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**Introduction to MPI
Concepts and Strategies**

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Introduction to MPI: Concepts and Strategies

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Overview

- ! Why serial is not enough
- ! Computing architectures
- ! Parallel paradigms
- ! Message Passing Interface
- ! How to compile and run MPI programs



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Serial computing

- ! Using a single computer to complete a single task
 - ! concurrent computing
- ! To improve performance
 - ! Optimize program code
 - ! Use mathematical libraries
 - ! Improve the hardware
 - ! Moore's law - empirical observation made in 1965 that the number of transistors on an integrated circuit for minimum component cost doubles every 24 months.
 - ! Bigger, faster and more memory (DDR3, FBDIMMS)
 - ! More storage!



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Why serial is not enough

- ! Realistic simulations require really really
 - ! Large numbers of particles
 - ! Large MC samples
 - ! Large statistics
 - ! Combinatorially large spaces to be searched
 - ! Excessively fine multidimensional discretizations
 - ! Huge data inputs to be processed
 - ! ...
- ! We want to solve problems harder, faster, better, stronger!
- ! Parallel hardware is available (clusters)
- ! Parallel software is available (libraries)
- ! And we want to learn something new...



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Modern computing architectures

- ! Shared memory (SMP)
 - ! Single large system where all CPUs can access the whole available memory
- ! Distributed memory
 - ! Each CPU can access only local memory attached to it (nodes with one single-core CPU)
- ! Hybrid systems (majority of clusters)
 - ! Nodes with several single-core CPUs
 - ! Nodes with a single multicore CPU
 - ! Nodes with several multicore CPUs



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Parallel paradigms (1)

- ! The two (three) architectures determine two basic paradigms
 - ! Data parallel (shared memory)
 - ! Single memory view, all processes (usually threads) could **directly access the whole memory**
 - ! Message Passing (distributed memory)
 - ! All processes could **directly access only their local memory**



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Parallel paradigms (2)

- ! It is easy to adopt a Message Passing scheme in a Shared Memory computers (*Unix processes have their private memory*)
- ! It is less easy to follow a Data Parallel scheme in a Distributed Memory computer (*emulation of shared memory*)
- ! It is relatively easy to design a program using the message passing scheme and implementing the code in a Data Parallel programming environments (*using OpenMP or HPF*)
- ! It is not easy to design a program using the Data Parallel scheme and implementing the code in a Message Passing environment.



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Parallel paradigms (3)

Programming environments	
Message Passing	Data Parallel
Standard compilers	Ad hoc compilers
Communication libraries	Source code directive
Ad hoc commands to run program	Standard Unix shell to run program
Standard: MPI	Standard: OpenMP

Parallel paradigms (4)

Architecture	
Distributed memory	Shared memory
Programming paradigm	
Message passing	Data parallel
Programming model	
Domain decomposition	Functional decomposition



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Programming models

- ! Domain decomposition
 - ! Data divided into equal chunks and distributed to available CPUs
 - ! Each CPU process its own local data
 - ! Exchange of data if needed
- ! Functional decomposition
 - ! Problem decomposed into many sub-tasks
 - ! Each CPU performs one of sub-tasks
 - ! Similar to server/client paradigm



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Flint's taxonomy (1)

- ! SISD (Single instruction, single data)
- ! **SIMD (Single instruction, multiple data)**
 - ! the same instructions are carried out simultaneously on multiple data items
 - ! SSE is a good example
- ! **MISD (Multiple instruction, single data)**
- ! **MIMD (Multiple instruction, multiple data)**
 - ! different instructions on different data
- ! **SPSD (Single program, single data)**
- ! **SPMD (Single program, multiple data)**
 - ! not synchronized at individual operation level
 - ! equivalent to MIMD since each MIMD program can be made SPMD



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Flint's taxonomy (2)

- ! SPSD (Single program, single data)
- ! **SPMD (Single program, multiple data)**
 - ! not synchronized at individual operation level
 - ! equivalent to MIMD since each MIMD program can be made SPMD
- ! **MPSD (Multiple program, single data)**
- ! **MPMD (Multiple program, multiple data)**



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Parallel paradigms (5)

Model	Paradigm	Flint's taxonomy
Domain decomposition	Message Passing	SPMD
	Data Parallel - HPF	
Functional decomposition	Data Parallel - OpenMP	MPSD
	Message Passing	MPMD

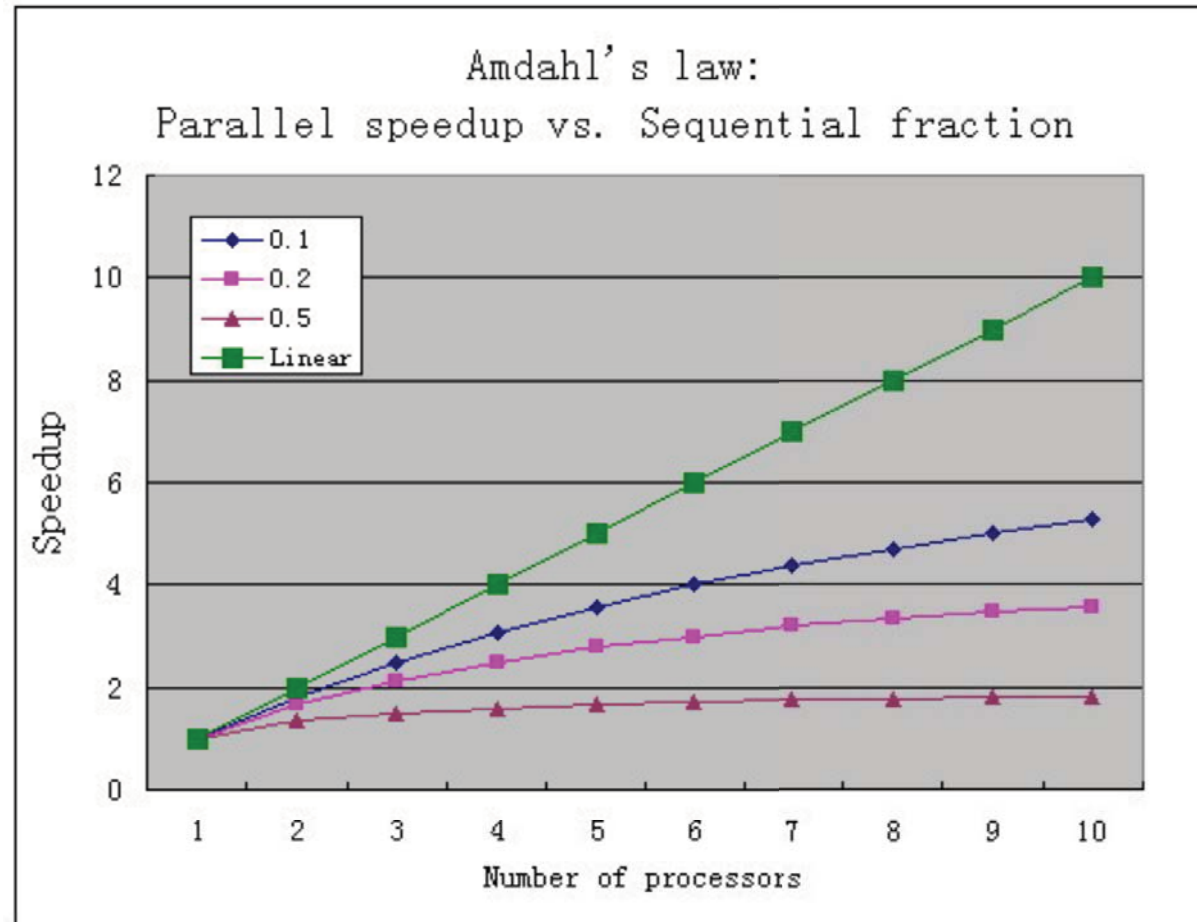
Parallelism requires...

- ! Balancing of the load
 - ! Applies to computation, I/O operations, network communication
 - ! Relatively easy for domain decomposition, not so easy for functional decomposition
- ! Minimizing communication
 - ! Join individual communications
 - ! Eliminate synchronization – the slowest process dominates
- ! Overlap of computation and communication
 - ! This is essential for true parallelism!



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Effective parallel performance



Message Passing

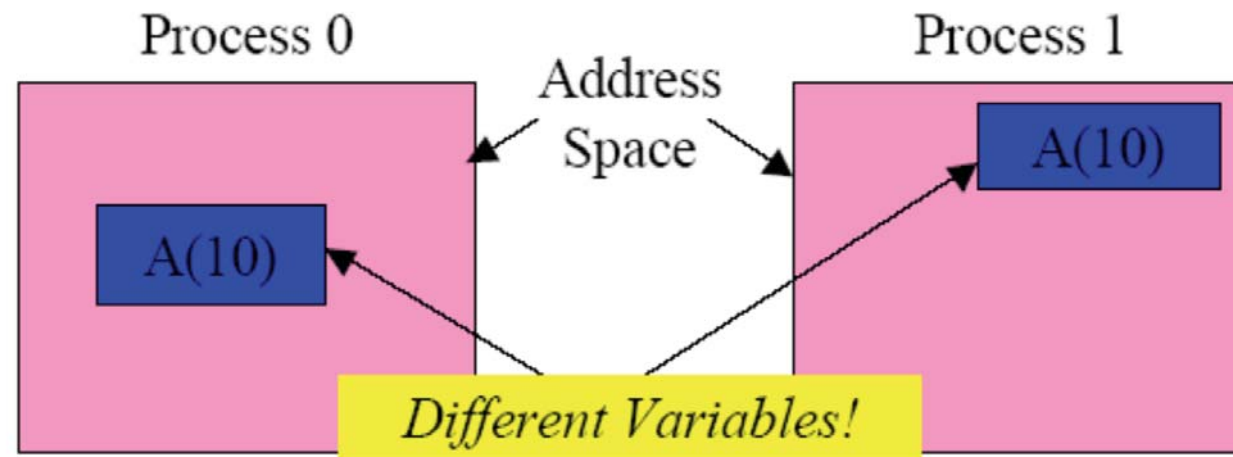
- ! Parallel programs consist of separate processes, each with its own address space
 - ! Programmer manages memory by placing data in a particular process
- ! Data sent explicitly between processes
 - ! Programmer manages memory movement
- ! Collective operations
 - ! On arbitrary set of processes
- ! Data distribution
 - ! Also managed by the programmer



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Distributed memory

- ! Nothing is shared between processes



What is MPI? (1)

- ! Message Passing Interface
- ! A message-passing library specification
 - ! extended message-passing model
 - ! not a language or compiler specification
 - ! not a specific implementation or product
- ! For parallel computers, clusters, and heterogeneous networks
- ! Full-featured
- ! Designed to provide access to advanced parallel hardware for end users, library writers, and tool developers



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What is MPI? (2)

- ! MPI is a standard
 - ! A list of rules and specifications
 - ! Left up to individual implementations as to how it is implemented.
 - ! There are several implementations available over several different networks
- ! Goals of MPI
 - ! To provide source-code portability
 - ! Virtually every supercomputer on Earth can use MPI
 - ! To allow efficient implementation of parallel computing



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MPI references

- ! The Standard itself:
 - ! at <http://www.mpi-forum.org>
 - ! All MPI official releases, in both postscript and HTML
- ! Other information on Web:
 - ! at <http://www.mcs.anl.gov/mpi>
 - ! pointers to lots of stuff, including talks and tutorials, a FAQ, other MPI pages



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MPI Implementations

- ! Because MPI is a standard, there are several implementations
- ! MPICH - <http://www-unix.mcs.anl.gov/mpi/mpich1/>
 - ! Freely available, portable implementation
 - ! Available on everything
- ! OpenMPI - <http://www.open-mpi.org/>
 - ! Includes the once popular LAM-MPI
- ! Vendor specific implementations
 - ! CRAY, SGI, IBM



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MPI-1 vs. MPI-2

! MPI-1

- ! Specifies traditional sender/reciever message passing scheme
- ! Two-sided communication model
- ! Communication involves both the sender and reciever
- ! Limited and not completely scalable without Herculean effort

! MPI-2

- ! Implements many concepts that became popular since MPI-1
- ! Remote memory access, parallel I/O and dynamic processing
- ! One-sided communication model
- ! All communication parameters are handled by one process



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OpenMPI

- ! Open source implementation of MPI-2
 - ! Single library supports all networks
 - ! TCP, Myrinet, InfiniBand
 - ! Network and process fault tolerance
 - ! VampirTrace
 - ! Performance analysis
 - ! Visualisation



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When do you need MPI?

- ! You need a portable parallel program
- ! You are writing a parallel library
- ! You have irregular or dynamic data relationships that do not fit a data parallel model
- ! You care about performance



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When MPI is not needed?

- ! You can use parallel Fortran 90 or any other data parallelism mechanism
- ! You don't need parallelism at all
- ! You can use libraries (which may be written in MPI)
- ! You need simple threading in a slightly concurrent environment



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Writing MPI program

- ! MPI is a library
- ! All operations are performed with function (subroutine) calls
- ! Basic definitions are in
 - ! mpi.h for C/C++
 - ! mpif.h for Fortran 77 and 90
 - ! MPI module for Fortran 90 (optional)



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MPI functions

Functions may be roughly divided into 4 classes:

- ! Calls used to initialize, manage, and terminate communications
- ! Calls used to communicate between pairs of processes (Point-to-point communication)
- ! Calls used to communicate among groups of processes (Collective communication)
- ! Calls to create data types



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Hello, MPI world program

```
#include <mpi.h>
#include <stdio.h>

int main(int argc, char **argv )
{
    MPI_Init(&argc, &argv);
    printf("Hello, MPI world!\n");
    MPI_Finalize();
    return 0;
}!
```



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How to compile an MPI program?

- ! No standard, left to implementations
- ! Generally:
 - ! You should specify the appropriate include directory:
 - ! -I/mpidir/include
 - ! You should specify the mpi library
 - ! -L/mpidir/lib -lmpi
 - ! With GCC
 - ! `gcc -I/usr/local/mpich/include -L/usr/local/mpich/lib -lmpich mpi-hello.c -o mpi-hello`
- ! Usually MPI compiler wrappers do this job for you. (i.e. mpicc, mpif77, mpif90, mpicxx)
 - ! `mpicc -o mpi-hello mpi-hello.c`
- ! Check on your machine...

Example: MPI ID program

```
#include <mpi.h>
#include <stdio.h>

int main(int argc, char **argv)
{
    int myid, np;
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &myid);
    MPI_Comm_size(MPI_COMM_WORLD, &np);
    printf("Process %d out of %d\n", myid, np);
    MPI_Finalize();
    return 0;
}!
```



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How to run an MPI program?

- ! The MPI-1 Standard does not specify how to run an MPI program, just as the Fortran standard does not specify how to run a Fortran program.
- ! Many implementations provide mpirun to run an MPI program
 - ! `mpirun -np 4 mpi-hello`
- ! In general, starting an MPI program depends on the implementation of MPI you are using, and might require various scripts, program arguments, and/or environment variables.
- ! `mpiexec` is part of MPI-2, as a recommendation, but not as a requirement
- ! Many parallel systems use a *batch environment to share resources among users*
- ! The specific commands to run a program on a parallel system are defined by the environment installed on the parallel computer



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What is next?

- ! Learn MPI function types and syntax
- ! Learn how to compile and run MPI programs on a single node
- ! Learn how to run MPI programs on a cluster, in batch mode
- ! **If this is not enough, use the Grid!**
 - ! One Ring to rule them all,
One Ring to find them,
One Ring to bring them all,
and in the darkness bind them



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