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INTRODUCTION

The Hypercluster at NASA-Lewis

The Hypercluster is a modification of the popular hypercube architecture. Each node of the Hypercluster consists of a cluster of processors, rather than a single processor, as illustrated in Figure 1 (see page 65). Each processor is identified by a node ID and a processor ID. Several computational processors per node are available to run applications, and vector processors may be accessible to the computational processors. Several processors are also used only for communication.

A message passing kernel (MPK) resides on each processor, and controls communication among processors. FORTRAN runs on top of the MPK, and the FORTRAN-callable subroutines in the parallel processing library invoke MPK operations to manipulate information among processors.

Each processor cluster can communicate within its own cluster using shared memory. A shared memory area must be established (using a parallel processing library subroutine) in order to be accessed from a FORTRAN program. Synchronization is necessary among processors accessing shared memory, so several synchronization alternatives are offered in the library.

Processors located in different clusters must communicate using message passing. Messages are routed throughout the Hypercluster using the hypercube topology. Parallel processing library subroutines allow each Hypercluster processor to access any other processor in the system. This architecture allows the programmer to explore both shared memory and distributed memory operations, as well as a combination of the two, within a single programming environment.
Introduction

The Parallel Processing Library

A Parallel Processing Library has been developed to assist the FORTRAN programmer working with the Hypercluster. This library consists of FORTRAN-callable subroutines which enable the user to manipulate and transfer information throughout the Hypercluster. The subroutines in this library are currently the only method available to FORTRAN programmers to communicate program data between Hypercluster processors.

The Parallel Processing Library is divided into three areas. The first area involves operations to establish and manipulate shared memory. The second area involves operations to manipulate information in a distributed memory environment. The third area involves miscellaneous operations such as manipulating a timer, or identifying a processor. Each of these areas is described in detail in a separate section of this manual.

The last section of this manual includes a simple programming example which employs many of the subroutines from the Parallel Processing Library. This sample problem may assist FORTRAN programmers in converting their own codes for execution on the Hypercluster.
SHARED MEMORY SUBROUTINES

Establishing Areas of Shared Memory

A shared memory area may be established within a node of the Hypercluster. A processor can establish a connection to a shared memory area on its node, and can access the information stored there as if the information were located in its own local memory. This allows processors within a node to exchange information, enabling parallel processing within a node.

A shared memory area can only be established among computational processors. Variables to be shared are located in the first common block that is declared in each program segment which uses one of the shared variables. A parallel processing library subroutine, ASHRDL, establishes a connection to the shared memory area and specifies on which processor a shared memory area is to be located. The entire shared common block is located on that specified processor; it cannot be divided so that some variables are stored on one processor and some variables are stored on another processor.

In the example below, program CALCTMP is executed on processor 1. The variables TEMP, PR, and DENS are stored and accessed from the local memory of processor 3.
Shared Memory Subroutines

P1

PROGRAM CALCTMP
COMMON /SHRDV/ TEMP,PR,DENS
COMMON /OTHER/ X,Y,Z,TIME
C
   CALL ASHRDL (3)
   CALL DSHRDL (3)
C
   STOP
END

Any link to a shared memory area which is established using ASHRDL must be eliminated using DSHRDL before exiting a program segment. This action is necessary to maintain FORTRAN's internal representation of common blocks.

Synchronization

All processors who have access to a shared memory area can potentially access that shared area simultaneously. Synchronization is necessary to control shared memory accesses, guaranteeing that information is updated appropriately.

The following synchronization routines are available in the Parallel Processing Library:

- SYNC, which is a barrier synchronization method
- LOCK and UNLOCK, which provide for protecting critical sections of code
- POSTEV, WAITEV, and CLREV, which provide a method of dictating the order of events which occur across multiple processors.

Subroutines

A detailed description of each shared memory subroutine included in the Parallel Processing Library follows.
SUBROUTINE: **ASHRDL**

**FORMAT:**

```fortran
CALL ASHRDL (pid)
```

| **pid** | Integer variable or constant specifying the processor on which a shared memory area is to be located. It can be any computational processor on the node. |

**DESCRIPTION:**

ASHRDL establishes a link to a shared memory area on the processor specified by parameter *pid*. This link is established within a particular program segment, defined as a main program or a subroutine. Any program segment which accesses a shared variable must call ASHRDL to establish a link to the shared memory area.

A shared memory area is defined by the first declared common block in a program segment. All accesses to variables in that common block are made to the shared area on processor *pid*. Processor *pid* owns the shared data area, but once ASHRDL is called, the calling processor has access to the shared data as if the data were its own local data. If the calling processor is *pid*, all accesses to variables in that common block are made to its own memory.

In the example on page 07, program CALLTMP is executed on processor 1, and program CALCPR is executed on processor 3. The shared memory area defined by common block `/SHRDV/` is located on processor 3. All references to variables TMP, PR, and DNS in the main program of CALLTMP, or T, P, and D in SUBR1 are made to processor 3's copy of these variables.

Any link to a shared memory area which is established in a program segment using ASHRDL must be eliminated in that program segment using subroutine DSHRDL, as demonstrated in the example.
Shared Memory Subroutines

SUBROUTINE: DSHRDL

FORMAT: CALL DSHRDL (pid)

pid Integer variable or constant specifying the processor on which a shared memory area is located. It must be the same computational processor on which the shared region was previously established using subroutine ASHRDL.

DESCRIPTION:

DSHRDL eliminates a link to a shared memory area on the processor specified by parameter pid. This link was previously established by the ASHRDL subroutine. Any program segment which established a link to a shared data area must call DSHRDL to eliminate that link.

An example follows.
EXAMPLE for ASHRDL and DSHRDL

**P1**

```plaintext
PROGRAM CALCTMP
COMMON /SHRDV/ TMP, PR, DNS
COMMON /OTHER/ X, Y, Z, T

C Establish a link to the shared area
C SHRDV on processor 3

CALL ASHRDL (3)

. .

TMP = A + B
X = PR * C

. .

CALL SUBR1

. .

C Eliminate link to SHRDV
CALL DSHRDL (3)
STOP
END

SUBROUTINE SUBR1
COMMON /SHRDV/ T, P, D

C This is a new program segment,
C so establish a link to SHRDV
C on processor 3
CALL ASHRDL (3)

. .

X1 = D * (A1 + A2)

. .

C Eliminate link to SHRDV
CALL DSHRDL (3)
RETURN
END
```

**P3**

```plaintext
PROGRAM CALCPR
COMMON /SHRDV/ T1, P1, D1

C Establish a link to the shared area
C SHRDV on processor 3

CALL ASHRDL (3)

. .

D1 = C + D * E
T1 = D + F

. .

C Eliminate link to SHRDV
CALL DSHRDL (3)
STOP
END
```
**Shared Memory Subroutines**

**SUBROUTINE:**   SYNC

**FORMAT:**       CALL SYNC (num, idlist)

- **num**  Integer variable or constant specifying the number of processors to synchronize.

- **idlist**  Integer array specifying the processor ids to be synchronized (includes the calling processor). All processors in idlist must be computational processors within a single node.

**DESCRIPTION:**

SYNC provides a synchronization facility to maintain shared memory activities within a node. It is a barrier-type synchronization operation, where num processors specified by idlist must come to a common synchronization point before any are allowed to continue execution. A timeout mechanism is built into this synchronization to avoid deadlock. If a timeout situation should occur, an advisory message is sent to the operating system, and program execution terminates.

This method is used to synchronize activities among processors. For example, only one processor should initialize a shared variable. Other processors on the node should not access the variable before it is initialized. SYNC is used to detain other processors until the initialization is complete, as illustrated in the example which follows.
EXAMPLE for SYNC

P1

PROGRAM CALCTMP
COMMON /SHRDV/ TMP,PR,DNS
COMMON /OTHER/ X,Y,Z,TIME
DIMENSION IVAR(2)

C Establish a link to the shared
C area SHRDV on processor 3
CALL ASHRDL (3)

C Synchronize with proc 3
C (waiting for 3 to
C initialize shared vars)
IVAR(1)= 1
IVAR(2)= 3
CALL SYNC (2,IVAR)

C Eliminate link to SHRDV
CALL DSHRDL (3)
STOP
END

P3

PROGRAM CALCPR
COMMON /SHRDV/ T1,P1,D1
DIMENSION IVAR(2)

C Establish a link to the shared area
C SHRDV on processor 3
CALL ASHRDL (3)

C Initialize shared variables
T1= 98.6
P1= 1.0
D1= 4.6

C Synchronize with proc 1
IVAR(1)= 1
IVAR(2)= 3
CALL SYNC (2,IVAR)

C Eliminate link to SHRDV
CALL DSHRDL (3)
STOP
END
**Shared Memory Subroutines**

**SUBROUTINE:** LOCK

**FORMAT:**

CALL LOCK (isem)

- isem: Integer variable used as a semaphore.

**DESCRIPTION:**

LOCK provides synchronization to protect a critical region in shared memory. It is used with the UNLOCK subroutine. Both subroutines operate on a special type of variable called a semaphore.

A semaphore, isem, is shared among the processors which operate on it. Subroutine LOCK guarantees that only one processor on a node has access to isem at one time. Once a processor gains access to isem, all other processors wanting access must idle until isem is UNLOCKed. The LOCKing processor essentially blocks others until it is finished with what it is doing. This allows one processor to gain access to a critical region and manipulate shared variables without interference from other processors. When finished, isem is UNLOCKed, allowing a waiting processor to access the critical region.

Any processors waiting for access to isem sit in an idle loop, waiting for isem to be UNLOCKed. A timeout mechanism is built into this idle loop to avoid deadlock. If a timeout situation should occur, an advisory message is sent to the operating system, and program execution terminates.

For an example, see page 12.
SUBROUTINE: UNLOCK

FORMAT: CALL UNLOCK (isem)

isme Integer variable used as a semaphore.

DESCRIPTION:

UNLOCK signals that a processor has exited a critical region. It is used in conjunction with subroutine LOCK. Both subroutines operate on a special type of variable called a semaphore. A semaphore, isem, is shared among the processors which operate on it. UNLOCK clears semaphore isem, enabling another processor to gain access using subroutine LOCK. The critical region which was protected by isem is now available to the next processor attempting to make access.

An example follows.
EXAMPLE for LOCK and UNLOCK

P1

PROGRAM MAIN1
COMMON /COM/ ISEM,N,NH
DIMENSION IVAR(2)

C Establish a link to the shared area COM on processor 3
CALL ASHRDL (3)

C Synchronize with proc 3 (waiting for 3 to initialize shared vars)
IVAR(1) = 1
IVAR(2) = 3
CALL SYNC (2,IVAR)

C Perform first half of iteration, steps 1..NH
DO 10 J = 1, NH
  .
C Attempt to access critical section
CALL LOCK (ISEM)
  (execute code in critical section)
  .
C Exit critical section
CALL UNLOCK (ISEM)
  .
10 CONTINUE

C Eliminate link to COM
CALL DSHRDL (3)
STOP
END

P3

PROGRAM MAIN2
COMMON /COM/ ISEM,N,NH
DIMENSION IVAR(2)

C Establish a link to the shared area COM on processor 3
CALL ASHRDL (3)

C Initialize shared variables
ISEM = 0
N = 100
NH = N/2

C Synchronize with proc 1
IVAR(1) = 1
IVAR(2) = 3
CALL SYNC (2,IVAR)

C Perform second half of iteration, steps NH+1..N
DO 10 J = NH+1, N
  .
C Attempt to access critical section
CALL LOCK (ISEM)
  (execute code in critical section)
  .
C Exit critical section
CALL UNLOCK (ISEM)
  .
10 CONTINUE

C Eliminate link to COM
CALL DSHRDL (3)
STOP
END
SUBROUTINE: POSTEV

FORMAT: CALL POSTEV (ievt)

ievt Integer variable used as an event flag. The value of this flag can be "posted" or "cleared."

DESCRIPTION:

POSTEV provides synchronization which allows a programmer to dictate the order of activities (or "events") which occur across multiple processors. This subroutine is used in conjunction with WAITEV and CLREV. Each of these subroutines operates on a special type of variable called an event flag. An event flag, ievt, is shared among the processors which operate on it.

An event is an occurrence of some specific event within a program's execution. For example, one processor may calculate a value which is required by other processors. That processor posts the event "calculation complete." Other processors waiting on this event (WAITEV) can then proceed. Note that it is not logical to re-post an event which has already been posted.

For an example, see page 16.
Shared Memory Subroutines

SUBROUTINE: WAITEV

FORMAT: CALL WAITEV (ievt)

ievt Integer variable used as an event flag. The value of this flag can be "posted" or "cleared."

DESCRIPTION:

WAITEV provides synchronization which allows a programmer to dictate the order of activities (or "events") which occur across multiple processors. This subroutine is used in conjunction with POSTEV and CLREV. Each of these subroutines operates on a special type of variable called an event flag. An event flag, ievt, is shared among the processors which operate on it.

A processor waits on an event which is posted by another processor. (Note that it is not logical for a processor to wait on an event which it posts itself.) If an event has been posted, control is returned to the calling program. When an event has not been posted, the processor idles until that event is posted. A timeout mechanism is built into this idle loop to avoid deadlock. If a timeout should occur, an advisory message is sent to the operating system, and program execution terminates.

For an example, see page 16.
SUBROUTINE: CLREV

FORMAT: CALL CLREV (ievt)

ievt Integer variable used as an event flag. The value of this flag can be "posted" or "cleared."

DESCRIPTION:

CLREV provides synchronization which allows a programmer to dictate the order of activities (or "events") which occur across multiple processors. This subroutine is used in conjunction with POSTEV and WAITEV. Each of these subroutines operates on a special type of variable called an event flag. An event flag, ievt, is shared among the processors which operate on it.

Once an event has been posted, and all waiting processors have proceeded, that event should be cleared. This is especially significant when the manipulation of event flags occurs within a loop, as demonstrated in the example that follows. A previously posted event must be cleared before the next iteration re-posts to that same event.
Shared Memory Subroutines

EXAMPLE for POSTEV, WAITEV, and CLREV

P1

PROGRAM MAIN1
COMMON /COM/ IEV1,IEV2,X
DIMENSION IVAR(2)

C Establish a link to the shared area
C COM on processor 1
CALL ASHRDL (1)

C Initialize shared variables
IEV1= 0
IEV2= 0
X= 100.0

C Synchronize with proc 2
IVAR(1)= 1
IVAR(2)= 2
CALL SYNC (2,IVAR)

DO 10 J= 1,100,2
    .
    (perform EVENT #1)
C Signal completion of event #1
CALL POSTEV (IEV1)

C Wait for event #2 to complete
C CALL WAITEV (IEV2)

C Clear event #2 for next iteration
C CALL CLREV (IEV2)

10 CONTINUE

C Eliminate link to COM
CALL DSHRDL (1)

STOP
END

P2

PROGRAM MAIN2
COMMON /COM/ IEV1,IEV2,X
DIMENSION IVAR(2)

C Establish a link to the shared area
C COM on processor 1
CALL ASHRDL (1)

C Synchronize with proc 1
C (waiting for 1 to initialize shared vars)
IVAR(1)= 1
IVAR(2)= 2
CALL SYNC (2,IVAR)

DO J= 2,100,2
    .
    (perform EVENT #2)
C Clear event #1 for next iteration
C CALL CLREV (IEV1)

10 CONTINUE

C Eliminate link to COM
CALL DSHRDL (1)

STOP
END
DISTRIBUTED MEMORY SUBROUTINES

Methods of Transferring Distributed Information

Because the Hypercluster is also a distributed memory architecture, a method of communicating information between distributed nodes is provided. The Parallel Processing Library provides two methods of distributed information transfer.

The first type is an indirect, synchronous transfer, which involves both the sender and the receiver in the transfer of information. The exact address of the source or destination of the information is unknown. Subroutines to perform this type of transfer include:

- OPENCH
- SEND
- SENDB
- RECV
- RECEVW
- BRDCST

The second type of distributed information transfer is a direct, asynchronous transfer, which involves only the initiator in the transfer of information. In this situation, the exact source and destination locations are known. It is the responsibility of the FORTRAN programmer to determine whether the transfer is complete before accessing the information involved. Subroutines to perform this type of transfer include:

- READM
- WRITEM
Distributed Memory Subroutines

These distributed information transfer methods are most often used between processors on different nodes, although they can be used between processors within a node. Each type of transfer is described individually below, along with a description of the subroutines which perform that type of transfer.

Parameters and Restrictions

Most distributed memory subroutines require the number of bytes being transferred as a parameter. Table 1 lists each FORTRAN data type, along with its corresponding number of bytes (see page 63).

One restriction on distributed memory transfers involves variables in shared memory. Certain distributed memory subroutines (SEND, READM, WRITEM) will not perform correctly when transferring variables in shared memory. The safest method to avoid transfer problems in this situation is to allow only the processor on which a shared area is located to transfer a variable in shared memory.

Indirect Information Transfers

Indirect information transfers provide a synchronous method of transferring information among processors in the Hypercluster. This method requires both the sender and the receiver to be involved in the transfer of information.

A logical link is established between the processors intending to transfer information. This logical link is referred to as a channel. Once a channel is established, information may be sent or broadcast to another processor who has access to that channel. That processor may then receive the information when needed.

Two types of sends (SEND, SENDB) and two types of receives (RECV, RECVW) are included in the Parallel Processing Library. The difference between the send subroutines involves where the information is located during the transfer. The difference between the receive subroutines involves the subroutine response when information is unavailable.
Distributed Memory Subroutines

Direct Information Transfers

Direct information transfers provide an asynchronous method for transferring information among processors in the Hypercluster. This method takes advantage of the MPK's built-in ability to read and write information between any two processors in the configuration.

A direct information transfer requires the physical location of the information source and destination, which is generally unavailable to FORTRAN programmers. To overcome this obstacle, FORTRAN programmers can use the structure of FORTRAN common blocks to their advantage, to "fool" the system into thinking they know the proper physical locations of the information being transferred.

The example below illustrates this technique. Common block A on node 1, processor 2 (N1P2) and common block B on N0P3 are located at the same physical address in their respective memories. Common block C on N1P2 and common block D on N0P3 are located at the same physical address in their respective memories. This is because of the way FORTRAN allocates common block storage. Thus the address of variable X on N1P2 is the same as the address of variable C on N0P3. The address of array U on N1P2 is the same as the address of array F on N0P3. In the example below, the WRITEM subroutine writes the value of X on N1P2 to variable H on N0P3. READM reads array F on N0P3, and stores it in array U on N1P2.

```
N1P2

PROGRAM MAIN1
COMMON /A/ X,Y,Z(100)
COMMON /C/ T,U(5),V
CALL WRITEM (X,0,3,Y,4,IFLG)
CALL READM (0,3,U,U,20)
STOP
END

N0P3

PROGRAM MAIN2
COMMON /B/ C,H,E(100)
COMMON /D/ A,F(5),G

CALL WRITEM (X,0,3,Y,4,IFLG)
CALL READM (0,3,U,U,20)
STOP
END
```

It must be remembered that these routines are asynchronous, so more responsibility is required from the programmer to guarantee that information exists before it is accessed, or that information has been transferred before it is altered.

Subroutines

A detailed description of each distributed memory subroutine included in the Parallel Processing Library follows.
Distributed Memory Subroutines

SUBROUTINE: OPENCH

FORMAT: CALL OPENCH (channel, node id, proc id)

channel Integer variable or constant specifying the identification number of a logical link to another processor. This other processor is defined by parameters node id and proc id.

node id Integer variable or constant specifying node id.

proc id Integer variable or constant specifying processor id.

DESCRIPTION:

OPENCH establishes a logical link, or channel, between the calling processor and the processor specified by parameters node id and proc id. A channel is required to send, receive, or broadcast a message through the Hypercluster. The closing of a channel is handled by the MPK.

There are 32 available channels, numbered 0 through 31. A channel used by the sender or broadcaster of a message must have the same id number as the channel used by the receiver(s) of the message. To avoid confusion in assigning channel numbers, a convention has been adopted where channel numbers 0,1,2,… will be assigned to messages being sent and received. Channel numbers 31,30,29,… will be assigned to messages being broadcast and received.

All processors involved in a specific broadcast must use the same channel id number. This channel number cannot be used by processors which are not involved in the broadcast. In particular, a channel which is set up for the purpose of a broadcast cannot be used for an individual send/receive. A "dummy" channel is established by the broadcasting processor. Non-valid entries of -1 are supplied as OPENCH parameters node id and proc id. These entries indicate that this processor is broadcasting a message to multiple processors on the same channel. Processors receiving a broadcast establish a valid channel, specifying the broadcaster's id as parameters node id and proc id.

An example follows.
EXAMPLE for OPENCH

PROGRAM MAIN1

CH = 1
NDID = 3
PRID = 2

C Open channel 1 to node 3, processor 2
CALL OPENCH (CH, NDID, PRID)

STOP
END
Distributed Memory Subroutines

SUBROUTINE: SEND

FORMAT: CALL SEND (channel, msg, num, flag addr)

channel Integer variable or constant specifying the identification number of a logical link to another processor.

msg Variable to be transferred.

num Integer variable specifying the number of bytes to transfer.

flag addr Integer variable which is returned to the user. It contains the address of a word which is cleared once the transfer is initiated.

DESCRIPTION:

SEND synchronously transmits information from one processor to another. This subroutine must be coupled with a receive subroutine (RECV or RECVW) executed on the receiving processor. The channel declared by the sender of the information must be the same as the channel used by the receiver of the information. Msg can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Num indicates the number of bytes to transfer, and must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

The sending processor can poll the word to which flag addr points to determine whether the transfer has been initiated. When this memory location is clear, the transfer has been initiated. SEND is distinguished from SENDB because the information being transferred using SEND is not physically included in the initial message. Thus the information transferred using SEND cannot be altered until the programmer is sure that the transfer has been initiated (i.e., the word pointed to by flag addr is clear). Note that the term word implies a two-byte memory location. The example below includes a test sequence which is recommended in order to poll this variable correctly. The function WORD is supplied by FORTRAN 77 (ABSOFT, 1986).

It must be noted that if SEND is used to transfer a variable in shared memory, then that shared data area must be located on the processor performing the SEND. If the shared variable is located elsewhere, SEND does not perform correctly. A SENDB can be used in this situation to avoid a transfer error.

An example follows.
EXAMPLE for SEND

N0P3

PROGRAM MAIN1
DIMENSION X(10)
INTEGER*2 IVAL

CALL OPENCH (2,3,2)
CALL SEND (2,X,40,IFADDR)

C Variable Y is now available for use
Z = 2*Y(3) - C

IVAL = WORD (IFADDR)
IF (IVAL .EQ. 0)
THEN WRITE (1,100)
100 FORMAT (" Message initiated")
ELSE GOTO 10

C Variable X can now be altered
C if so desired
X(1) = 100.23

STOP
END

N3P2

PROGRAM MAIN2
DIMENSION Y(10)

CALL OPENCH (2,0,3)
CALL RECVW (2,Y,40)

C Variable Y is now available for use
Z = 2*Y(3) - C

STOP
END
Distributed Memory Subroutines

SUBROUTINE: SENDB

FORMAT:
CALL SENDB (channel, msg, num)

channel
Integer variable or constant specifying the identification number of a logical link to another processor.

msg
Variable to be transferred.

num
Integer variable or constant specifying the number of bytes to transfer.

DESCRIPTION:

SENDB synchronously transmits information from one processor to another. This subroutine must be coupled with a receive subroutine (RECV or RECVW) executed on the receiving processor. The channel declared by the sender of the information must be the same as the channel used by the receiver of the information. Msg can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Num indicates the number of bytes to transfer, and must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

SENDB composes a message internally, containing a copy of the information to be transferred. Since the message contains a copy of the information, the programmer does not have to wait until the message is sent before altering this information. This distinguishes SENDB from SEND. Although costly in terms of having to make a copy of the information to be transferred, SENDB does not have to query to determine whether the transfer has been initiated in order to alter the information being sent.

An example follows.
EXAMPLE for SENDB

N0P3

PROGRAM MAIN1
DIMENSION X(10)

CALL OPENCH (2,3,2)
CALL SENDB (2,X,40)

C Variable X can now be altered if so desired
X(1)= 100.23

STOP
END

N3P2

PROGRAM MAIN2
DIMENSION Y(10)

CALL OPENCH (2,0,3)
CALL RECVW (2,Y,40)

C Variable Y can now be accessed
Z= 2*Y(3)-C

STOP
END
Distributed Memory Subroutines

SUBROUTINE: RECV

FORMAT: CALL RECV (channel, msg, num, flag)

channel
Integer variable or constant specifying the identification number of a logical link to another processor.

msg
Variable to store the received information.

num
Integer variable or constant specifying the number of bytes to be received. It must be the same number of bytes which was sent.

flag
Integer variable specifying the status of the receive operation.

DESCRIPTION:

RECV synchronously accesses information which was previously sent or broadcast by another processor. The channel declared by the sender of the information must be the same as the channel used by the receiver of the information. Msg can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Num indicates the number of bytes to be received, which must be the same number of bytes that was sent. Num must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

When the RECV subroutine is executed for a particular channel, that channel is polled to determine if a message exists. If a message is available, and the number of bytes of available information is num, then the information is transferred to variable msg, and flag is set to one. If a message is available but num bytes are not available, then the entire message has not reached the receiving processor. Flag is set to zero, indicating that the information is unavailable to the programmer. Flag is also set to zero when a message does not exist. Information is written to msg only when num bytes of information are available at the time RECV is executed. The RECV subroutine is illustrated in Example 1 on page 27.

On occasion, information may be expected across several channels. Rather than processing each channel in sequence, it may be desirable to process information in the order in which it becomes available. RECV is capable of probing a channel to determine if information is available. If the information is available, it is received from that channel and processed. If the information on that channel is not available, then the other channels are scanned. It is not necessary to wait for information on one channel while information sits idle on another channel. This scenario is illustrated in Example 2 on page 28.
EXAMPLE 1 for RECV

**N0P3**

```plaintext
PROGRAM MAIN1
DIMENSION X(10)
INTEGER*2 IVAL

CALL OPENCH (2,0,3)
CALL SEND (2,X,40,IFADDR)
C Query to determine whether the
C transfer has been initiated

10 IVAL = WORD (IFADDR)
IF (IVAL .EQ. 0)
THEN WRITE (1,100)
100 FORMAT (1X,"Message initiated")
ELSE GOTO 10

C Variable X can now be
C altered if so desired
X(1)= 100.23

STOP
END
```

**N3P2**

```plaintext
PROGRAM MAIN2
DIMENSION Y(10)

CALL OPENCH (2,0,3)

C Query to determine if
C message has been received

10 CALL RECV (2,Y,40,IFLG)
IF (IFLG .NE. 0) GOTO 20
WRITE (1,100)
100 FORMAT (1X,"Message not received")
GOTO 30

C Variable Y can now be accessed

20 Z= 2*Y(3)-C

STOP
END
```
Distributed Memory Subroutines

EXAMPLE 2 for RECV

PROGRAM MAIN1
DIMENSION X(100), Y(8), Z(39)
INTEGER STAT1, STAT2, STAT3

.;.

ICNT = 0

10 CALL RECV (1,X,400,STAT1)
IF (STAT1 .EQ. 1)
   CALL PROC C1 (X)
   ICNT = ICNT + 1
   IF (ICNT .EQ. 3) GOTO 20
ENDIF

CALL RECV (2,Y,32,STAT2)
IF (STAT2 .EQ. 1)
   CALL PROC C2 (Y)
   ICNT = ICNT + 1
   IF (ICNT .EQ. 3) GOTO 20
ENDIF

CALL RECV (3,Z,156,STAT3)
IF (STAT3 .EQ. 1)
   CALL PROC C3 (Z)
   ICNT = ICNT + 1
   IF (ICNT .EQ. 3) GOTO 20
ENDIF

GOTO 10

20 CONTINUE;
.;.
STOP
END
SUBROUTINE: RECVW

FORMAT: CALL RECVW (channel, msg, num)

channel
Integer variable or constant specifying the identification number of a logical link to another processor.

msg
Variable to store the received information.

num
Integer variable or constant specifying the number of bytes to be received. It must be the same number of bytes which was sent.

DESCRIPTION:

RECVW synchronously accesses information which was previously sent or broadcast by another processor. The channel declared by the sender of the information must be the same as the channel used by the receiver of the information. Msg can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Num indicates the number of bytes to be received, which must be the same number of bytes that was sent. Num must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

When the RECVW subroutine is executed for a particular channel, that channel is polled to determine if a message exists. If a message does not exist, the processor continues to poll, waiting for a message to become available. If a message is available, and the number of bytes of available information is num, then the information is transferred to variable msg. If a message is available but num bytes are not available, then the entire message has not reached the receiving processor. The processor continues to wait until the remaining information becomes available. Once num bytes are available, the information is transferred to variable msg. Information is written to msg only after num bytes of the information are available.

A timeout mechanism is built into RECVW to avoid a deadlock in the event that the information never becomes available. If a timeout should occur, an advisory message is sent to the operating system, and program execution terminates.

An example follows.
Distributed Memory Subroutines

EXAMPLE for RECVW

NOP3

PROGRAM MAIN1
DIMENSION X(10)

CALL OPENCH (2,3,2)
CALL SENDB (2,X,40)

C Variable X can now be
C altered if so desired
X(1) = 100.23

STOP
END

N3P2

PROGRAM MAIN2
DIMENSION Y(10)

CALL OPENCH (2,0,3)
CALL RECVW (2,Y,40)

C Variable Y is now
C available for use
Z = 2*Y(3)-C

STOP
END
SUBROUTINE: Brdcst

FORMAT: CALL BRDCST (channel, msg, num, bcode)

channel: Integer variable or constant specifying the identification number of a logical link among several processors.

msg: Variable to be transferred.

num: Integer variable or constant specifying the number of bytes to transfer.

bcode: Integer variable or constant specifying a broadcast code. Currently bcode = 2 is the only valid broadcast code.

DESCRIPTION:

BRDCST transmits a single message to many processors as efficiently as possible, using a broadcast algorithm which is built into the MPK. This algorithm transmits a message from one processor to all processors specified by a broadcast code, bcode. Several broadcast codes are provided for in the MPK; however, the Parallel Processing Library uses bcode = 2, which specifies that a message is broadcast to all computational processors.

A channel declared by the broadcaster is considered a global logical link to all other processors. Because of the global nature of this channel, non-valid entries of -1 are supplied as OPENCH parameters node id and proc id. These entries indicate that this processor is broadcasting a message to multiple processors on the same broadcast channel. All processors involved in a specific broadcast must use the same channel id number. This channel number cannot be used by processors which are not involved in a broadcast. In particular, a channel which is set up for the purpose of a broadcast cannot be used for an individual send/receive.

Msg can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Num indicates the number of bytes to transfer, and must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

BRDCST is similar to a SENDB in that a message is composed containing a copy of the information to be transferred. The programmer does not have to wait until the transfer is initiated before altering the information.

As the broadcast message is received by each individual processor, it is treated by each processor as if it were individually sent. A receive operation may access the
Distributed Memory Subroutines

information from the appropriate location as soon as it becomes available.

The situation may occur where a processor wants to transmit messages to a large number of processors, but not to all of them. At some point, it would be more efficient to broadcast that message, rather than sending it individually to so many processors. In such a case, the message would be sent to a few processors which never performed an OPENCH, RECVW, or RECV for that particular channel. Rather than generating an error message, the broadcast message is ignored by the few processors which should not receive it. Note that this situation could actually indicate an error, but this error will be overlooked for the sake of efficiency provided by the broadcast situation.

An example follows.
### EXAMPLE for BRDCST

#### N0P3

```fortran
PROGRAM BRDPROC
DIMENSION X(10)

C Open broadcast channel
CALL OPENCH (31,-1,-1)

C Broadcast array X to all computational processors
CALL BRDCST (31,X,40,2)

STOP
END
```

#### N3P2

```fortran
PROGRAM RCVPROC1
DIMENSION Y(10)

C Open channel to N0P3
CALL OPENCH (31,0,3)

CALL RECVW (31,Y,40)

C Variable Y can now be accessed
Z = 2*Y(3)-C

STOP
END
```

#### N2P2

```fortran
PROGRAM RCVPROC2
DIMENSION Y(10)

C Open channel to N0P3
CALL OPENCH (31,0,3)

CALL RECVW (31,Y,40)

C Variable Y can now be accessed
Z = 2*Y(3)-C

STOP
END
```

#### N1P2

```fortran
PROGRAM RCVPROC3
DIMENSION Y(10)

C Open channel to N0P3
CALL OPENCH (31,0,3)

CALL RECVW (31,Y,40)

C Variable Y can now be accessed
Z = 2*Y(3)-C

STOP
END
```
Distributed Memory Subroutines

SUBROUTINE: READM

FORMAT: CALL READM (node id, proc id, svar, dvar, num)

- node id: Integer variable or constant specifying the source node.
- proc id: Integer variable or constant specifying the source processor.
- svar: Variable representing the information source.
- dvar: Variable representing the information destination.
- num: Integer variable or constant specifying the number of bytes to read.

DESCRIPTION:

READM asynchronously accesses information from another processor. This information access does not require a response from the processor whose data is being read; only the reading processor is actively involved in the read operation. Parameters node id and proc id specify the processor from whom data is to be read, while num indicates the number of bytes to transfer. Num must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

A direct information transfer requires that the physical location of the information source and destination must be known. The programmer uses mapped FORTRAN common blocks in order to relate variables on one processor to variables on another. This is described on page 19. Svar represents the variable which is to be read. Although it is given in terms of the variable name on the reading processor, it may have a different name on the processor where the data is actually located. Dvar represents the variable which is to receive the data which has been read.

It is the responsibility of the FORTRAN programmer to guarantee that events are synchronized appropriately. Because of the asynchronous nature of this subroutine, it is typical to attach an extra element to the data being read, which is used as a flag to indicate whether the data has been received. A simple example is illustrated below. In this case, the array Z (or E in terms of NOP3) contains 100 data elements, and the 101st element is used as a flag to determine whether the data has been read.

It must be noted that if READM is used to read a variable which exists in another processor's shared memory area, then that shared data area must be
located on the processor from whom that data is being read. If the value being read is to be stored in a shared area by the reader, then that shared data area must be located on the processor performing READM. If the shared variable is located elsewhere, READM does not perform correctly. A synchronous send/receive combination may be used in this situation to avoid transfer errors.

**EXAMPLE for READM**

```
N1P2

PROGRAM MAIN1
COMMON /A/ Z(101)

. . .

C Clear read flag
Z(101) = 0

CALL READM (0,3,Z,Z,404)

C Wait for data to become available
ICNT = 100
20 IF (Z(101).NE.0) GOTO 30
   ICNT = ICNT-1
   IF (ICNT .GT. 0) GOTO 20
GOTO 40

C Variable Z can now be accessed
30 X = 2*Z(I)-D

40 STOP
END

N0P3

PROGRAM MAIN2
COMMON /B/ E(101)

DO 10 I=1, 100
   E(I) = 3*(F+G)
10

C Set read flag to indicate that data is available
E(101) = 1

CNT = 100
IF (Z(101).NE.0) GOTO 30
   ICNT = ICNT-1
   IF (ICNT .GT. 0) GOTO 20
GOTO 40

C Variable Z can now be accessed
30 X = 2*Z(I)-D

40 STOP
END
```
Distributed Memory Subroutines

SUBROUTINE: WRITEM

FORMAT: CALL WRITEM (svar, node id, proc id, dvar, num, flag addr)

svar Variable to be transferred.
node id Integer variable or constant specifying the destination node.
proc id Integer variable or constant specifying the destination processor.
dvar Variable representing the information destination.
um Integer variable or constant specifying the number of bytes to write.
flag addr Integer variable which is returned to the user. It contains the address of a word which is cleared once the transfer is initiated.

DESCRIPTION:

WRITEM asynchronously transfers information to another processor. This information transfer does not require the assistance of the destination computational processor. Svar can be any variable in the FORTRAN program. It can be an array name, or even a section of an array. Node id and proc id specify the processor to which the data is to be written, while num indicates the number of bytes to transfer. Num must be less than 64 kbytes. The number of bytes for various FORTRAN data types is listed in Table 1 (see page 63).

A direct information transfer requires that the physical location of the information source and destination must be known. The programmer uses mapped FORTRAN common blocks to relate variables on one processor to variables on another. This is described on page 19. Dvar can be any variable in the FORTRAN program. It also can be an array name, or even a section of an array.

The programmer is responsible for guaranteeing that information exists before it is accessed, or that information has been transferred before it is altered. The writing processor can poll the word to which flag addr points to determine whether the transfer has been initiated. When this memory location is clear, the transfer has been initiated. This is similar to the synchronous SEND subroutine. The information transferred using WRITEM cannot be altered until it is sure that the transfer has been initiated (i.e., the word pointed to by flag addr is clear). Note that the term word implies a two-byte memory location. The example below includes a test sequence which is recommended in order to poll this variable correctly. The function WORD is supplied by FORTRAN 77 (ABSOFT, 1986).
Distributed Memory Subroutines

When data is written to another processor, that processor is not notified that the data exists. It is the responsibility of the FORTRAN programmer to guarantee that events are synchronized appropriately. Because of the asynchronous nature of this subroutine, it is typical to attach an extra element to the data being written, which is used as a flag to indicate to the receiving processor that the information exists. A simple example is illustrated below. In this case, the array U (or F in terms of N0P3) contains 20 data elements, and the 21st element is used as a flag to determine whether the data has been written.

It must be noted that if WRITEM is used to write a variable which exists in a shared memory area, then that shared data area must be located in the processor performing WRITEM. If the value being written is to be stored in a shared area on the destination, then that shared data area must be located on the processor where the data is being written. If the shared variable is located elsewhere, WRITEM does not perform correctly. A synchronous send/receive combination may be used in this situation to avoid transfer errors.
Distributed Memory Subroutines

EXAMPLE for WRITEM

N1P2

PROGRAM MAIN1
COMMON /A/ X,Y,Z(100)
COMMON /C/ T,U(21),V
INTEGER*2 IVAL

C Set write flag
U(21) = 1

C Write variable U to N0P3
CALL WRITEM (U,0,3,U,84,IFADDR)

C Query to determine whether
C the transfer has been initiated

10 IVAL = WORD (IFADDR)
   IF (IVAL .EQ. 0)
      THEN WRITE (1,100)
      ELSE GOTO 10

100 FORMAT (" Message
          initiated")
   END

C Variable U can now be
C altered if so desired
U(2)= 164.3

STOP
END

N0P3

PROGRAM MAIN2
COMMON /B/ C,H,E(100)
COMMON /D/ A,F(21),G

C Clear write flag
F(21) = 0

10 ICNT = 100
   IF (F(21) .EQ. 1) GOTO 20
   ICNT = ICNT-1
   IF (ICNT .GT. 0) GOTO 10
   GOTO 30

20 T = F(4) * 2.3

30 STOP
END

MISCELLANEOUS SUBROUTINES

Timer Operations and Processor Identification

A few miscellaneous subroutines have been included in the Parallel Processing Library to assist the FORTRAN programmer.

Several subroutines involve accessing and reading a timer. Subroutines which perform timer operations are:

- TRSET
- TRSTART
- TRSTOP
- TRREAD

Other miscellaneous subroutines included in the library assist in identifying particular processors. These subroutines are:

- NODE
- PROC
- GRAY
- GINV

Subroutines

A detailed description of each miscellaneous subroutine included in the Parallel Processing Library follows.
Miscellaneous Subroutines

SUBROUTINE: TRSET

FORMAT: CALL TRSET (pid, ivar)

pid  Integer variable or constant specifying a processor whose timer is to be set. This must be a communication processor.

ivar Integer array of timer characteristics. The elements of this array are described below.

ivar
(1) Timer type (=0 MIZAR 8115)
(2) Flag to change timer frequency
(3) Frequency range code
(4) Frequency value code
(5) Flag to change timer initial value
(6) Timer initial value

DESCRIPTION:

TRSET initializes the timer of communication processor pid. The timer characteristics to be initialized are specified by parameter ivar.

Currently only a timer on a communication processor (MIZAR 8115) can be manipulated, therefore ivar(1) must equal zero. All other values of ivar(1) are currently invalid. Should other timers be added for user access, array ivar will be altered to reflect the addition. The MIZAR timer and its parameters are described in detail in the MIZAR 8115 CPU Module User's Manual (Mizar, 1986).

Parameter ivar(2) indicates whether new frequency values are to be used for a specific timer. If ivar(2) = 1, then a new frequency range (ivar(3)) and a new frequency value (ivar(4)) must be supplied. These values can be taken from Table 2 on page 63. If ivar(2) = 0, then the default values of frequency range and frequency value are used. These default values are noted with an asterisk in Table 2 (see page 63).

Parameter ivar(5) indicates whether a new timer initial value is to be loaded. If ivar(5) = 1, then the new value is supplied in ivar(6). This parameter can have a value in the range $2 \leq \text{ivar}(6) \leq 65535$. If ivar(5) = 0, then a default value of 65535 is used.

A timer must be set before it is started or read. A processor cannot set a timer on another node. An example follows.
EXAMPLE for TRSET

NOP4

PROGRAM TIMEPRG
DIMENSION IVAR (6)

IVAR(1) = 0
IVAR(2) = 1

C Select baud range
IVAR(3) = 16
C Set for 300 baud
IVAR(4) = 68

IVAR(5) = 1
C Initial counter value
IVAR(6) = 4096
CALL TRSET (2, IVAR)
.
.
STOP
END
SUBROUTINE: TRSTRT

FORMAT: CALL TRSTRT (pid)

pid Integer variable or constant specifying the processor whose timer is
to be started. It must be a communication processor.

DESCRIPTION:

TRSTRT starts the timer of the local processor specified by pid. The timer will
continue to count down until it is stopped, or until a timeout interrupt is
generated. If a timeout should occur, an advisory message is sent to the operating
system, and program execution terminates.

For an example, see page 45.
SUBROUTINE: TRSTOP

FORMAT: CALL TRSTOP (pid)

pid Integer variable or constant specifying the processor whose timer is to be stopped. It must be a communication processor.

DESCRIPTION:

TRSTOP stops the timer of the local processor specified by pid. Every timer which is started must be stopped in order to prevent a timeout interrupt from occurring. If a timeout should occur, an advisory message is sent to the operating system, and program execution terminates.

For an example, see page 45.
Miscellaneous Subroutines

SUBROUTINE: TRREAD

FORMAT: CALL TRREAD (pid, tvar)

pid  Integer variable or constant specifying the processor whose timer is to be read. It must be a communication processor.

tvar  Integer variable which returns the timer value.

DESCRIPTION:

TRREAD reads the timer of the local processor specified by pid. This timer value is returned to the FORTRAN program in variable tvar. TRREAD is illustrated in the example below, along with other timer subroutines. Note that the timer should not be stopped until after all TRREADs have been performed.

In the example below, the timer is set at a frequency of 300 BAUD using TRSET. Note that since this is a count down timer, the second timer value is subtracted from the first in order to calculate the number of clock ticks which have transpired. The number of seconds is computed as the number of clock ticks multiplied by one over the BAUD rate. This example illustrates how to calculate timer overhead, and how to subtract it from the timing calculations.
EXAMPLE for TRSET, TRSTRT, TRSTOP, and TRREAD

NOP4

PROGRAM TIMEPRG
DIMENSION IVAR (6)

    IVAR(1) = 0
    IVAR(2) = 1
    IVAR(3) = 16
    IVAR(4) = 68
    IVAR(5) = 1
    IVAR(6) = 4096
    CALL TRSET (1, IVAR)

    BAUD = 300.0
    X = 1.0 / BAUD

    CALL TRSTRT (1)
    CALL TRREAD (1, ITIME1)
    CALL TRREAD (1, ITIME2)
    CALL TRREAD (1, ITIME1)  
             (calculation to be timed)
    CALL TRREAD (1, ITIME2)
    CALL TRSTOP (1)

    C Calculate clock ticks
    ICALC = ITIME1 - ITIME2 - IOVER

    C Calculate seconds
    FTIME = FLOAT(ICALC) * X

    WRITE (1,10) ICALC, FTIME
10 FORMAT (1X,"Calculation required",1X,I5,1X, "clock ticks, which is",1X,F10.5,1X, "seconds.")

STOP
END
Miscellaneous Subroutines

SUBROUTINE: NODE

FORMAT: CALL NODE (ndid)

ndid Integer variable which returns the current node id.

DESCRIPTION:

NODE accesses the node id of the current processor. This value is returned to the FORTRAN program in variable ndid.

For an example, see page 48.
SUBROUTINE: PROC

FORMAT: CALL PROC (pid)

pid Integer variable which returns the current processor id.

DESCRIPTION:

PROC accesses the processor id of the current processor. This value is returned to the FORTRAN program in variable pid.
Miscellaneous Subroutines

EXAMPLE for NODE and PROC

PROGRAM IDENT

CALL NODE (IND)
CALL PROC (IPR)

WRITE (1,10) IND, IPR
10 FORMAT (1X,"Greetings from node",1X,I2,1X,"processor",1X,I2)

STOP
END
SUBROUTINE: GRAY

FORMAT: CALL GRAY (ipos, igray)

ipos Integer variable or constant specifying the number to be converted to its gray code equivalent.

igray Integer variable which returns the gray code for ipos.

DESCRIPTION:

GRAY calculates the $i$th integer in the binary reflected gray code. This value is returned to the FORTRAN program in variable igray. This subroutine, along with GINV, assists in identifying nodes during program execution. Both of these subroutines involve the binary reflected gray code, which orders node numbers so that consecutive gray code numbers are adjacent nodes in the hypercube interconnection scheme. These subroutines enable a user to map a ring structure within the Hypercluster.

Table 3 lists the binary reflected gray code (see page 64). Figure 2 illustrates a ring mapped within a 3-D cube (see page 66).

For an example, see page 51.
**Miscellaneous Subroutines**

**SUBROUTINE:** GINV

**FORMAT:**

```fortran
CALL GINV (inode, iloc)
```

- **inode**: Integer variable or constant specifying the node id for which a corresponding gray code location is to be found.

- **iloc**: Integer variable which returns the location of **inode** in the gray code ordering.

**DESCRIPTION:**

GINV calculates the location of **inode** in the gray code ordering. This value is returned to the FORTRAN program in variable **iloc**. This subroutine, along with **GRAY**, assists in identifying nodes during program execution. Both of these subroutines involve the binary reflected gray code, which orders node numbers so that consecutive gray code numbers are adjacent nodes in the hypercube interconnection scheme. These subroutines enable a user to map a ring structure within the Hypercluster.

Table 3 lists the binary reflected gray code, along with the location of each id in that code (see page 64). Figure 2 illustrates a ring mapped within a 3-D cube (see page 66).
EXAMPLE for GRAY and GINV

PROGRAM IDENT

CALL NODE (IND)

C Calculate the location of IND in the gray code ordering
CALL GINV (IND, IGINV)

C Calculate the gray code of the location following IGINV.
C IRN is the right neighbor of IND in a ring.
CALL GRAY (IGINV+1, IRN)

C Calculate the gray code of the location preceding IGINV.
C ILN is the left neighbor of IND in a ring.
CALL GRAY (IGINV-1, ILN)

WRITE (1,10) IND,ILN,IRN
10 FORMAT (1X,"Node",1X,I2,1X,"Left",1X,I2,1X,"Right",1X,I2)

STOP
END
A simple programming example is included in this manual to illustrate how to use subroutines from the Parallel Processing Library. This example also gives a new user an indication of how problems can be partitioned using the Hypercluster architecture.

The example is a simple heat flow problem (Gerald, 1980) which uses Laplace's equation
\[
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0
\]
to determine the steady state temperature of a flat plate exposed to constant boundary conditions. The problem is stated as follows:

A thin steel plate is a 20 x 20 cm square. If one edge is held at 100°C, and the others are held at 0°C, what are the steady state temperatures at interior points?

The flat plate has a certain initial temperature, and is subjected to a temperature at each of its four boundaries (see Figure 3, page 67). What follows is a description of how this problem is discretized and mapped onto the Hypercluster.

To discretize this problem, the flat plate is divided into sections of size Δx by Δy. In this application, it is assumed that Δx = Δy. The resulting grid is now numbered so that each intersection represents a point of the flat plate at which a temperature can be evaluated (see Figure 4, page 68). A 14 x 14 grid is used for this example.

A central difference approximation is used to calculate the temperature $T_{ij}$ at each interior grid point. All exterior grid points assume the boundary temperatures. The iterative equation

\[
T_{ij}^{(t+1)} = \frac{T_{i+1,j}^{(t)} + T_{i-1,j}^{(t)} + T_{i,j+1}^{(t)} + T_{i,j-1}^{(t)}}{4}
\]
is used to calculate a temperature solution for each grid point \((i,j)\). The value of \(T_{ij}\) at iteration \((t+1)\) is an average of the temperatures of its four nearest neighbors at iteration \((t)\). A solution is obtained when no grid point temperature changes its value as a result of performing an iteration.

This problem can be solved using a traditional computer. As grid sizes increase, however, the amount of memory and the computational time required to solve this problem may become too large for the traditional computer. Since the temperature value at each grid point is calculated from only the neighboring grid point values, the problem can easily be divided among multiple processors. The division of the problem is illustrated in Figure 5 (see page 69). Note that at boundaries, columns are repeated to accommodate data transfers.

A program has been written for the Hypercluster to execute this problem using a variable number of processors. Each computational processor executes an identical program which is included below. Currently the program runs on one processor per node, but can easily be extended to multiple processors per node. One processor (node \(=\) IOUTN, processor \(=\) IOUTP) is singled out as a "controlling" processor, which performs I/O and convergence tests. This processor is identified in the FORTRAN PARAMETER statement.

A ring is mapped within the Hypercluster, and the computational grid is mapped to each processor as illustrated in Figure 5. The ring structure is determined within the program using library subroutines NODE, PROC, GINV, and GRAY. Each processor sends the boundary values of its portion of the grid to its neighbors; subroutines SENDB and RECVW are used to accomplish this data transmission. Each processor then performs its own calculation for a particular iteration, and determines its own convergence.

The individual convergence results are transmitted to the controlling processor on every tenth iteration to determine the convergence of the entire problem. Subroutines SENDB, RECVW, and BRDCST are used to transmit convergence information among processors. Once convergence is determined, each processor transmits its section of the grid temperature values to the controlling processor, which writes the information to an output file. The output file for this application appears on page 60. Note again that columns are repeated at the boundaries.

Implementing this application requires a significant amount of communication because of the convergence test. A more economical method could be used in place of the method demonstrated here. Subroutines to time the code performance have been included in this application. Timing results are illustrated in Table 4 (see page 64).
Application

PROGRAM CALCTEMP

C PARAMETER DESCRIPTION:

C IMAX   GRID DIMENSION IN THE Y DIRECTION
C JMAX   GRID DIMENSION IN THE X DIRECTION
C IPROC  PROCESSOR ID OF THE PROCESSOR WITHIN EACH NODE ON
C       WHICH TO EXECUTE THE CODE
C NODES  NUMBER OF NODES BEING USED FOR COMPUTATION
C IOUTN  NODE ID OF THE CONTROLLING PROCESSOR
C IOUTP  PROCESSOR ID OF THE CONTROLLING PROCESSOR
C MAXIT  MAXIMUM NUMBER OF ITERATIONS
C IPERND NUMBER OF PROCESSES USED PER NODE FOR
C       COMPUTATION

PARAMETER (IMAX=14, JMAX=5, IPROC=4, NODES=4)
PARAMETER (IOUTN=0, IOUTP=4, MAXIT=1500, IPERND=1)

DIMENSION X(IMAX,JMAX), XT(IMAX,JMAX), IVAR(6)
LOGICAL*1 CONV, RCNV, ICHK, EVEN, ICNTRL

C DETERMINE MY NODE AND PROCESSOR ID

CALL NODE (IND)
CALL PROC (IPR)

C CALCULATE MY RIGHT AND LEFT NEIGHBOR IN A RING

CALL GINV (IND, IGINV)
EVEN = MOD(IGINV,2) .EQ. 0
CALL GRAY (IGINV+1,IRN)
IF (ARGIN .NE. 0) CALL GRAY (ARGIN-1,ILN)

C IF I'M ON A BOUNDARY, SET THAT NEIGHBOR TO AN INVALID ID

IF (IND .EQ. 0) ILN = -1
IF (IRN .GE. NODES) IRN = -1

C DETERMINE IF I AM THE CONTROLLING PROCESSOR

ICNTRL = (IOUTN .EQ. IND) .AND. (IOUTP .EQ. IPR)
IF (ICNTRL) THEN
   OPEN (UNIT=2,ACTION='WRITE',ACCESS='SEQUENTIAL',
      * FORM='FORMATTED')
C INITIALIZE TIMER

IVAR(1) = 0
IVAR(2) = 1
IVAR(3) = 16
IVAR(4) = 17
IVAR(5) = 1
IVAR(6) = 65535
CALL TRSET (1,IVAR)
BAUD = 110.
F = 1./BAUD
CALL TRSTRT (1)
CALL TRREAD (1,ITIME1)
CALL TRREAD (1,ITIME2)
IOVER = ITIME1-ITIME2
ENDIF

C DETERMINE APPROPRIATE CHANNELS TO REACH EACH NEIGHBOR

IF (EVEN) THEN
  IRCH = 1
  ILCH = 2
ELSE
  IRCH = 2
  ILCH = 1
ENDIF

C OPEN CHANNELS TO VALID NEIGHBORS

IF (IRN .NE. -1) CALL OPENCH (IRCH,IRN,IPROC)
IF (ILN .NE. -1) CALL OPENCH (ILCH,ILN,IPROC)

C OPEN CHANNELS TO CONTROLLING PROCESSOR

IF (ICNTRL) THEN
  DO 5 I = 0,NODES-1
  DO 5 J = IPROC, IPROC+IPERND-1
    IF ((IND .NE. I) .OR. (IPR .NE. J)) THEN
      ICH = I*IPERND+J
      CALL OPENCH (ICH, I, J)
    ENDIF
  CONTINUE
  CALL OPENCH (31,-1,-1)
ENDIF
Application

ELSE
    IPCH = IND*IPERND + IPR
    CALL OPENCH (IPCH, IOUTN, IOUTP)
    CALL OPENCH (31, IOUTN, IOUTP)
ENDIF

C INITIALIZE GRID TEMPERATURE VALUES (BOUNDARIES)

DO 10 J = 1, JMAX
    X(1, J) = 0.
    IF (IMAX, J) = 0.
    DO 15 I = 1, IMAX
        X(I, 1) = 0.
    15 IF (IRN .NE. -1) GOTO 20
    DO 20 I = 1, IMAX
        X(I, JMAX) = 100.
    20 IF (IRN .NE. -1) GOTO 30
    DO 25 I = 1, IMAX
        X(I, JMAX) = 100.

C INITIALIZE GRID TEMPERATURE VALUES (INTERIOR POINTS)

30 DO 35 J = 2, JMAX - 1
    DO 35 I = 2, IMAX - 1
    35 X(I, J) = 25.

C ADDITIONAL PARAMETERS:

C ICOL  NUMBER OF BYTES IN A COLUMN OF DATA TO BE TRANSFERRED
C E    CONVERGENCE TOLERANCE
C IT    ITERATION COUNT

   ICOL = (IMAX-2)*4
   E = 0.001
   IT = 1

C ITERATION LOOP

   IF (ICNTRL) CALL TRREAD (1, ITIME1)

C TRANSMIT DATA TO NEIGHBORS

40 IF (IRN .NE. -1) CALL SENDB (IRCH, X(2, JMAX-1), ICOL)
   IF (ILN .NE. -1) CALL SENDB (ILCH, X(2, 2), ICOL)

C RECEIVE DATA FROM NEIGHBORS

IF (IRN .NE. -1) CALL RECVW (IRCH, X(2, JMAX), ICOL)
IF (ILN .NE. -1) CALL RECVW (ILCH, X(2, 1), ICOL)

C PERFORM CALCULATION ON MY SECTION OF GRID, AND DETERMINE MY OWN CONVERGENCE

CONV = .TRUE.
DO 50 J = 2, JMAX - 1
DO 50 I = 2, IMAX - 1
  NT(I, J) = (X(I + 1, J) + X(I - 1, J) + X(I, J + 1) + X(I, J - 1))/4.0
50  CONV = CONV .AND. (ABS(NT(I, J) - X(I, J)) .LE. E)

C UPDATE COMPUTATIONAL GRID WITH NEWLY CALCULATED VALUES

DO 55 J = 2, JMAX - 1
DO 55 I = 2, IMAX - 1
  X(I, J) = NT(I, J)
55

C CHECK CONVERGENCE ON EVERY 10TH ITERATION

ICHK = MOD(IT, 10) .EQ. 0
IF (ICHK) THEN
  IF (ICNTRL) THEN
    C CALCULATE CONVERGENCE FOR ENTIRE PROBLEM

    DO 6 I = 0, NODES - 1
    DO 6 J = IPROC, IPROC + IPERND - 1
      IF (((IND .NE. I) .OR. (IPR .NE. J)) THEN
        ICH = I*IPERND + J
        CALL RECVW (ICH, RCNV, 1)
        CONV = CONV .AND. RCNV
      ENDIF
    6 CONTINUE

  ELSE
    C BROADCAST CONVERGENCE RESULT TO ALL COMPUTATIONAL PROCESSORS

    CALL BRDCST (31, CONV, 1, 2)

  ELSE

C END

Application
Application

C SEND MY OWN CONVERGENCE INFORMATION TO THE CONTROLLING C PROCESSOR

    CALL SENDB (IPCH,CONV,1)

C RECEIVE CONVERGENCE RESULT FOR THE ENTIRE PROBLEM

    CALL RECVW (31,CONV,1)

ENDIF

ELSE

    CONV = .FALSE.

ENDIF

IF (CONV) THEN

    IF (ICNTRL) THEN

        CALL TRREAD (1,ITIME2)
        CALL TRSTOP (1)
        ICALC = ITIME1-ITIME2-IOVER
        FTIME = FLOAT(ICALC) * F
        RATE = FTIME/ FLOAT(IT)

        C OUTPUT RESULTS FROM CONTROLLING PROCESSOR

        WRITE (2,91) IT
        FORMAT ('" PROGRAM COMPLETED IN ",I6," ITERATIONS."')
        WRITE (2,92) FTIME
        FORMAT ('" TIME REQUIRED: ",F6.2," SECONDS")
        WRITE (2,93) RATE
        FORMAT ('" RATE: ",F8.4," SEC/IT"',//)
        WRITE (2,94) IND, IPR
        FORMAT ('" DATA FROM NODE ",I2," PROCESSOR ",I2," : ",//)
        DO 200 I=1,1MAX
            WRITE (2,95) (X(I,J), J=1,JMAX)
        CONTINUE
        WRITE (2,96)
        FORMAT (IX,//)

91   WRITE (2,91) IT
92   FORMAT (" TIME REQUIRED: ",F6.2," SECONDS")
93   FORMAT (" RATE: ",F8.4," SEC/IT"',//)
94   FORMAT (" DATA FROM NODE ",I2," PROCESSOR ",I2," : ",//)
95   CONTINUE
96   FORMAT (IX,//)
C RECEIVE AND OUTPUT RESULTS FROM REMAINING PROCESSORS

DO 7 I = 0, NODES - 1
    DO 7 J = IPROC, IPROC + IPERND - 1
        IF (((IND .NE. I) .OR. (IPR .NE. J)) THEN
            ICH = IPERND + J
            CALL RECVW (ICH, XT, IMAX*JMAX*4)
            WRITE (2, 94) IJ
            DO 201 IP = 1, IMAX
                WRITE (2, 95) (XT(IP, JP), JP = 1, JMAX)
            CONTINUE
            WRITE (2, 96)
        ENDIF
    7 CONTINUE
ELSE
C SEND RESULTS TO THE CONTROLLING PROCESSOR FOR OUTPUT
    CALL SENDB (IPCH, X, IMAX*JMAX*4)
ENDIF
ELSE
C CONTINUE CALCULATION WITH THE NEXT ITERATION
    IT = IT + 1
    IF (IT .LE. MAXIT) GOTO 40
    IF (ICNTRL) CALL TRSTOP (1)
ENDIF
C WHEN CALCULATION IS COMPLETE, CLOSE I/O UNIT
110 IF (ICNTRL) CLOSE (UNIT = 2)
    STOP
END
Application

Program Completed: 110 iterations
Time Required: .93 seconds
Rate: .0084 sec/it

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Tables and Figures

TABLES AND FIGURES

The following Tables and Figures are available for reference.

Tables

- Table #1, Size of FORTRAN Data Types
- Table #2, MIZAR Timer Parameters
- Table #3, Binary Reflected Gray Code
- Table #4, Application Timing Results

Figures

- Figure 1a, Two-Dimensional Hypercube
- Figure 1b, Two-Dimensional Hypercluster
- Figure 2, A Ring Mapped within a Three-Dimensional Cube
- Figure 3, A Simple Heat Flow Problem
- Figure 4, A 14 x 14 Computational Grid
- Figure 5, Problem Division for Multiple Nodes
Table 1
Size of Fortran Data Types

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<tr>
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<tr>
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<tr>
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<tr>
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<tr>
<td>9600</td>
<td>16</td>
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</tr>
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<td>19.2 K</td>
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</tr>
<tr>
<td>38.4 K</td>
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### Table 3
**Binary-Reflected Gray Code**

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</tr>
<tr>
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### Table 4
**Application Timing Results**

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<th>Number of Processors</th>
<th>Grid size</th>
<th>Time (seconds)</th>
<th>Speedup</th>
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</table>
Figure 1a. 2-D hypercube

Figure 1b. 2-D Hypercluster

P = Processor
M = Shared Memory
Figure 2. Ring mapped within a 3-D cube.
Figure 3. Thin steel plate which is 20 cm x 20 cm.
One edge is held at 100°C. The other edges are held at 0°C.
Tables and Figures

Figure 4: 14 x 14 computational grid
Tables and Figures

Figure 5. Division of problem for multiple nodes.

Hypercluster Library User's Manual
The Hypercluster is a many-facettted architecture. A list of reference manuals is included here for users needing further details about the system.

- For more information on the MIZAR timers, refer to the *MZ 8115 CPU Module User's Manual*, Board Revision E, 1986.

- For information on the FORTRAN compiler, refer to the *FORTRAN 77 Compiler and Debugger Reference Manual*, V2.2 ABSOFT, Inc., 1986.


This User’s Manual describes the Hypercluster Parallel Processing Library, composed of FORTRAN-callable subroutines which enable a FORTRAN programmer to manipulate and transfer information throughout the Hypercluster at NASA Lewis Research Center. Each subroutine and its parameters are described in detail. A simple heat flow application using Laplace’s equation has been included to demonstrate the use of some of the library’s subroutines. The manual can be used initially as an introduction to the parallel features provided by the library. Thereafter it can be used as a reference when programming an application.