Time[Category] / PartitionSize;
    Category += Category + 1;
  ENDLOOP;
WriteString(" Average ");
PrintRow[AllTotal];
NewLine[]; NewLine[];
END; — PrintStats

HWaitDone: PROCEDURE[TM: TimeMeasure]
  RETURNS[Who: INTEGER, Timeused: MilliSecs]
  =
  < < wait until a child says it's finished, and return who said that > >
BEGIN
  Done: BOOLEAN = FALSE;
inMsgPtr: MsgBufferPtr = Nil;
WHILE NOT Done
  DO
    inMsgPtr += GetInputData[];
    Who = inMsgPtr t source;
    WITH a: inMsgPtr t .message SELECT FROM
      AnswerMessage = > (
        IF (Who NOT IN [1..7]) OR
          a.Sequence # AllStats[Who].Sequence THEN
            (WriteString("bad from ");
              WriteDecimal[Who];
              WriteString(" type ");
              WriteDecimal[LOOPHOLE[a.Status]];
              WriteString(" expected ");
              WriteLongDecimal[AllStats[Who].Sequence];
              WriteString(" got ");
              WriteLongDecimal[Sequence];
              NewLine[])
          ELSE
            (AllStats[Who].Sequence += AllStats[Who].Sequence + 1;
             SELECT a Status FROM
             PleaseStop = > (Done = TRUE;
               ApplyFinish[])
             BatchDone = > (IF Debug >= 1 THEN
               (WriteChar[".
                 WriteDecimal[Who];
                 WriteChar["
                 WriteLongDecimal[a.Times[CommTime]];
                 WriteString("") ");
                 AcceptRoot[{
                 Reporting = > (IF Debug >= 1 THEN
                   (WriteChar[".
                     WriteDecimal[Who];
                     WriteString(" ");
                     PrintDewey[AnswerDewey],
                     NewLine[]));
                   AnAnswer = > AcceptAnswer[{
                   Quitting = > (IF Who = 1 THEN
                     Timeused = ElapsedTime[TM];
                     if Debug >= 1 THEN
                       (WriteChar[".
                         WriteDecimal[Who];
                         WriteChar["
                         WriteLongDecimal[a.Times[CommTime]],
                         WriteChar["
                         AllStats[Who].Time += a.Times;
ENDCASE});
ENDCASE;
zone FREE[]inMsgPtr];
IF Done THEN EXIT.

ENDLOOP;
END; — HWaitDone

HostPort: PROCEDURE[] =
BEGIN
  Size: INTEGER;
  FProb: ProblemType;
  Who: INTEGER;
  BeginTime: TimeMeasure;
  Timeused: MilliSecs;
  ch: CHARACTER;
BEGIN
  ENABLE
  ABORTED = > CONTINUE;
END;
WHILE data = NIL
  DO
    ProcessPause[30];
    data += GetWindowHandle[];
    ENDLOOP;
    WriteString("Please input Node Number ";
    NewLine[];
    PartitionSize += ReadDecimal[];
    NewLine[];
    Setup[PartitionSize];
    NewLine[];
    DO
      ENABLE
        JobStopped = > EXIT;
      END;
      WriteString("c: count reporting, not every answer ";
        NewLine[];
        WriteString("d: set debug level ";
        NewLine[];
        WriteString("f: full reporting of every answer ";
        NewLine[];
        WriteString("h: set number of helpers when out of work "");
        NewLine[];
        WriteString("n: new problem ");
        NewLine[];
        WriteString("q: quit ");
        NewLine[];
        WriteString("r: Input Selection. ");
        NewLine[];
        ch = ReadChar[];
        NewLine[];
        IF (ch = "c") AND (ch = "n") THEN EXIT;
        ENDLOOP;
SELECT ch FROM
  "q = > SIGNAL. JobStopped;
  "f = > Style = Full;
  "d = > {WriteString("Debug level ( ");
    WriteDecimal[Debug];
    WriteString(" ) = "];
    Debug += ReadDecimal[];
    NewLine[]};
  "h = > {WriteString("New number of helpers ( ");
    WriteDecimal[NUMHelpers];
    WriteString(" ) = "];
    NUMHelpers += ReadDecimal[];
    NewLine[]};
  "c = > Style = Count;
  "n = > {Application[];
    WriteString("Please input Problem Size ");
    NewLine[];
    Size += ReadDecimal[];
    NewLine[];
    FProb = FirstProb[Size];
    HSendProblem[@FProb, Style];
    ClearStats[];
END; — HWaitDone
BEGIN
FormItems: TYPE = {assert, iam};
DataHandle: TYPE = LONG POINTER TO Data;
Data: TYPE = RECORD [
  msgSW: Window.Handle ← NIL,
  formSW: Window.Handle ← NIL,
  ttySW: Window.Handle ← NIL,
  address: System.NetworkAddress ← System nullNetworkAddress,
  nodeNumber: INTEGER ← 0,
  myName: LONG STRING ← NIL],
MsgBufferPtr: TYPE = LONG POINTER TO MsgBuffer;
MsgBuffer: TYPE = MACHINE DEPENDENT RECORD[
  prefix: PACKED ARRAY [0..0] OF Stream.Byte,
  status: INTEGER ← 0,
  source: INTEGER,
  dest: INTEGER,
  message: HostDfs.Message,
  next: MsgBufferPtr ← NIL],
NodeData: TYPE = RECORD [
  name: LONG STRING,
  addr: System.NetworkAddress,
  NodeinUseType: TYPE = ARRAY[0..13] OF System.NetworkAddress;
BytesInMsgBuffer: CARDINAL = 2 * SIZE[MsgBuffer],
BytesInNodeInUse: CARDINAL = 2 * SIZE[NodeinUseType],
NodeNameSST, Stream.SubSequenceType = 1,
MessageSST : Stream.SubSequenceType = 2,
END.
IO: DEFINITIONS =

BEGIN

SetEcho: PROCEDURE [new: BOOLEAN] RETURNS [old: BOOLEAN];
«SetEcho changes whether or not you want to echo characters for the
string — line — oriented Read procedures. The value returned is the
state of echoing.»

ReadChar: PROCEDURE [i] RETURNS [CHARACTER];
«ReadChar returns the next character typed by the user in this
little window.»

ReadLine: PROCEDURE [s: LONG STRING];

Rубут: SIGNAL [];
«Rубут indicates that the user typed the DEL/RUBOUT key
during execution of ReadEditedString, ReadID, or ReadLine.»

LineOverflow: SIGNAL [s: LONG STRING] RETURNS [ns: LONG STRING];
«LineOverflow indicates that the string supplied to
ReadEditedString, ReadID, or ReadLine was not sufficiently
long to hold the characters received. A longer string
(with contents of old's copied in) is typically returned.»

ReadDecimal: PROCEDURE [i] RETURNS [INTEGER];
«ReadDecimal uses ReadID to get a string, and tries to convert
it to an integer, assuming the string is a signed decimal
number. If this conversion fails, the SIGNAL
StringInvalidNumber
is raised.»

WriteChar: PROCEDURE [c: CHARACTER];
«WriteChar prints the character at the cursor position in this
little window.»

WriteString: PROCEDURE [s: LONG STRING];
«WriteString prints the string at the cursor position in this
little window.»

WriteDecimal: PROCEDURE [n: INTEGER];
«WriteDecimal prints the given integer as a decimal number,
written as characters.»

WriteLongDecimal: PROCEDURE [n: LONG INTEGER];

WriteFloat: PROCEDURE [n: REAL];

NewLine: PROCEDURE [];
«NewLine prints a new — line character»

END. — IO
DIRECTORY
   IO, Interface6Fs, Hinterface6Fs,
   Real,
TTY USING [Handle, SetEcho, GetChar, GetLine, LineOverflow, Rubout, GetDecimal,
   PutChar, PutString, PutDecimal, PutLongDecimal, PutCR],
   TTY$W USING|GetTTYHandle|;

IoImpl: PROGRAM
IMPORTS TTY, TTY$W, Real, Interface6Fs
EXPORTS IO =
BEGIN
   data: Interface6Fs, DataHandle <- Nil;
   ttyWindow: TTY.Handle;
   SetEcho: PUBLIC PROCEDURE [new: BOOLEAN] RETURNS [old: BOOLEAN] =
      BEGIN
         old <- SELECT TTY SetEcho[h:ttyWindow, new: IF new THEN plain ELSE none] FROM
         plain = > TRUE, END CASE = > ERROR
      END «SetEcho»;
   ReadChar: PUBLIC PROCEDURE [] RETURNS [CHARACTER] =
      {RETURN|TTY.GetChar|ttyWindow|};
   ReadLine: PUBLIC PROCEDURE [s: LONG STRING] =
      BEGIN
         TTY.GetLine|ttyWindow, s |
         TTY.LineOverflow = >
         {RESUME|SIGNAL|LineOverflow|s|};
         TTY.Rubout = >
         {SIGNAL|Rubout|};
         RESUME
      END |
   Rubout: PUBLIC SIGNAL [] = CODE;
   ReadDecimal: PUBLIC PROCEDURE [] RETURNS [INTEGER] =
      BEGIN
         RETURN|TTY.GetDecimal|ttyWindow |
         TTY.LineOverflow = >
         {RESUME|SIGNAL|LineOverflow|s|};
         TTY.Rubout = >
         {SIGNAL|Rubout|};
         RESUME
      END |
   WriteChar: PUBLIC PROCEDURE [c: CHARACTER] = {TTY.PutChar|ttyWindow, c|};
   WriteString: PUBLIC PROCEDURE [s: LONG STRING] =
      {TTY.PutString|ttyWindow, s|};
   WriteDecimal: PUBLIC PROCEDURE [n: INTEGER] =
      {TTY.PutDecimal|ttyWindow, n|};
   WriteLongDecimal: PUBLIC PROCEDURE [n: LONG INTEGER] =
      {TTY.PutLongDecimal|ttyWindow, n|};
   WriteFloat: PUBLIC PROCEDURE [n: REAL] =
      {Real|WriteReal|WriteChar|n, Real Default Single Precision, FALSE|};
   NewLine: PUBLIC PROCEDURE [] = {TTY.PutCR|ttyWindow|};
END «IoImpl».

Unload: Exec.ExecProc = {
   Exec.RemoveCommand(h, "DiBNode --");
   if wh # NIL THEN
      Tool.Destroy(h)
      ELSE Format.Line
         [Exec.OutputProc(h), "No DiBNode tool to delete."];
   END;
}

Tool interface procedures

ClientTransition: ToolWindow.TransitionProcType = {
   SELECT TRUE FROM
      old = inactive = >
      if data = NIL THEN data += zone.NEW[data + []];
      new = inactive = >
      if receiver # NIL THEN {
         p: PROCESS = receiver;
         Process.Aert(p);
         JOIN p;
      }
      if data # NIL THEN zone.FREE[data];
   ENDCASE;

   MakeSW: Tool.MakeSWProc = {
      root: LONG STRING = "DiBNode log";
      logName: LONG STRING = "DiBNode.logXX";
      data.msgSw = Tool.MakeMsgSw(window, window, lives, 4, h: 48);
      data.formSw = Tool.MakeFormSw(window, window, formProc: MakeForm);
      Tool.Unused.LogName(unused: logName, root: root);
      data.ttySw = Tool.MakeTTSySw(window, window, name: logName, h: 96);
      < <sender + FORK Sender][ ] > > ;
   }

   MakeForm: FormSw.ClientItemsProcType = {
      OPEN FormSw;
      items: CARDINAL = [FormItems.LAST ORD - FormItems.FIRST ORD] + 1;
      items = AllocateItemDescriptor[items];
      items.items[FormItems.INSERT ORD] = CommandItem;
      tag: "Assist", place: [6, line0], proc: Assert;
      items.items[FormItems.LAM ORD] = StringItem;
      tag: "I am", inHeap: TRUE, place: [66, line0],
      string: @data.myName;
      RETURN(items: items, freeDesc: TRUE);
   }

   GetWindowHandle: PUBLIC PROCEDURE[] RETURNS[dataHandle] = BEGIN
      RETURN[data];
   END;

   InQueueEmptyCheck: PUBLIC PROCEDURE[] RETURNS[Boolean] = BEGIN
      if FrontInBuffers = NIL THEN
         receiver + FORK Receiver[]
      ELSE RETURN(FALSE); END;
   END;

   GetData: PUBLIC ENTRY PROCEDURE[] RETURNS[MsgBufferPtr] = BEGIN
      tmpPtr: MsgBufferPtr = NIL;
      WHILE FrontInBuffers = NIL OR FrontInBuffers * status = 0 DO
         WAIT dataAvailable;
         ENDLOOP;
         tmpPtr = FrontInBuffers;
         FrontInBuffers + FrontInBuffers * .next;
         if FrontInBuffers = NIL THEN
            FrontInBuffers = FrontInBuffers;
            RETURN[tmpPtr];
         END;
      END;

   ClearInQueue: PUBLIC PROCEDURE[] = BEGIN
      next. MsgBufferPtr = NIL;
   END;
WHILE FrontinBuffers # NIL
   DO
      next = FrontinBuffers;
      FrontinBuffers = FrontinBuffers .next;
      zone.FREE[.next];
   END LOOP;
   NotifyBuffers = FrontinBuffers;
END;

StoreinData: ENTRY PROCEDURE [tmpPtr, MsgBufferPtr] =
BEGIN
   IF FrontinBuffers = NIL THEN
      (FrontinBuffers = tmpPtr;
      NotifyBuffers = FrontinBuffers)
   ELSE (NotifyBuffers .next = tmpPtr;
      NotifyBuffers .mptr);
   NotifyBuffers .status += 1;
   NOTIFY dataAvailable;
END;

Send: PUBLIC PROCEDURE [outMsgPtr, MsgBufferPtr] =
BEGIN
   stream = Stream.Handle = NIL;
   Rety: SIGNAL = CODE;

BEGIN
   ENABLE BEGIN
      Rety = (IF stream # NIL THEN
                  (stream.delete[stream];
                  stream = NIL;)
                  WriteString("Sender = Close is not good, RETRY. ").L;
                  WriteDecimal[.outMsgPtr .dest],NewLine();
                  RETRY);
   END;
   NetworkStream.ConnectionFailed = > (IF stream # NIL THEN
                (stream.delete[stream];
                stream = NIL;)
                WriteString("Sender = ConnectionFailed,".L;)
                WriteDecimal[.outMsgPtr .dest]
                IF outMsgPtr .dest = 0 THEN
                  WriteString("RETRY: 0.L;
                  RETRY")
                ELSE (WriteString("ByPass ".L;)
                  WriteDecimal[.outMsgPtr .dest]
                  NewLine();
                  CONTINUE)
             )
         NetworkStream.ConnectionSuspended = > (IF stream # NIL THEN
                  (stream.delete[stream];
                  stream = NIL;)
                  WriteString("Sender = ConnectionSuspended,RETRY... ".L;
                  WriteDecimal[.outMsgPtr .dest],NewLine();
                  RETRY);
   END;
   IF why = endRecord THEN
      SIGNAL Rety;
      data.nodeNumber = b.mchnum;
      NodelnUse = b.usedNode;
      IF size = 0 OR (size # NetworkStream.closeSST)
      SIGNAL Rety;
IF NetworkStream.CloseReply# good THEN
    SIGNAL retry;
    stream.delete(stream);
    stream = NIL;
    DO
        ENABLE BEGIN
            ABORTED = > EXIT;
            NetworkStream.ConnectionFailed,
            NetworkStream.ConnectionSuspended = > {
                IF stream # NIL THEN
                    {stream.delete(stream);
                    stream = NIL;
                    WriteString("Receiver - ConnectionFailed or ConnectionSuspended,
                    CONTINUE");
                    LOOP*
                    LOOP}.
                END;
                [] <-> NetworkStream.Listen(listener: listener);
                stream = NetworkStream.ApproveConnection{
                    listener: listener,
                    classOfService: transactional},
                Process.Detach(FORK ReceiveInstance#stream)
                ENDLOOP;
            END;
            NetworkStream.DeleteListener(listener:ABORTED = > CONTINUE)
    END;
    ReceiveInstance: PROCEDURE [stream: Stream.Handle] =
    BEGIN
        tmpPtr: MsgBufferPtr = NIL;
        EmptyBlock: MACHINE DEPENDENT RECORD[
            prefix: PACKED ARRAY [0.0] OF Stream.Byte,
            pseudo: MsgBuffer];
        size: CARDINAL = 0;
        why: Stream.CompletionCode = normal;
        sst, dummy: Stream.SubSequenceType = 0;
        BEGIN
            ENABLE BEGIN
                NetworkStream.ConnectionFailed,
                NetworkStream.ConnectionSuspended = > {
                    IF stream # NIL THEN
                        {stream.delete(stream);
                        stream = NIL;
                        WriteString("Receiver1 - ConnectionFailed or ConnectionSuspended,
                        CONTINUE");
                        CONTINUE}.
                    END;
                END;
                stream.setTimeout(sst: stream, waitTime = 200000);
                Stream.SetOptions(stream, [terminateOnEndRecord: TRUE]);
                tmpPtr = zone.NEW(MsgBuffer);
                size + 0;
                dummy = 0;
                why = sst.Change;
                WHILE size = 0
                    DO
                        IF why = sst.Change THEN sst + dummy;
                        [size, why, dummy] = Stream.GetBlock{
                            stream,
                            [*tmpPtr t: prefix:0,BytesInMsgBuffer]
                            / Stream Timeout = > {
                            'WriteString("receiver stream timeout");
                            NewLine();
                            RESUME}}.
                        ENDLOOP;
                        IF why # endRecord OR size < BytesInMsgBuffer THEN
                            {zone FREE@tmpPtr;
                            GO TO Exit;
                            StoreInData[tmpPtr];
                            [size, why, sst] = Stream.GetBlock{
                                stream,
                                [*EmptyBlock, prefix:0,BytesInMsgBuffer]
                                / Stream Timeout = > RESUME};
                            IF (size # 0) OR (sst # NetworkStream.closeSST) THEN
                                GO TO Exit;
                                IF NetworkStream.CloseReply# good THEN
                    END.
NICOMPL: PROGRAM
IMPORTS TTY, TTYSW, NewInterfaceDfs, Real
EXPORTS IO =
BEGIN
data: InterfaceDfs, DataHandle ← NIL;
ttyWindow: TTY.Handle;

SetEcho: PUBLIC PROCEDURE [new: BOOLEAN] RETURNS [old: BOOLEAN] =
BEGIN
  old ← SELECT TTY.SetEcho[n]: ttyWindow, new: IF new THEN plain ELSE none
  FROM
  none = > FALSE,
  plain = > TRUE,
ENDCASE = > ERROR
END «SetEcho»;

ReadChar: PUBLIC PROCEDURE [] RETURNS [character] =
{ RETURN(TTY.GetChar(ttyWindow)); }

ReadLine: PUBLIC PROCEDURE [s: LONG STRING] =
BEGIN
  TTY.DrawLine(ttyWindow,s !

  TTY.LineOverflow = >
  { RESUME[SIGNAL.LineOverflow[s]];

  TTY.Rubout = >
  { SIGNAL.Rubout[];
  RESUME
  }

  TTY.ReadLine<s !

  TTY.ReadLine = >
  { RESUME[SIGNAL.ReadLine[s]];

  TTY.Rubout = >
  { SIGNAL.Rubout[];
  RESUME
  ]}

END «ReadLine»;

WriteChar: PUBLIC PROCEDURE [c: CHARACTER] = { TTY.PutChar(ttyWindow,c) !

WriteString: PUBLIC PROCEDURE [s: LONG STRING] =
{ TTY.PutString(ttyWindow,s) !

WriteDecimal: PUBLIC PROCEDURE [n: INTEGER] =
{ TTY.PutDecimal(ttyWindow,n) !

WriteLongDecimal: PUBLIC PROCEDURE [n: LONG INTEGER] =
{ TTY.PutLongDecimal(ttyWindow,n) !

WriteFloat: PUBLIC PROCEDURE [n: REAL] =
{ Real.WriteReal(ttyWindow,n, Real.DefaultSinglePrecision, FALSE) !

NewLine: PUBLIC PROCEDURE [] = { TTY.PutCR(ttyWindow) !

END «NICOMPL».
NodeDefs: DEFINITIONS =

BEGIN
Open: INTEGER = -1; = - value for the Worker field in WorkGiven
< < WorkGiven records all problems we have given to peers to work on.
It also includes the current problem that we have given to
ourselves to work on, and any problems that are in our heap.
WorkGiven records all problems that we have received from others,
including the host. >>
WorkGottenPtr: TYPE = LONG POINTER TO WorkGottenType;
WorkGottenType: TYPE = RECORD[
    id: DeweyDfs.Dewey,
    Owner: INTEGER, -- who is waiting for the results
    UnsolvedCount: INTEGER, < < how many subproblems are still under
    computation. >>
    Value: AppliDfs.ProblemType,
    Next: WorkGottenPtr]
WorkGivenPtr: TYPE = LONG POINTER TO WorkGivenType;
WorkGivenType: TYPE = RECORD[
    id: DeweyDfs.Dewey,
    Value: AppliDfs.ProblemType,
    Worker: BOOLEAN, < < may we work on this problem for us
    Available: BOOLEAN, < < may we work on it?
    If not given to anyone, Worker = -1 (Open), Available = TRUE
    If given to machine m, Worker = m, Available = FALSE
    If given but ready to redo, Worker = m, Available = TRUE
    If given and I am redoing, Worker = m, Available = FALSE >>
    Parent: WorkGottenPtr,
    Redunandy: INTEGER,
    Next: WorkGivenPtr]

BroadcastInfo: PROCEDURE[Info: AppliDfs.InfoType];
ReportResult: PROCEDURE[P: AppliDfs.ProblemType];
END.
BEGIN
  OPEN DeweyDs, HOSTDs, NodeDs, InterfaceDs, NInterfaceDs, ApplicDs, I0, Heap, RandomDs, TimeMeasureDs;
  zone: UNCOUNTED_ZONE = Heap, system.ZONE,
data: Database = NIL;

MaxDeweyReport: INTEGER = 4;
MaxPartitionSize: INTEGER = 7;
MaxTimingDepth: INTEGER = 15;
HelpersList: TYPE = ARRAY[0..MaxPartitionSize - 1] OF INTEGER,
MyName: INTEGER = 0;
Termination: BOOLEAN = FALSE;
NextToAsk: INTEGER = 1;
HelpersList: HelpersListType = ALL[0];
pgen: LONG POINTER TO GeneratorState = NIL; -- for random variable

Start time: TimeMeasure = [(2114294000), 1];
AvailWorkCount: INTEGER = 0;
WorkGivenSize: INTEGER = 0;
Debug: INTEGER = 4; -- debugging level, comes from host
WorkGivenHeader: WorkGivenPtr = NIL;
WorkGottenHeader: WorkGottenPtr = NIL;

-- communication variable
outMsg Ptr: MsgBufferPtr = NIL;
PartitionSize: INTEGER = 0;
NumHelpers: INTEGER = 0;
LocalSequence: INTEGER = 0;
HaveBeenIdle: BOOLEAN = TRUE;
AnswerSpec: AnswerSpecification = Count;
DeweyPrefix: Dewey = [ALL[0], 0];
WorkFrac: INTEGER = 0;

-- Timing variables.
Time: TimeTemp = ALL[0];
OldTime1: Milliseconds;
TimingStack: ARRAY[0..MaxTimingDepth] OF INTEGER,
TimingStackTop: INTEGER;
TimeSpent: Milliseconds; -- Elapsed time when debug is called

-- Recursion stack for Backtrack
CurrentProblemType: TYPE = ARRAY[0..MaxDepth] OF ProblemType;
Depth: INTEGER = 0;
CurrentProblem: LONG POINTER TO CurrentProblemType = NIL;
OweBy: ARRAY[0..MaxDepth] OF INTEGER = ALL[0];
GiveAwayDepth: INTEGER = 0;
CurrentRedundancy: INTEGER = 0;

Error: PROCEDURE[Condition: BOOLEAN, Reason: LONG STRING] =
BEGIN
  IF Condition THEN
    {WriteString"** error **"},
    {WriteString"** error **"},
  END;
END;

StartTiming: PROCEDURE[What: INTEGER] =
BEGIN
  TimingStackTop = 0;
  TimingStack[TimingStackTop] = What;
  OldTime1 = ElapsedTime[StartTime];
END; -- StartTiming

PushTiming: PROCEDURE[What: INTEGER] =
BEGIN
  OldTime1 = ElapsedTime[StartTime] - OldTime1;
  TimingTemp = TimingStack[TimingStackTop];
  IF TimingTemp <= 3 + MaxRedundancy THEN
    TimingTemp = TimingTemp + OldTime1;
    TimingStackTop = TimingStackTop + 1;
    TimingStack[TimingStackTop] = What;
    OldTime1 = ElapsedTime[StartTime];
  END; -- PushTiming

PopTiming: PROCEDURE[] =
BEGIN
  OldTime1 = ElapsedTime[StartTime] - OldTime1;
  TimingTemp = TimingStack[TimingStackTop];
  IF TimingTemp <= 3 + MaxRedundancy THEN
    TimingTemp = TimingTemp + OldTime1;
    TimingStackTop = TimingStackTop - 1;
    Error[TimingStackTop < 0, "Stack error"];
    OldTime1 = ElapsedTime[StartTime];
  END; -- PopTiming

DEBUG: PROCEDURE[a: INTEGER, Mess: LONG STRING] =
BEGIN
  IF Debug > = a THEN
    {WriteLongDecimalTimeSpent + ElapsedTime[StartTime];
    WriteString" "},
    {WriteString" "},
    {WriteString" "},
    {Newline[]},
    {PopTiming[]};
  END; -- DEBUG

CheckWorkEmpty: PROCEDURE[] =
BEGIN
  IF [WorkGottenHeader ≠ NIL] OR
    [WorkGivenHeader ≠ NIL] THEN
    BEGIN[
      Debug3,"Entries in WorkGiven ",
      Str, 1 = WorkGivenPtr;
      WHILE PTR ≠ NIL DO
        IF Debug > = 2 THEN
          {WriteLongDecimalTimeSpent + ElapsedTime[StartTime];
          WriteString" "},
          {PrintDeweyPtr[1, 0]};
        END;
        IF PTR ≠ NIL THEN
          PTR = PTR + 1;
          END_LOOP;
        ENDLOOP;
        DEBUG3,"Entries in WorkGotten ",
        PTR = WorkGottenPtr;
        WHILE PTR ≠ NIL DO
          IF Debug > = 3 THEN
            {WriteLongDecimalTimeSpent + ElapsedTime[StartTime];
            WriteString" "},
          END;
        ENDLOOP;
      END[
      Debug3," Entries in Work "],
    END;}
< < Someone has just solved a problem. The Dewey prefix is given by Dew. Find which entry in WorkGotten applies. If none does, return null; that means that the problem has been solved redundantly. > >
BEGIN
Answer = WorkGottenHeader;
WHILE DeweyCompare(Answer ID, Dew) # Equal
DO
Answer = Answer Next;
IF Answer = NIL THEN
{if Debug > 3 THEN
{WriteLongDecimal(TimeSpent ElapsedTime[StartT1me]);
WriteString " : " ;
WriteDecimal(Which Who);
Newline();
}
IF WorkGottenHeader = NIL THEN
{WorkGottenHeader = zone New[WorkGottenType];
WorkGottenHeader Next = NIL;
ELSE {TmpPtr = WorkGottenHeader;
WorkGottenHeader Next = TmpPtr;
{OPEN WorkGottenHeader ID = Dew;
Value = Prob;
Worker = Who;
Error(Who = 0, "Bad Who");
Available (Worker = Open);
IF Available THEN
AvailWorkCount = AvailWorkCount + 1;
Redundancy = Redund;
Error(Redundancy < 0, "Bad Redundancy");
Parent = ParPtr;
Parent Next = UnsolvedCount + 1;
WorkGottenSize = WorkGottenSize + 1;
END; -- Getting
GETTING
PROCEDURE[Dew, Prob, ProblemType, Who, INTEGER]
RETURNS[ParPtr WorkGottenPtr]
<< We have just gotten 'Dew' from 'Who'. Record this fact in Work gotten. >>
BEGIN
TmpPtr = WorkGottenPtr;
IF Debug > 2 THEN
{WriteLongDecimal(TimeSpent ElapsedTime[StartT1me]);
WriteString " : " ;
PrintDewey(Dew);
WriteString " : " ;
WriteDecimal(Which Who);
Newline();
}
IF WorkGottenHeader = NIL THEN
{WorkGottenHeader = zone New[WorkGottenType];
WorkGottenHeader Next = NIL;
ELSE {TmpPtr = WorkGottenHeader;
WorkGottenHeader Next = TmpPtr;
{OPEN ParPtr ID = Dew;
Value = Prob;
Owner = Who;
UnsolvedCount = 0;
END; -- Getting
FIND WorkGotten PROCEDURE[Dew, Dewey]
RETURNS[Answer WorkGottenPtr]
<< We are about to give 'Prob' to 'Who'. Record this fact in WorkGotten. >>
BEGIN
TmpPtr = WorkGottenPtr;
IF Debug > 2 THEN
{WriteLongDecimal(TimeSpent ElapsedTime[StartT1me]);
WriteString " : " ;
PrintDewey(Dew);
WriteString " : " ;
WriteDecimal(Which Who);
Newline();
}
IF WorkGottenHeader = NIL THEN
{WorkGottenHeader = zone New[WorkGottenType];
WorkGottenHeader Next = NIL;
ELSE {TmpPtr = WorkGottenHeader;
WorkGottenHeader Next = TmpPtr;
{OPEN ParPtr ID = Dew;
Value = Prob;
Owner = Who;
UnsolvedCount = 0;
END; -- Getting
FIND WorkGotten PROCEDURE[Dew, Dewey]
RETURNS[Answer WorkGottenPtr] =
ReleaseWorkGotten PROCEDURE[Which WorkGottenPtr]
<< 'Which' points to some work that we gave away that is now finished.
It will not be nil; if someone else finished the work, then we are
called. Remove it from the WorkGotten structure. It will not
be any other redundant copies of the same problem as seen from
the dewey number. >>
BEGIN
Fore = WorkGottenPtr;
Atf = WorkGottenPtr;
WHILE Fore Which DO
Atf = Fore;
Fore = Fore Next;
ENDLOOP;
IF Debug > 2 THEN
{WriteLongDecimal(TimeSpent ElapsedTime[StartT1me]);
WriteString " : " ;
WriteDecimal(Which Who);
WriteChar '[';
PrintDewey(Which ID);
Newline();
WorkGottenSize = WorkGottenSize - 1;
IF Which != Available THEN
AvailWorkCount = AvailWorkCount - 1;
IF Fore = WorkGottenHeader THEN
WorkGottenHeader = WorkGottenHeader Next;
ELSE Atf Next = Fore Next;
zone FREE[Which];
END; -- ReleaseWorkGotten
ReleaseSubsumedWork PROCEDURE[Dew, Dewey]
BEGIN
Fore, Atf = WorkGottenPtr NILL;
WHILE DeweySubsumes(Dew, WorkGottenHeader ID) DO
END; -- ReleaseWorkGotten
Afl ← WorkGivenHeader;
WorkGivenHeader ← WorkGivenHeader † Next;
zone.FREE[@AFl];
ENDLOOP;
Afl ← WorkGivenHeader;
Fore ← Afl † Next;
WHILE Fore # NIL DO
  IF DeweySubsumes[Fore † .ID] THEN
    {WriteLongDecimal[Timespent ← ElapsedTime[StartTime]];}
    WriteString" Excise ["L];
    WriteDecimal[Fore † .Redundancy];
    WriteChar[ ];
    PrintDewey[Fore † .ID];
    NewLine[];
  WorkGivenSize ← WorkGivenSize − 1;
  IF Fore † .Available THEN
    AvailWorkCount ← AvailWorkCount − 1;
    Avl ← Avl † Fore † .Next;
ENDDO;
ELSE Avl ← Fore † .Next;
Fore ← Fore † .Next;
ENDDO;
ENDDO;
BEGIN
  Fore.Afl ← WorkGottenPtr;
  Fore ← WorkGottenHeader;
  WHILE Fore # Which DO
    Fore ← Fore † .Next;
ENDDO;
  WorkGottenHeader ← WorkGottenHeader † Next;
ENDDO;
ENDDO;
ReleaseWorkGotten
WorkClear: PROCEDURE[Redun: INTEGER] =
BEGIN
  Fore ← WorkGivenPtr;
  Fore ← WorkGivenHeader;
  WHILE Fore # NIL DO
    IF Fore † .Redundancy > Redun THEN
      Fore † .Redundancy ← Redun;
      Fore ← Fore † .Next;
    ENDDO;
  ENDDO;
ENDDO;
WorkClear
ReDong: PROCEDURE() RETURNS[Work, WorkGivenPtr] =
BEGIN
  IF Work.GivenPtr ≠ NIL THEN
    Work ← Work.GivenPtr;
    Work ← Work.GivenHeader;
    TmpPtr ← Work † .Next;
    Work ← Work † .Next;
    While TmpPtr ≠ NIL DO
      IF (TmpPtr † .Redundancy < NewWork † .Redundancy) OR
        (TmpPtr † .Redundancy = NewWork † .Redundancy) AND
        (DeweyCompare[TmpPtr † .ID, NewWork † .ID] = Smaller) THEN
        NewWork ← TmpPtr;
      ENDIF;
    ENDWHILE;
    Work ← Work † .Next;
  ENDIF;
ENDPROCEDURE
ReDong
SelectWork: PROCEDURE[MyName: INTEGER] RETURNS[SomeWork: WorkGivenPtr] =
BEGIN
  IF Work † .open THEN
    Work † .Redundancy ← Work † .Redundancy + 1;
  ENDIF;
  Work ← Work † .Next;
ENDPROCEDURE
SelectWork
HouseKeeping: PROCEDURE[] =
BEGIN
  next1 ← WorkGivenPtr ← NIL;
  next2 ← WorkGivenPtr ← NIL;
  WHILE WorkGivenHeader ≠ NIL DO
    next1 ← WorkGivenHeader;
    WorkGivenHeader ← WorkGivenHeader † Next;
    zone.FREE[@next1];
    ENDWHILE;
  ENDWHILE;
  WorkGivenHeader ← WorkGivenHeader † Next;
  zone.FREE[@next2];
  ENDWHILE;
  WorkGivenSize ← 0;
  AvailWorkCount ← 0;
  HaveBeenIdle ← TRUE;
  ClearInQueue[];
ENDPROCEDURE
HouseKeeping
Broadcast: PROCEDURE() =
BEGIN
  ToWhom: INTEGER ← 1;
  a: InterNodeMessage Message;
  PushTiming[CommTime];
ENDPROCEDURE
Broadcast
WHILE ToWhom <= PartitionSize
    DO
        IF ToWhom # MyName THEN
            outMsgPtr + zone.NEW[MsgBuffer];
            outMsgPtr.t.message + a;
            outMsgPtr.t.source + MyName;
            outMsgPtr.t.dest + ToWhom;
            Send(outMsgPtr);
            ToWhom + ToWhom + 1;
        ENDLOOP;
        PopTiming();
    END;
END; -- TellInfo

ReportResult: PUBLIC PROCEDURE[ProblemType] =
< send a result value back to the host >
BEGIN
    a: AnswerMessage Message;
    IF AnswerSpec = FULL THEN
        PushTiming[TossTime];
        outMsgPtr + zone.NEW[MsgBuffer];
        a: Status + AnAnswer;
        a: Prob + P;
        a: Sequence + LocalSequence;
        LocalSequence + LocalSequence + 1;
        outMsgPtr.t.message + a;
        outMsgPtr.t.source + MyName;
        outMsgPtr.t.dest + 0;
        Send(outMsgPtr);
        PopTiming();
    END; -- ReportResult

DropOut: PROCEDURE[] =
< tell host we are quitting. >
BEGIN
    a: AnswerMessage Message;
    PushTiming[TossTime];
    outMsgPtr + zone.NEW[MsgBuffer];
    a: Status + Quitting;
    a: Sequence + LocalSequence;
    a: Times + Time;
    LocalSequence + LocalSequence + 1;
    outMsgPtr.t.message + a;
    outMsgPtr.t.source + MyName;
    outMsgPtr.t.dest + 0;
    Send(outMsgPtr);
    CheckWorkEmpty();
    IF MyName = 1 THEN
        outMsgPtr + zone.NEW[MsgBuffer];
        a: Status + PleaseStop;
        a: Sequence + LocalSequence;
        LocalSequence + LocalSequence + 1;
        outMsgPtr.t.message + a;
        outMsgPtr.t.source + MyName;
        outMsgPtr.t.dest + 0;
        Send(outMsgPtr);
        PopTiming();
    END; -- DropOut

TellGenerate: PROCEDURE[] =
< only called in node 1. Sends a 'terminate' message to every other node and sets the 'termination' flag in node 1 >
BEGIN
    Node: INTEGER <= 2;
    a: InterNodeMessage Message;
    PushTiming[CommTime];
    DEBUG[2, "in TellGenerate" ];
    WHILE Node <= PartitionSize
        DO
            outMsgPtr + zone.NEW[MsgBuffer];
            a: Kind + Terminate;
            outMsgPtr.t.message + a;
            outMsgPtr.t.source + MyName;
            outMsgPtr.t.dest + Node;
            Send(outMsgPtr);
            Node + Node + 1;
        ENDLOOP;
        Termination + TRUE;
        PopTiming();
    END; -- TellGenerate

BugHost: PROCEDURE[ID: Dewey] =
< We have finished a subproblem (or the whole problem); tell the Dewey number of what we just finished to the host. >
BEGIN
    a: AnswerMessage Message;
    PushTiming[TossTime];
    outMsgPtr + zone.NEW[MsgBuffer];
    a: Status + Reporting;
    a: AnswerDewey + ID;
    a: Sequence + LocalSequence;
    LocalSequence + LocalSequence + 1;
    outMsgPtr.t.message + a;
    outMsgPtr.t.source + MyName;
    outMsgPtr.t.dest + 0;
    Send(outMsgPtr);
    PopTiming();
END; -- BugHost

TellHost: PROCEDURE[Root: ProblemType] =
< We have finished the whole problem; tell the updated root to the host. >
BEGIN
    a: AnswerMessage Message;
    PushTiming[TossTime];
    outMsgPtr + zone.NEW[MsgBuffer];
    a: Status + BatchDone;
    a: Prob + Root;
    a: Times + Time;
    a: Sequence + LocalSequence;
    LocalSequence + LocalSequence + 1;
    outMsgPtr.t.message + a;
    outMsgPtr.t.source + MyName;
    outMsgPtr.t.dest + 0;
    Send(outMsgPtr);
    PopTiming();
END; -- TellHost

WorkDone: PROCEDURE[Dewy: Dewey, ProbPtr: LONG POINTER TO ProblemType] =
< Either we or someone else has finished this problem; tell each parent. There may be several parents, since we may have the same problem at different redundances. >
BEGIN
    GivenWork: WorkGivenPtr,
    Parent: WorkGottenPtr;
    DO
        GivenWork + FindWorkGiven[Dewy];
        IF GivenWork = NIL THEN EXIT;
        Parent + GivenWork->Parent;
        ReleaseWorkGiven[GivenWork];
        TellParent[ProbPtr,Dewey,Parent];
    ENDLOOP;
END; -- WorkDone

TellRepeating: PROCEDURE[GivenWork: WorkGivenPtr] =
< If I have decided to do GivenWork again. Tell its owner,
  {fault – tolerance rule a) so that if the owner has other work for me
to do, it will tell me. >
BEGIN
a: InterNodeMessage Message;

PushTiming(CommTime);
OPEN GivenWork t:
outMsgPtr = zone.NEW(MsgBuffer);
a. Kind = Repeating;
a. Askor = MyName;
a.Redundancy = Redundancy;
a. ChildDewey = ID;
outMsgPtr.t.message <- a;
outMsgPtr.t.source = MyName;
outMsgPtr.t.dest = Worker;
Sender(outMsgPtr);
PopTiming();
END; -- TellRepeating

TellUpdate: PROCEDURE[GivenPtr: WorkGivenPtr] =
< < The problem in GivenPtr t. Value has changed, so we must tell
the worker we have given it to (it's not us, and it's not free)
about the change. >>
BEGIN
a: InterNodeMessage Message;

PushTiming(CommTime);
outMsgPtr = zone.NEW(MsgBuffer);
a. Kind = Updating;
out = GivenPtr t. Value;
a. ChildDewey = GivenPtr t. ID;
IF Debug > = 3 THEN
{ PushTiming(TosTime);
WriteLongDecimal(TimeSpent = ElapsedTime(StartTime));
WriteString(TellUpdate t. "LI.
WriteDecimal(GivenPtr t. Worker]);
PopTiming());
outMsgPtr t. message = a;
outMsgPtr t. source = MyName;
outMsgPtr t. dest = GivenPtr t. Worker;
Sender(outMsgPtr);
PopTiming();
END; -- TellUpdate

DoUpdate: PROCEDURE[Dew: Dewey,
Prob: LONG POINTER TO ProblemType] =
< < The children of Prob, with ID = Dew, need to have Update called,
recursively if necessary. >>
BEGIN
D: INTEGER;
GivenPtr: WorkGivenPtr;
Again: BOOLEAN;

GivenPtr = WorkGivenHeader;
WHILE GivenPtr # NIL DO
{ OPEN GivenPtr t;
IF (ID. Length = Dew.DewyLength + 1) AND
DeweySubsumes(Dew, ID) THEN
SELECT TRUE FROM
(Worker # MyName) AND (NOT Available) = >
{ Again = Update[@Value,ProbPtr];
IF Again THEN
WriteString(""L;
TellUpdate(GivenPtr));
DeweyCompare(D,DewyPrefix) = Equal = >
{ Again = Update[@CurrentProblem[D],@Value];
D = D + 1;
WHILE Again AND (D < Depth) DO
WriteString(""L;
Again = Update[@CurrentProblem[D],@CurrentProblem[D - 1]],
D = D + 1;
ENDLOOP).
ENDCASE = > { Again = Update[@Value,ProbPtr];
IF Again THEN

{WriteString(""L;
DoUpdate([0, @Value]));
ENDLOOP;
END; -- DoUpdate

TelIParent: PROCEDURE[ChildPtr: LONG POINTER TO ProblemType,
ChildDewey: Dewey,
Parent: WorkGottenPtr] =
< < Child has been finished. Its parent in WorkGotten is pointed to by
Parent. Update the Parent and inform its owner if all its children
have finished. >>
BEGIN
NeedUpdate: BOOLEAN;
a: InterNodeMessage Message;

DEBUG[], " TelIParent ";
IF DeweyCompare(ChildPtr # ID, ChildDewey) # Equal THEN
{ NeedUpdate = Combine(ChildPtr,Parent t. Value);
IF NeedUpdate THEN
DoUpdate(ChildPtr # ID, Parent t. Value));
ELSE Parent t. Value = ChildPtr t;
Parent t. UnsolvedCount = Parent t. UnsolvedCount - 1;
IF Parent t. UnsolvedCount = 0 THEN
{ If Parent t. Owner = MyName THEN
WorkDone(ChildPtr # ID, Parent t. Value);
ELSE IF Parent t. Owner = 0 THEN
{ If Debug > = 1 THEN
{ WriteString(""L in TellParent, owner is ... "",
WriteLongDecimal(Parent t. Value,LeafCount));
NewLine()];
TellHost(Parent t. Value);
TellTerminate());
ELSE
{ PushTiming(CommTime);
WriteLongDecimal(TimeSpent = ElapsedTime(StartTime));
WriteString("Tell["L;
WriteDecimal(CurrentRedundancy);
WriteChar[]);
PrintDewey(Prob t. ID);
WriteString(" > "L;
WriteDecimal(Prob t. Owner];
PopTiming());
outMsgPtr t. message = a;
outMsgPtr t. source = MyName;
outMsgPtr t. dest = Parent t. Owner;
Sender(outMsgPtr);
IF Parent t. ID. Length = MaxDeweyReport THEN
BuchHost(Prob t. ID);
PopTiming());
END; -- TellIIParent

AskForHelp: PROCEDURE[FirstTime: BOOLEAN, Beggar: Hops: INTEGER] =
< < If FirstTime then we ask node; afterwards, send a request to
Numhelpers nodes next in line if Beggar # MyName, we are forwarding
the request, so we only send out one copy. Tell the helper the
number of hops. >>
BEGIN
Seq, Index, Count, Temp: INTEGER,
Helpers: HelperListType;
a: InterNodeMessage Message;

PushTiming(CommTime);
IF FirstTime OR (Beggar # MyName) THEN
Count = 1
ELSE Count = NumHelpers,
IF (Beggar # MyName) AND (PartitionSize = 2) THEN
  Count += 1;
  WHILE Seq < Count
    DO
      Helpers[PartitionSize - Seq - 1] = NextToAsk;
      NextToAsk = NextToAsk MOD PartitionSize + 1;
      IF NextToAsk = MyName THEN
        NextToAsk = NextToAsk MOD PartitionSize + 1;
      Seq = Seq + 1;
      ENDLOOP;
      Helpers += HelperList;
    Seq = 1;
    WHILE Seq < Count
      DO
        Index = RandomPartitionSize
        Temp = Helpers[Index];
        Helpers[Index] = Helpers[PartitionSize - Seq - 1];
        Helpers[PartitionSize - Seq - 1] = Temp;
        IF Temp # MyName THEN
          Seq += 1;
          ENDLOOP;
        IF FirstTime THEN
          Helpers[PartitionSize - 2] = 1;
        Seq = 1;
        WHILE Seq < Count
          DO
            outMsgPtr = zone.NEW[MsgBuffer];
            a Kind = Request;
            a Beggar = Beggar;
            a Count = Hops;
            outMsgPtr f.message += a;
            IF Debug > = 2 THEN
              {PushTiming}TossTime;
              WriteLongDecimal[Timespent = ElapsedTime[StartTime]];
              WriteString"Too deep to give away; depth "L];
              WriteDecimalGiveAwayDepth;
              PopTiming();
            END;
            IF NotNonTrivial[CurrentProblem][GiveAwayDepth + 1] THEN
              {PushTiming}TossTime;
              WriteLongDecimal[Timespent = ElapsedTime[StartTime]];
              WriteString"Trivial when deeper than "L];
              WriteDecimalGiveAwayDepth;
              PopTiming();
            END;
            WorkPtr = FindWorkGiven[DeweyPrefix];
            IF WorkPtr = NIL THEN
              {DEBUG}2, "nothing at the moment";
            END;
            IF DeweyCompare[WorkPtr t JD, WorkPtr t Parent t ID] = Equal THEN
              {ParPtr = WorkPtr t Parent;
              ParPtr t Value = WorkPtr t Value;
              ReleaseWorkGiven[WorkPtr];
            ParPtr t UnsolvedCount = ParPtr t UnsolvedCount - 1;}
            ELSE ParPtr = Getting[WorkPtr t JD, WorkPtr t Value, MyName];
            GiveAwayDepth = GiveAwayDepth + 1;
            {OPEN DeweyPrefix;
            Length = Length + 1;
            DNums[length] = DeweyDelta[GiveAwayDepth];
            P = CurrentProblem[GiveAwayDepth];
            Gving[ParPtr.P, DeweyPrefix, MyName, CurrentRedundancy];
            TempDewey = DeweyPrefix;
            First = FALSE;
          DO
            Done = Generate[First, @ParPtr t .Value, @P];
            IF Done THEN EXIT;
            {OPEN TempDewey;
            DNums[length] = DNums[length] + 1;
            Gving[ParPtr.P, TempDewey, Open, CurrentRedundancy];
          ENDLOOP;
        IF AllWorkCount > 0 THEN EXIT;
        ENDLOOP;
      End;}GiveAwayCount = AllWorkCount;
      IF WorkFract < 0 THEN
        IF GiveAwayCount > 0 THEN
          GiveAwayCount = 1;
        ELSE IF GiveAwayCount > 0 THEN
        {GiveAwayCount = (GiveAwayCount * WorkFract) + 5) / 10;
        IF GiveAwayCount = 0 THEN
          GiveAwayCount = 1;
        PopTiming();
        END;}CommTime;
        IF GiveAwayCount > 0 THEN
          {Seq += 1;
          WHILE Seq < = GiveAwayCount
            DO
              outMsgPtr = zone.NEW[MsgBuffer];
              SomeWork = SelectWork[MyName];
              IF Debug > = 2 THEN
                {PushTiming}TossTime;
                WriteLongDecimal[Timespent = ElapsedTime[StartTime]];
                WriteString"Give "L];
                WriteDecimal[CurrentRedundancy];
                WriteChar"L];
                PrintDewey[SomeWork t ID];
                WriteString"To "L];
                WriteDecimal[Who];
              PopTiming();
            a Kind = Work;
            a Count += 1;
            a Child = SomeWork t Value;
            a ChildDewey = SomeWork t ID;
            a Redundancy = SomeWork t Redundancy,
            Error[Redundancy < 0, "Bad redundancy"];
            END;}
IF DeweyCompare(SomeWork & ID, SomeWork & Parent & ID] = Equal THEN
  {AskForSomeWork & Parent & Owner;
   ReleaseWorkGotten(SomeWork & Parent);
   ReleaseWorkGiven(SomeWork)}
ELSE {AskForMyName;
   SomeWork & Worker & Who;
   Error(Who == 0, "Bad Who");
   outMsgPrt t_message & a;
   outMsgPrt t_source & MyName;
   outMsgPrt t_dest & Who;
   Sender(outMsgPrt);
   Seq & Seq + 1;
ENDLOOP}
ELSE IF Hops < PartitionSize THEN
  AskForHelp(FALSE, Who, Hops + 1);
  PopTiming();
END; -- ~ HandleRequest

CheckIncoming: PROCEDURE[BusyWait: BOOLEAN] =
  < < called periodically to see if our predecessor node has asked or
  forwarded to us a request for some work to do. If it has, we
  "get half of our outstanding work to the requester. If we have no
  work to hive away, we will split the current level of
  CurrentProblem if it is not trivial, otherwise we will pass the
  request to our successor. If BusyWait is set, we don't return
  if nothing has come in: we keep checking. We set Abort to true
  if work just came in that is less redundant than the current
  level, > >
BEGIN;
  GivenWork: WorkGivenPrt;
  ParPrt: WorkGottenPrt;
  Empty: BOOLEAN;
  inMsgPrt: MsgBufferPrt & NIL;
  askAgain: CARDINAL & 0;
  EndTiming[CommTime];
  Abort & FALSE;
  DO
    Empty = inQueueEmptyCheck();
    IF NOT Empty THEN
      {inMsgPrt & GetInData();
      WITH a inMsgPrt t message SELECT FROM
      internodeMessage => > {
        SELECT TRUE FROM
        (a.Kind = TerminationToken) OR Termination => > Termination => TRUE;
        a.Kind = >
        IF a.Asker # MyName THEN
          HandleRequest(a.Asker, a.Count);
          DEBUG() " Got request ";
          IF TimingStack[TimingStackTop] == IdleTime AND
          (NOT HaveBeenIdle) THEN
            {AskForHelp(FALSE, MyName, PartitionSize);
             HaveBeenIdle & TRUE};
          a.Kind = Updathing => > DoUpdate[a ChildDewey, @a Child];
          a.Kind = Work => >
          IF a.Redundancy < CurrentRedundancy THEN
            {WorkClear[a Redundancy];
             Error[a Redundancy < 0, "Got bad redundancy"];}
            Abort & TRUE;
            CurrentRedundancy & a Redundancy;
          IF DeweySubsume[DeweyPrefix, a ChildDewey] THEN
            {PushTiming[TossTime];
             WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
             WriteString[# #: got "L"];
             PrintDewey[a ChildDewey];
             WriteString[# #: while working on "L"];
             PrintDewey[DeweyPrefix];
             PopTiming();
            }
            Abort & TRUE;
          CurrentRedundancy & a Redundancy;
          IF a.Redundancy > CurrentRedundancy THEN
            {PushTiming[TossTime];
             WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
             WriteString[# #: similar work "L"];
             PrintDewey[a ChildDewey];
             PopTiming();
            };
            ParPrt = Getting[a ChildDewey, a Child, a Ask];
            Giving[ParPrt, a Child, a ChildDewey, Open, CurrentRedundancy];
            BusyWait & FALSE;
            IF Debug => 3 THEN
              {PushTiming[TossTime];
               WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
               WriteString[# #: repeating "L"];
               WriteDecimal[a ChildDewey];
               WriteString[# #: "L"];
               WriteDecimal[inMsgPrt t source];
               PopTiming();
              };
              GivenWork = WorkGivenHeader;
              WHILE GivenWork # NIL DO
                IF (NOT GivenWork # Available) AND
                (GivenWork & Worker # MyName) AND
                DeweySubsume[a ChildDewey, GivenWork & ID] THEN
                  {IF Debug => 1 THEN
                    {PushTiming[TossTime];
                     WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
                     WriteString[# #: repeating "L"];
                     WriteDecimal[a ChildDewey];
                     NewLine();
                     PopTiming();
                    };
                    HandleRequest[GivenWork t Worker, PartitionSize];
                    GivenWork = GivenWork & Next;
                    ENDLOOP}
              ELSE IF Debug => 3 THEN
                {PushTiming[TossTime];
                 WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
                 WriteString[# #: repeating "L"];
                 WriteDecimal[a ChildDewey];
                 WriteString[# #: "L"];
                 WriteDecimal[inMsgPrt t source];
                 PopTiming();
                }
            IF a Kind = Result => >
              {IF Debug => 2 THEN
                {PushTiming[TossTime];
                 WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
                 WriteString[# #: Report "L"];
                 PrintDewey[a ChildDewey];
                 WriteString[# #: "L"];
                 WriteDecimal[inMsgPrt t source];
                 PopTiming();
                };
                PushTiming[TimeMeasures + CurrentRedundancy];
                WorkDone[a ChildDewey, @a Child];
                IF DeweySubsume[a ChildDewey, DeweyPrefix] THEN
                  {DEBUG(2, " stopped redundant work ");
                   Abort & TRUE;
                  };
                PopTiming();
              };
            a.Kind = GlobalInfo => >
              {PushTiming[TimeMeasures + CurrentRedundancy];
               UseNewInfo[a SomeInfo];
               PopTiming();
              };
            a.Kind = Repeating => >
              {IF Debug => 1 THEN
                {PushTiming[TossTime];
                 WriteLongDecimal[TimeSpent + ElapsedTime[StartTime]];
                 WriteString[# #: "L"];
                 PrintDewey[DeweyPrefix];
                 PopTiming();
                }
              IF a Redundancy > CurrentRedundancy THEN
                {DEBUG(1, " we will treat as a request");
               Pro...
HandleRequest[a,asker,PartitionSize]]; ENCASE = > Error[TRUE,"Bad message type"]; zone.FREE[&inMsgPtr]; ENCASE; ELSE {if Termination OR Abort OR NOT BusyWait} THEN EXIT ELSE {if WorkGivenSize > 0 THEN {GivenWork = Redoing}; Error[GivenWork ™ Worker < = 0, "Bad Worker"]; TellRepeating[GivenWork]; if Debug = = 1 THEN {PushTiming[TossTime]; WriteLog[Decima[TimeSpent + ElapsedTime[StartTime]]; WriteString\"#\#: Redo \"\"\]\]; WriteDecima[GivenWork ™ Redundancy]; WriteDecima"] < \]; WriteDecima[GivenWork ™ Worker]; PrintDeWey[GivenWork t ID]; PopTiming[]; EXIT}}}]; TimingStack[TimingStackTop] = IdleTime; askAgain = askAgain + 1; if askAgain > 60000 THEN {askAgain = 0; DEBUG[2, "Asking again!"]; AskForHelp[FALSE, MyName, 0];} ENDOF; if Termination AND (TimingStack[TimingStackTop] = CommTime) OR (TimingStack[TimingStackTop] = IdleTime) THEN TimingStack[TimingStackTop] = TermTime; PopTiming[]; END; EXIT BackTrack: PROCEDURE[] = << Recursive backtrace to solve the problem. Uses an explicit stack of unfinished work. CurrentProblem: The problem to expand is the first in the heap at the current GivenAwayDepth. >> BEGIN First, Done, Abort: BOOLEAN; PrevDepth: INTEGER; TmpWork: WorkGivenPtr; RootWork: WorkGivenPtr; ParentPtr: LONG POINTER TO ProblemType; NeedUpdate: BOOLEAN; inMsgPtr: MsgBufferPtr < = NIL; Empty: BOOLEAN;HaveBeenIdle < FALSE; if AvailWorkCount > 0 THEN {RootWork = SelectWork[MyName]; {OPEN RootWork ™; CurrentRedundancy + Redundancy; PushTiming[TimeMeasures + CurrentRedundancy]; CurrentProblem[0] + Value; PrevDepth = = 1; Depth = 0; GivenAwayDepth + 0; DeweyPrefix = ID]; if Debug = = 1 THEN {PushTiming[TossTime]; WriteLog[Decima[TimeSpent + ElapsedTime[StartTime]]; WriteString\"Backtrack on \"\"\]\]; PrintDeWey[RootWork ID]; NewLine[]]; PopTiming[]; DO if PrevDepth < Depth THEN {if Depth = GivenAwayDepth THEN {TmpWork = FindWorkGiven[DeWeyPrefix]; ParentPtr = &[TmpWork Value] ELSE ParentPtr = &[CurrentProblem Depth]; First ™ TRUE; if Debug = = 6 THEN {PrintProblem[ParentPtr] ™; WriteString\"*\]; PrintAnswer[ParentPtr ™; NewLine[]]; Done + Generate[First,ParentPtr, @CurrentProblem[Depth + 1]; PrevDepth = = Depth; IF NOT Done THEN {Depth + 1; DeweyDelta[Depth] + 1;}; < < ELSE go back up: leave PrevDepth = Depth as a sigh there were no children of this node. >> } ELSE {if Depth <= GivenAwayDepth THEN {if Debug = = 2 THEN {PushTiming[TossTime]; WriteLog[Decima[TimeSpent + ElapsedTime[StartTime]]; WriteString\"Just finished\"]; PrintDeWey[DeWeyPrefix]; PopTiming[]]; TmpWork = FindWorkGiven[DeWeyPrefix]; if Debug = = 1 THEN {WriteString\"in backtrack... done... \"\"\]\]; WriteLog[Decima[TmpWork Value,LeafCount]; NewLine[]]; WorkDone[DeWeyPrefix, @TmpWork Value]; EXIT}}} END; EXIT << -- Depth > GivenAwayDepth >> IF Depth = GivenAwayDepth + 1 THEN {TmpWork = FindWorkGiven[DeWeyPrefix]; IF TmpWork = NIL THEN EXIT; ParentPtr = &[TmpWork Value] ELSE {ParentPtr = &[CurrentProblem Depth 1]; TmpWork = NIL; NeedUpdate = Combine[CurrentProblem Depth, ParentPtr]; IF NeedUpdate AND (TmpWork ™ NIL) THEN DoUpdate[DeWeyPrefix, ParentPtr]; First ™ FALSE; Done + Generate[First,ParentPtr, @CurrentProblem Depth]; IF Done THEN {PrevDepth = Depth; Depth = Depth 1; Process.Yield[]]} ELSE {if Found a sibling DeweyDelta[Depth] = DeweyDelta[Depth] + 1; PrevDepth = Depth 1; Empty = inQueue isEmptyCheck[]; if NOT Empty THEN {Abort + CheckIncoming[FALSE]; IF Termination OR Abort THEN {if Abort AND (RootWork ™ Redundancy > CurrentRedundancy) THEN RootWork Redundancy = RootWork ™ Redundancy 1}}}} ENDOF; PopTiming[]; EXIT BackTrack Synchronize: PROCEDURE[] = << if we are machine PartitionSize, send startup messages to the other machine. Otherwise, wait for such a message before continuing. >> BEGIN Machine: INTEGER ™ 1; inMsgPtr: MsgBufferPtr < = NIL; a: InterNodeMessage Message; PushTiming[TossTime]; IF MyName = PartitionSize THEN {WHILE Machine < MyName DO outMsgPtr = zone.NEW[MsgBuffer]; a Kind ™ Sych; outMsgPref Value ™ a []; outMsgPref Source ™ MyName; Nodeimpl.mesa
outMsgPtr.t.dest = Machine;
Sender(outMsgPtr);
Machine = Machine + 1;
ENDLOOP)
ELSE -- wait for last machine to awaken us
DO
WHILE inMsgPtr = NIL
DO
Process.Pause[30];
inMsgPtr = GetInData();
ENDLOOP;
if inMsgPtr.t.source = PartitionSize THEN
WITH a: inMsgPtr.t.message SELECT FROM
InPutNodeMessage = >
if a.Kind = Synch THEN
{zone.FREE[@inMsgPtr];
EXIT};
ENDCASE;
zone.FREE[@inMsgPtr];
ENDLOOP);
StartTime += Get();
PopTiming[];
END; -- Synchronize
NodeInit: PROCEDURE[] =
< A process gets a larger stack, and we need that. Accept work from
the host, either 'ask for help' or 'there is a problem' - synchronize
with the other machines, then do what was asked of us. >
BEGIN
P: ProblemType;
Style: INTEGER;
Seq: INTEGER = 0;
Dew: Dewey;
Dummy: BOOLEAN;
ParPtr.Work gottenPtr;
inMsgPtr: MsgBufferPtr = NIL;
BEGIN
ENABLE
ABORTED = > (IF CurrentProblem # NIL THEN
zone.FREE[@CurrentProblem],
CONTINUE); 
WHILE MyName = 0
DO
Process.Pause[60];
data = GetWindowHandle();
if data # NIL THEN
MyName = data.nodeNumber;
ENDLOOP;
BEGIN
randomize[MyName];
DO
IF Debug > 3 THEN
{WriteString"Waiting for message from Host ";
NewLine[]; NewLine[]},
DO -- ignore spurious messages
inMsgPtr = GetInData();
if inMsgPtr.t.source = 0 THEN
EXIT
ELSE -- not from host
IF Debug > 2 THEN
{WriteString"got a spurious message from ";
WriteDecinal[inMsgPtr.t source];
NewLine[]},
zone.FREE[@inMsgPtr];
ENDLOOP;
WITH a: inMsgPtr.t.message SELECT FROM
ProblemMessage = >
{Style = a.Kind,
P = a.Prob,
AnswerSpec = a.Answer;
PartitionSize = a.PartSize,
WorkFract = a.WorkFraction;
WorkFract = -1;
NumHelpers = a.NumHelp;
IF NumHelpers > = PartitionSize THEN
 NumHelpers = PartitionSize - 1;
Debug = a.Debug.Level};
ENDCASE;
zone.FREE[@inMsgPtr];
WHILE Seq < MyName - 1
DO
HelperList[Seq] = Seq + 1;
Seq = Seq + 1
ENDLOOP;
WHILE Seq < PartitionSize - 1
DO
HelperList[Seq] = Seq + 2;
Seq = Seq + 1
ENDLOOP;
IF Termination = FALSE,
NextToAsk = MyName MOD PartitionSize + 1;
DeweyPrefix.Length = MaxDepth;
StartTime += Get();
Append[];
StartTime[CommTime],
Syncronize[];
Seq = 0;
WHILE Seq < = 3 + MaxRedundancy
DO
Time[Seq] = 0;
Seq = Seq + 1;
ENDLOOP;
LocalSequence = 0;
IF Style = 0 THEN
{DEBUG2, "start by begging ";
CurrentRedundancy = 10;
Depth = 0;
GimmeAwayDepth = 1;
WHILE (NOT Termination) AND (AvailWorkCount = 0)
DO
AskForHelp[TRUE, MyName, 0];
Dummy = CheckIncoming[TRUE];
ENDLOOP
ELSE -- we are born rich
{CurrentRedundancy = 0;
Dew.Length = 0;
ParPtr.Getting[Dew, P, 0];
GivingParPtr, P, Dew.Open, CurrentRedundancy];
WHILE (NOT Termination) AND (AvailWorkCount # 0)
DO
BackTrack[];
Depth = 0;
GiveAwayDepth = 1;
IF (NOT Termination) AND (AvailWorkCount = 0)
DO
AskForHelp[FALSE, MyName, 0];
CurrentRedundancy = 10;
WHILE (NOT Termination) AND (AvailWorkCount = 0)
DO
Dummy = CheckIncoming[TRUE];
ENDLOOP;
ELSE either (1) we aborted or (2) finished some work or
(3) heard Termination. In cases (1) and (2), there
is already something waiting of greater importance
in WorkGiven >>
ENDLOOP;
IF Termination THEN
DropOut[];
zone.FREE[@CurrentProblem];
HouseKeeping[];
ENDLOOP;
END;
END -- NodeInit
}
DIRECTORY
IO,
TimeMeasureDs,
System USING [GetClockPulses, GetGreenwichMeanTime, PulsesToMicroseconds];

TimeMeasureimpl: PROGRAM
IMPORTS IO, System
EXPORTS TimeMeasureDs =

BEGIN
OPEN IO, System, TimeMeasureDs;

Get: PUBLIC PROCEDURE[] RETURNS [TimeMeasure] =
{RETURN [TimeMeasure[gmt: GetGreenwichMeanTime(),
pulses: GetClockPulses()]];

ElapsedTime: PUBLIC PROCEDURE[time: TimeMeasure] RETURNS [Millisecs] =
BEGIN
  timeNew: TimeMeasure ← Get();
  RETURN
  IF timeNew.gmt − time.gmt > 3600 THEN (timeNew.gmt − time.gmt)*11
  ELSE PulsesToMicroseconds[(timeNew.pulses − time.pulses)]/1000;
END;

WriteMillisecs: PUBLIC PROC [m: Millisecs] =
BEGIN
  sec: LONG CARDINAL;
  min: LONG CARDINAL;
  hr: LONG CARDINAL;
  sec ← m/1000;
  min ← sec/60;
  hr ← min/60;
  m ← m MOD 1000;
  sec ← sec MOD 60;
  min ← min MOD 60;
  WriteLineDecimal[hr]; WriteChar[‘ ’];
  WriteLineDecimal[min]; WriteChar[‘ ’];
  WriteLineDecimal[sec]; WriteChar[‘ ’];
  WriteLineDecimal[sec];
END,