Parallel Programming Basic MPI

Timothy H. Kaiser, Ph.D.
tkaiser2@nrel.gov

Session 1: Introduction to MPI (this invitation)
Monday, January 24th 11:00 AM - 12:00 PM Mountain

The first session will introduce MPI. We will give a background, show some sources of Documentation. We will show the classic "Hello world" program in MPI running on multiple processors. We will discuss Basic communications and show a simple send and receive program where messages are passed between processors. We will be running examples in the official languages supported by MPI, C and Fortran. Also, we will briefly discuss support for Python, R, and Java. Source code and scripts will be provided that can be run on Eagle.

Session 2: Expansion to Higher-level MPI Calls
Monday, January 31st 11:00 AM - 12:00 PM Mountain

The second session will expand on the first, showing many of the higher-level MPI calls commonly used to write parallel programs. Examples will be provided that can run on Eagle. We will look at: using the various predefined data types, broadcast, wildcards, asynchronous communications, and using probes and status information to control flow.

Session 3: Additional Collective Operations
Monday, February 7th 11:00 AM - 12:00 PM Mountain

In the third MPI session, we will look at additional collective operations including scatter, gather, and reductions. We'll also show examples of the "variable" versions of these calls where the amount of information shared is processor-dependent. We'll look at creating derived data types and managing subsets of processes using communicators.

Session 4: Finite Difference Model
Monday, February 14th 11:00 AM - 12:00 PM Mountain

In the fourth session, we will introduce a finite difference model that will demonstrate what a computational scientist needs to do to take advantage of computers using MPI. The model we are using is a two-dimensional finite-difference code. After discussing the serial code, we will show the modifications necessary to turn it into a parallel program using MPI. We will look at domain decomposition, initialization, data distribution, message passing, reduction operations, and multiple methods for data output. We will also look at the performance of the application on various numbers of processors to illustrate Amdahl's parallel program scaling law.

Examples and Slides

Examples:

```
git clone https://github.com/timkphd/examples
cd examples/mpi
```

Slides:

https://github.com/timkphd/slides

Talk Overview

- Background on MPI
- Documentation
- Hello world in MPI
- Basic communications
- Simple send and receive program

Background on MPI

- MPI - Message Passing Interface
  - Library standard defined by a committee of vendors, implementers, & parallel programmers
  - Used to create parallel programs based on message passing
- Portable: one standard, many implementations
- Available on almost all parallel machines in C and Fortran
- Over 100 advanced routines but 6 basic
- Also used to create libraries.

Unofficial Languages

- Subsets available for R and Java
- Fairly complete implementation for Python
- Let me know if you are interested in these
- I have not looked at Julia

Documentation

- MPI home page (contains the library standard) https://www.mpi-forum.org
- Books
  - "MPI: The Complete Reference" by Snir, Otto, Huss-Lederman, Walker, and Dongarra, MIT Press (also in Postscript and html)
  - "Using MPI" by Gropp, Lusk and Skjellum, MIT Press
- Tutorials
  - many online, just do a search

MPI Implementations

- Most parallel supercomputer vendors provide optimized implementations
- Intel
- HP/SGI/Cray - mpt
- IBM

Open Source MPI Implementations

- MPICH:
  - https://www.mpich.org
- Mvapich
  - http://mvapich.cse.ohio-state.edu
- OpenMPI
  - www.open-mpi.org

Key Concepts of MPI

- Used to create parallel programs based on message passing
  - Normally the same program is running on several different processors
  - Processors communicate using message passing
- Typical methodology:

```
start job on n processors
  do i=1 to j
    each processor does some calculation
    pass messages between processor
  end do
end job
```

Communicators

- Communicator
  - A collection of processors working on some part of a parallel job
  - Used as a parameter for most MPI calls
  - MPI_COMM_WORLD includes all of the processors in your job
  - Processors within a communicator are assigned numbers (ranks) 0 to n-1
  - Can create subsets of MPI_COMM_WORLD

Messages

- Simplest message: an array of data of one type.
- Predefined types correspond to commonly used types in a given language
  - MPI_REAL (Fortran), MPI_FLOAT (C)
  - MPI_DOUBLE_PRECISION (Fortran), MPI_DOUBLE (C)
  - MPI_INTEGER (Fortran), MPI_INT (C)
- User can define more complex types and send packages.

Include files

- The MPI include file
  - C: mpi.h
  - Fortran: mpif.h (a f90 module is a good place for this)
- Defines many constants used within MPI programs
- In C defines the interfaces for the functions
- Compilers know where to find the include files

Minimal MPI program

- Every MPI program needs these…
  - C version

```
/* the mpi include file */
#include <mpi.h>
   int nPEs,ierr,iam;
/* Initialize MPI */
   ierr=MPI_Init(&argc, &argv);
/* How many processors (nPEs) are there?*/
   ierr=MPI_Comm_size(MPI_COMM_WORLD, &nPEs);
/* What processor am I (what is my rank)? */
   ierr=MPI_Comm_rank(MPI_COMM_WORLD, &iam);
...
   ierr=MPI_Finalize();
```

In C MPI routines are functions and return an error value

Minimal MPI program

- Every MPI program needs these…
  - Fortran version

```
! MPI include file
      include 'mpif.h'
! The mpi module can be used for Fortran 90 instead of mpif.h
!     use mpi
      integer nPEs, ierr, iam
!  Initialize MPI
      call MPI_Init(ierr)
!  How many processors (nPEs) are there?
      call MPI_Comm_size(MPI_COMM_WORLD, nPEs, ierr)
!  What processor am I (what is my rank)?
      call MPI_Comm_rank(MPI_COMM_WORLD, iam, ierr)
      ...
      call MPI_Finalize(ierr)
```

In Fortran, MPI routines are subroutines, and last parameter is an error value

Exercise 1 : Hello World

- Write a parallel "hello world" program
  - Initialize MPI
  - Have each processor print out "Hello, World" and its processor number (rank)
  - Quit MPI

Fortran and C examples

```
el2:mpi> cat helloc.c
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
#include <math.h>

/*************************************************************
This is a simple hello world program. Each processor prints
name, rank, and total run size.
*************************************************************/
int main(int argc, char **argv)
{
    int myid,numprocs,resultlen;
    char myname[MPI_MAX_PROCESSOR_NAME] ;
    MPI_Init(&argc,&argv);
    MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
    MPI_Comm_rank(MPI_COMM_WORLD,&myid);

    MPI_Get_processor_name(myname,&resultlen);

    printf("Hello from %s %d %d\n",myname,myid,numprocs);
    MPI_Finalize();
}
```

Fortran and C examples

```
el2:mpi> cat hellof.f90
!*********************************************
!  This is a simple hello world program. Each processor
!  prints out its name, rank and  number of processors
!  in the current MPI run.
!*********************************************
      program hello
      include "mpif.h"
      integer myid,numprocs,ierr,nlength
      character (len=MPI_MAX_PROCESSOR_NAME):: myname
      call MPI_INIT( ierr )
      call MPI_COMM_RANK( MPI_COMM_WORLD, myid, ierr )
      call MPI_COMM_SIZE( MPI_COMM_WORLD, numprocs, ierr )

      call MPI_Get_processor_name(myname,nlength,ierr)

      write (*,*) "Hello from ",trim(myname)," # ",myid," of ",numprocs
      call MPI_FINALIZE(ierr)
      stop
      end
el2:mpi>
el2:mpi>
```

Compiling

- Most MPI compilers are actually just scripts that call underlying Fortran or C compilers
- Load module that points to your compilers
- For Intel compilers use
  - module load intel-mpi
  - mpiifort, mpiicc, mpicpc - Intel backend compilers
  - mpif90 mpicc, mpicxx - gcc/gfortran backend compilers
- For HP's version of MPI
  - module load mpt gcc/8.4.0
  - mpif77 mpif90
  - mpicc mpiCC

Compiling IntelMPI and MPT

```
el2:mpi> ml intel-mpi
el2:mpi>
el2:mpi> mpiicc helloc.c -o helloc
el2:mpi> mpiifort hellof.f90 -o hellof
el2:mpi> #### or ####
el2:mpi> mpicc helloc.c -o helloc
el2:mpi> mpif90 hellof.f90 -o hellof
```

Or

```
el2:mpi> module load mpt gcc/8.4.0
el2:mpi>
el2:mpi> mpicc helloc.c -o hello
el2:mpi> mpif90 hellof.f90 -o hellof
el2:mpi>
```

Compiling OpenMPI

- Most MPI compilers are actually just scripts that call underlying Fortran or C compilers
- Load module that points to your compilers
- Openmpi
  - module load openmpi
  - mpif77 mpif90
  - mpicc mpiCC mpic++ mpicxx
- This will give you gcc/gfortran as the backend compilers
- To get Intel backend compilers
  - export OMPI_FC=ifort
  - export OMPI_CC=icc
  - export OMPI_CXX=icpc

makefile

```
el1:mpi> ml intel-mpi
el1:mpi> make
mpicc   c_ex00.c -o c_ex00
mpicc   c_ex01.c -o c_ex01
mpicc   c_ex02.c -o c_ex02
mpicc   c_ex03.c -o c_ex03
mpicc   c_ex04.c -o c_ex04
mpicc   c_ex05.c -o c_ex05
mpicc   c_ex06.c -o c_ex06
mpicc   c_ex07.c -o c_ex07
mpicc   c_ex08.c -o c_ex08
mpicc   c_ex09.c -o c_ex09
mpicc   c_ex10.c -o c_ex10
mpicc   c_ex11.c -o c_ex11
mpicc   c_ex12.c -o c_ex12
mpicc   c_ex13.c -o c_ex13
c_ex13.c: In function 'main':
c_ex13.c:34:23: warning: cast to pointer from integer of different size [-Wint-to-pointer-cast]
  mpi_err = MPI_Gather((void*)mysize,1,MPI_INT,
                       ^
mpicc   helloc.c -o helloc
mpif90   f_ex00.f90 -o f_ex00
mpif90   f_ex01.f90 -o f_ex01
mpif90   f_ex02.f90 -o f_ex02
mpif90   f_ex03.f90 -o f_ex03
mpif90   f_ex04.f90 -o f_ex04
mpif90   f_ex05.f90 -o f_ex05
mpif90   f_ex06.f90 -o f_ex06
mpif90   f_ex07.f90 -o f_ex07
mpif90   f_ex08.f90 -o f_ex08
mpif90   f_ex09.f90 -o f_ex09
mpif90   f_ex10.f90 -o f_ex10
mpif90   f_ex11.f90 -o f_ex11
mpif90   f_ex12.f90 -o f_ex12
mpif90   f_ex13.f90 -o f_ex13
mpif90   hellof.f90 -o hellof
el1:mpi>
```

Running

- Most often you will use a batch system
- Write a batch script file.
- Use the command ~~**mpiexec**~~ or ~~**mpirun**~~ **srun** to actually start the program. You must tell the system how many copies to run
- On some systems you must tell where to run the program

A very simple Slurm Script - "sim"

```
#!/bin/bash
#SBATCH --job-name="flow"
#SBATCH --nodes=1
#SBATCH --export=ALL
#SBATCH --oversubscribe
#SBATCH --time=00:10:00
#SBATCH --partition=debug
#SBATCH --account=hpcapps

module purge
ml intel-mpi

srun -n 4 ./helloc
```

The run...

```
el1:mpi> sbatch --account=hpcapps sim
Submitted batch job 8182395
el1:mpi> cat slurm-8182395.out
 Hello from r1i7n35 #      2  of      4
 Hello from r1i7n35 #      0  of      4
 Hello from r1i7n35 #      1  of      4
 Hello from r1i7n35 #      3  of      4
el1:mpi>
```

A useful example - "doeagle"

```
#!/bin/bash
#SBATCH --job-name="flow"
#SBATCH --nodes=1
#SBATCH --export=ALL
#SBATCH --oversubscribe
#SBATCH --time=00:10:00
#SBATCH --partition=debug
#SBATCH --account=hpcapps

module purge
ml intel-mpi

if [ -z ${EXE+x} ]; then export EXE=c_ex00 ; fi

echo "running " $EXE
srun -n 4 ./$EXE
```

You can set the program to run with and export before you submit the run

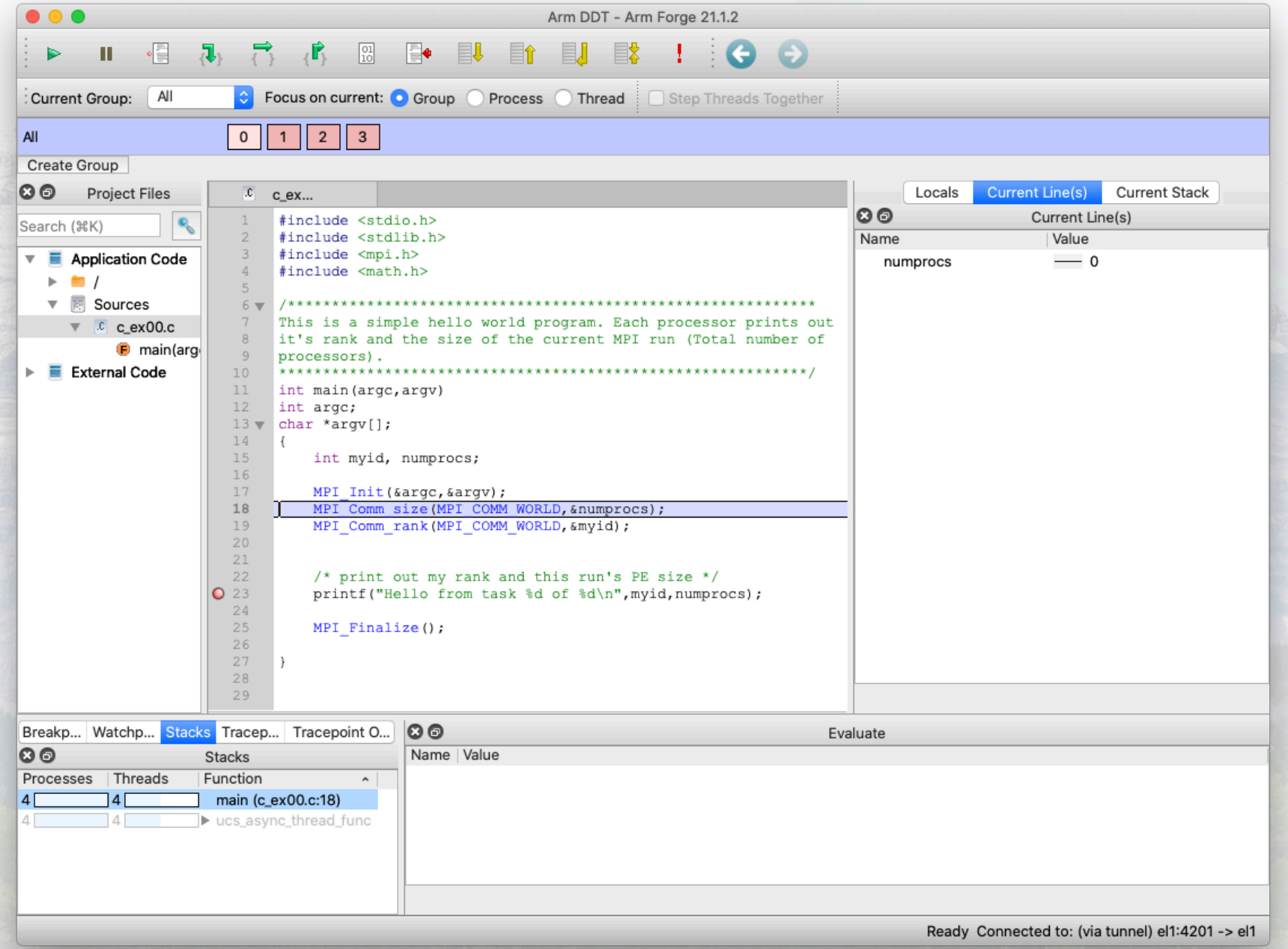
```
el1:mpi> export EXE=f_ex02
el1:mpi> sbatch --account=hpcapps doeagle
Submitted batch job 8182393
el1:mpi> cat *8182393*
running  f_ex02
 Hello from fortran process:           3  Numprocs is           4
 Hello from fortran process:           1  Numprocs is           4
 Hello from fortran process:           2  Numprocs is           4
 Hello from fortran process:           0  Numprocs is           4
 getting            1
 i=         100
el1:mpi>
```

The run...

Slight Digression

- One way you can understand what is going on in a MPI application is to look at it running in a debugger
- We have ARM/ddt
- We also have ARM/map and ARM/Profile for profiling
- Let me know if interested

ARM ddt


Arm DDT - Arm Forge 21.1.2
Current Group: All
Focus on current: Group Process Thread
Step Threads Together
All 0 1 2 3
Create Group
Project Files
Search (⌘K)
Application Code
/
Sources
c_ex00.c
main(arg
External Code
c_ex...
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
#include <math.h>
/***
This is a simple hello world program. Each processor prints out
it's rank and the size of the current MPI run (Total number of
processors).
***/
int main(argc,argv)
int argc;
char *argv[];
{
int myid, numprocs;
MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
MPI_Comm_rank(MPI_COMM_WORLD,&myid);
/* print out my rank and this run's PE size */
printf("Hello from task %d of %d\n",myid,numprocs);
MPI_Finalize();
}
Locals Current Line(s) Current Stack
Current Line(s)
Name Value
numprocs 0
Breakp... Watchp... Stacks Tracep... Tracepoint O...
Stacks
Processes Threads Function
4 4 main (c_ex00.c:18)
4 4 ucs_async_thread_func
Evaluate
Name Value
Ready Connected to: (via tunnel) el1:4201 -> el1

Basic Communication

- Data values are transferred from one processor to another
  - One processor sends the data
  - Another receives the data
- Synchronous
  - Call does not return until the message is sent or received
- Asynchronous
  - Call indicates a start of send or receive, and another call is made to determine if finished

Synchronous Send

- C
  - MPI_Send(&buffer, count ,datatype, destination, tag,communicator);
- Fortran
  - Call MPI_Send(buffer, count, datatype, destination,tag,communicator, ierr)
- Call blocks until message on the way

Call MPI_Send(buffer, count, datatype, destination, tag, communicator, ierr)

- **Buffer**: The data array to be sent
- **Count** : Length of data array (in elements, 1 for scalars)
- **Datatype** : Type of data, for example : MPI_DOUBLE_PRECISION, MPI_INT, etc
- **Destination** : Destination processor number (within given communicator)
- **Tag** : Message type (arbitrary integer)
- **Communicator** : Your set of processors
- **Ierr** : Error return (Fortran only)

Synchronous Receive

- C
  - MPI_Recv(&buffer,count, datatype, source, tag, communicator, &status);
- Fortran
  - Call MPI_ RECV(buffer, count, datatype, source,tag,communicator, status, ierr)
- Call blocks the program until message is in buffer
- Status - contains information about incoming message
  - C
    - MPI_Status status;
  - Fortran
    - Integer status(MPI_STATUS_SIZE)

Call MPI_Recv(buffer, count, datatype, source, tag, communicator, status, ierr)

- **Buffer**: The data array to be received
- **Count** : Maximum length of data array (in elements, 1 for scalars)
- **Datatype** : Type of data, for example : MPI_DOUBLE_PRECISION, MPI_INT, etc
- **Source** : Source processor number (within given communicator)
- **Tag** : Message type (arbitrary integer)
- **Communicator** : Your set of processors
- **Status**: Information about message
- **Ierr** : Error return (Fortran only)

Exercise 2 : Basic Send and Receive

- Write a parallel program to send & receive data
  - Initialize MPI
  - Have processor 0 send an integer to processor 1
  - Have processor 1 receive an integer from processor 0
  - Both processors print the data
  - Quit MPI

Send and Recv in MPI

```
el2:mpi> cat f_ex01.f90
      module fmpi
!DEC$ NOFREEFORM
      include "mpif.h"
!DEC$ FREEFORM
      end module
!**************************************************************
!  This is a simple send/receive program in MPI
!  Processor 0 sends an integer to processor 1,
!  while processor 1 receives the integer from proc. 0
!**************************************************************
      program hello
      use fmpi
!     include "mpif.h"
      integer myid, ierr,numprocs
      integer tag,source,destination,count
      integer buffer
      integer status(MPI_STATUS_SIZE)
      call MPI_INIT( ierr )
      call MPI_COMM_RANK( MPI_COMM_WORLD, myid, ierr )
      call MPI_COMM_SIZE( MPI_COMM_WORLD, numprocs, ierr )
      tag=1234
      source=0
      destination=1
      count=1
      if(myid .eq. source)then
         buffer=5678
         Call MPI_Send(buffer, count, MPI_INTEGER,destination,&
          tag, MPI_COMM_WORLD, ierr)
         write(*,*)"processor ",myid," sent ",buffer
      endif
      if(myid .eq. destination)then
         Call MPI_Recv(buffer, count, MPI_INTEGER,source,&
          tag, MPI_COMM_WORLD, status,ierr)
         write(*,*)"processor ",myid," got ",buffer
      endif
      call MPI_FINALIZE(ierr)
      stop
      end
```

Send an Recv in MPI

```
el2:mpi> cat c_ex01.c
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
#include <math.h>

/*************************************************************
This is a simple send/receive program in MPI
*************************************************************/

int main(argc,argv)
int argc;
char *argv[];
{
    int myid, numprocs;
    int tag,source,destination,count;
    int buffer;
    MPI_Status status;

    MPI_Init(&argc,&argv);
    MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
    MPI_Comm_rank(MPI_COMM_WORLD,&myid);
    tag=1234;
    source=0;
    destination=1;
    count=1;
    if(myid == source){
      buffer=5678;
      MPI_Send(&buffer,count,MPI_INT,destination,tag,MPI_COMM_WORLD);
      printf("processor %d  sent %d\n",myid,buffer);
    }
    if(myid == destination){
        MPI_Recv(&buffer,count,MPI_INT,source,tag,MPI_COMM_WORLD,&status);
        printf("processor %d  got %d\n",myid,buffer);
    }
    MPI_Finalize();
}
```

```
el2:mpi> cat slurm-7068778.out
 processor             0  sent        5678
 processor             1  got         5678
el2:mpi>
```

Summary

- MPI is used to create parallel programs based on message passing
- Usually the same program is run on multiple processors
- Well over 100 "Advanced Calls"
- The 6 basic calls in MPI are:

```
– MPI_INIT( ierr )
– MPI_COMM_RANK( MPI_COMM_WORLD, myid, ierr )
– MPI_COMM_SIZE( MPI_COMM_WORLD, numprocs, ierr )
– MPI_Send(buffer, count,MPI_INTEGER,destination, tag, MPI_COMM_WORLD, ierr)
– MPI_Recv(buffer, count, MPI_INTEGER,source,tag, MPI_COMM_WORLD, status,ierr)
– MPI_FINALIZE(ierr)
```

MPI is not limited to huge HPC

- Can be built on laptops and desktops
  - Might be useful for testing
  - Might actually get good performance
- I have it on my laptop & high end desktop
- I have it running on my home 4 node Raspberry Pi cluster
  - https://www.raspberrypi.org
  - < $100/node

Unofficial Languages

- Subsets available for R and Java
- Fairly complete implementation for Python
- Let me know if you are interested in these
- I have not looked at Julia

Java

- Comes in two versions OpenMPI and Intel
- They are not compatible even at the source (API) level
  - cd ../java
  - diff Hello.java Ihello.java

```
...
<    int myrank = MPI.COMM_WORLD.getRank();
<    int size = MPI.COMM_WORLD.getSize() ;
>    mpi.Comm  comm = mpi.Comm.WORLD;
>    int myrank = comm.getRank();
>    int size = comm.getSize();

<       MPI.COMM_WORLD.send(message, tosend, MPI.INT, 1, tag);
>       mpi.PTP.send(message,10,mpi.Datatype.INT,1,tag,comm);

<       MPI.COMM_WORLD.recv(message, toget, MPI.INT, 0, tag);
>       mpi.PTP.recv(message,10,mpi.Datatype.INT,0,tag,comm);
```

Build Rmpi & MPI4py

I used a Conda environment that already had R and Python. Then I compiled using IntelMPI, not OpenMPI

```
cd mixedlang

ml conda
conda activate plex1
which python
which R
ml comp-intel/2020.1.217
ml intel-mpi/2020.1.217
which mpicc
```

```
curl --insecure https://cran.r-project.org/src/contrib/Rmpi_0.6-9.2.tar.gz -o Rmpi.tar.gz

export TYPE=OPENMPI
export MY_MPI_PATH=/nopt/nrel/apps/compilers/intel/2020.1.217/impi/2019.7.217/intel64

R CMD INSTALL --configure-args="\
--with-Rmpi-include='$MY_MPI_PATH/include' \
--with-Rmpi-libpath='$MY_MPI_PATH/lib/release' \
--with-mpi='$MY_MPI_PATH/bin/mpicc' \
--with-Rmpi-type='$TYPE'"  Rmpi.tar.gz


pip install mpi4py
```

It is possible(sometimes) to mix languages

```
(/home/tkaiser2/.conda-envs/plex1) el3:mixedlang> cat together
#!/bin/bash
#SBATCH --job-name="flow"
#SBATCH --nodes=1
#SBATCH --export=ALL
#SBATCH --oversubscribe
#SBATCH --time=00:10:00
#SBATCH --partition=debug
#SBATCH --account=hpcapps
#
##r_ex01c.R does not work with openmpi and other programs
#j_ex01c.java only works with openmpi
#ij_ex01c.java is for Intel MPI and works with all others
#
#
export PATH=/nopt/nrel/apps/openmpi/4.1.0-gcc-8.4.0-j15/jdk-15.0.2/bin:$PATH
module purge
ml conda
conda activate plex1
which python
which R
ml comp-intel/2020.1.217
ml intel-mpi/2020.1.217
which mpicc

mpif90 f_ex01c.f90 -o f_ex01c ; rm -rf fmpi.mod
mpicc c_ex01c.c -o c_ex01c

#for source in f_ex01c  c_ex01c r_ex01c.R  P_ex01c.py  "java ij_ex01c.java" ; do
#for source in f_ex01c  c_ex01c r_ex01c.R  P_ex01c.py  ; do
for source in f_ex01c  c_ex01c r_ex01c.R  P_ex01c.py   ; do
   echo DRIVER: $source
#mpiexec -n 1 $source  2 5 : -n 1 ./f_ex01c : -n 1 ./c_ex01c : -n 1 ./r_ex01c.R  : -n 1  ./P_ex01c.py  : -n 1 java ij_ex01c.java
| egrep "got"
   echo 0 ./$source     > mapfile
   echo 1 ./f_ex01c    >> mapfile
   echo 2 ./c_ex01c    >> mapfile
   echo 3 ./r_ex01c.R  >> mapfile
   echo 4 ./P_ex01c.py >> mapfile
   echo 5 java ./ij_ex01c.java >> mapfile
   #srun -n 5 --multi-prog mapfile | grep got
   srun --partition=debug --time=00:10:00 -n 6 --multi-prog mapfile | grep got
   echo " "
done
```

```
DRIVER: f_ex01c
Fortran processor    1   got     4678    3678    2678    1678
Fortran processor    1   got     4679    3679    2679    1679
Fortran processor    1   got     4680    3680    2680    1680
C processor 2  got 4678  3678  2678  1678
C processor 2  got 4679  3679  2679  1679
C processor 2  got 4680  3680  2680  1680
Java processor 5  got 4678 3678 2678 1678
Java processor 5  got 4679 3679 2679 1679
Java processor 5  got 4680 3680 2680 1680
[1] "R processor    3 got  4678  3678  2678  1678"
[1] "R processor    3 got  4679  3679  2679  1679"
[1] "R processor    3 got  4680  3680  2680  1680"
Python processor  4  got  [4678 3678 2678 1678]
Python processor  4  got  [4679 3679 2679 1679]
Python processor  4  got  [4680 3680 2680 1680]

DRIVER: c_ex01c
C processor 2  got 1  101  201  301
Fortran processor    1   got       1     101     201     301
Fortran processor    1   got       2     102     202     302
Fortran processor    1   got       3     103     203     303
C processor 2  got 2  102  202  302
C processor 2  got 3  103  203  303
Java processor 5  got 1 101 201 301
Java processor 5  got 2 102 202 302
Java processor 5  got 3 103 203 303
[1] "R processor    3 got  1  101  201  301"
[1] "R processor    3 got  2  102  202  302"
[1] "R processor    3 got  3  103  203  303"
Python processor  4  got  [  1 101 201 301]
Python processor  4  got  [  2 102 202 302]
Python processor  4  got  [  3 103 203 303]
```

```
DRIVER: r_ex01c.R
Fortran processor    1   got       3       5       7       9
C processor 2  got 3  5  7  9
Fortran processor    1   got       4       6       8      10
C processor 2  got 4  6  8  10
Fortran processor    1   got       5       7       9      11
C processor 2  got 5  7  9  11
[1] "R processor    3 got  3  5  7  9"
[1] "R processor    3 got  4  6  8  10"
[1] "R processor    3 got  5  7  9  11"
Java processor 5  got 3 5 7 9
Java processor 5  got 4 6 8 10
Java processor 5  got 5 7 9 11
Python processor  4  got  [3 5 7 9]
Python processor  4  got  [ 4  6  8 10]
Python processor  4  got  [ 5  7  9 11]

DRIVER: P_ex01c.py
Fortran processor    1   got     6679    7679    8679    9679
C processor 2  got 6679  7679  8679  9679
Fortran processor    1   got     6680    7680    8680    9680
C processor 2  got 6680  7680  8680  9680
Fortran processor    1   got     6681    7681    8681    9681
C processor 2  got 6681  7681  8681  9681
Java processor 5  got 6679 7679 8679 9679
Java processor 5  got 6680 7680 8680 9680
Java processor 5  got 6681 7681 8681 9681
[1] "R processor    3 got  6679  7679  8679  9679"
[1] "R processor    3 got  6680  7680  8680  9680"
[1] "R processor    3 got  6681  7681  8681  9681"
Python processor  4  got  [6679 7679 8679 9679]
Python processor  4  got  [6680 7680 8680 9680]
Python processor  4  got  [6681 7681 8681 9681]
```