Parallel Programming

IE 496 Lecture 9

Reading for This Lecture

- Roosta, Chapter 4, Sections 1 and 3, Chapter 5
- MPI Introduction and Specification
- OpenMP Introduction, Specification, and Tutorial

Parallel Algorithm Design

Design Issues

- Platform/Architecture
- Task Decomposition
- Task Mapping/Scheduling
- Communication Protocol

Parallelizing Sequential Algorithms

- The most obvious approach to developing a parallel algorithm is to parallelize a sequential algorithm.
- The primary additional concept one must keep in mind is data access patterns.
  - In the case of shared memory architectures, one must be cognizant of possible collisions in accessing the main memory.
  - In the case of distributed memory architectures, one must be cognizant of the need to move data to where it is needed.
- In either case, losses in efficiency result from either idle time or wasted computation due to lack of availability of data locally.

Platforms

- High Performance Parallel Computers
  - Massively parallel
  - Distributed
- "Off the shelf" Parallel Computers
  - Small shared memory computers
  - Multi-core computers
  - Clusters

Task Decomposition

- Fine-grained parallelism
  - Suited for massively parallel systems (many small processors)
  - These are the algorithms we've primarily talked about so far .
- Course-grained parallelism
  - Suited to small numbers of more powerful processors.
  - Data decomposition
    - Recursion/Divide and Conquer
    - Domain Decomposition
  - Functional parallelism
    - Data Dependency Analysis
    - Pipelining

Task Agglomeration

- Depending on the number of processors available, we may have to run multiple tasks on a single processor.
- To do this effectively, we have to determine which tasks should be combined to achieve maximum efficiency.
- This requires the same analysis of communication patterns and data access done in task decomposition.

Mapping

- Concurrency
  - Data dependency analysis
- Locality
  - Interconnection network
  - Communication pattern
- Mapping is an optimization problem.
- These are very difficult to solve in general.

Communication Protocols

Message-passing

- Used primarily in distributed-memory or "hybrid" environments.
- Data is passed through explicit send and receive function calls.
- There is no explicit synchronization.
- In general, this is the most flexible and portable protocol.
- MPI is the established standard.
- PVM is a similar older standard that is still used.

Comunication Protocols

OpenMP/Threads

- Used in shared-memory environments.
- Parallelism through "threading".
- Threads communicate through global memory.
- Can have explicit synchronization.
- OpenMP is a standard implemented by most compilers.

MPI Basics

- MPI stands for *Message Passing Interface*.
- It is an API for point-to-point communication that hides the platform-dependent details from the user.
- Each platform has its own implementation of MPI.
- The user launches the MPI processes in a distributed fashion and forms one or more “communicators.”
- Data can be sent explicitly between processes using message-passing calls.
- Allows for extremely portable parallel

Messaging Concepts

- Buffer
- Source
- Destination
- Tag
- Communicator

Types of Communication Calls

- Synchronous send
- Blocking send / blocking receive
- Non-blocking send / non-blocking receive
- Buffered send
- Combined send/receive
- "Ready" send

Basic Functions in MPI

`int MPI_Init(int *argc, char ***argv)`	Join MPI
`int MPI_Comm_rank (MPI_Comm comm, int *rank)`	This process's position within the communicator
`int MPI_Comm_size (MPI_Comm comm, int *size)`	Total number of processes in the communicator
`int MPI_Send( void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm )`	Send a message to process with rank `dest` using `tag`
`int MPI_Recv( void *buf, int count, MPI_Datatype datatype, int source, int tag, MPI_Comm comm, MPI_Status *status )`	Receive a message with the specified `tag` from the process with the rank `source`
`int MPI_Finalize()`	Resign from MPI

Simple Example

```
int numtasks, rank, dest, source, rc, count, tag=1;
char inmsg, outmsg='x';
MPI_Status Stat;

MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
if (rank == 0) {
  dest = 1;
  source = 1;
  rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
  rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
}

else if (rank == 1) {
  dest = 0;
  source = 0;
  rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
  rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
}
```

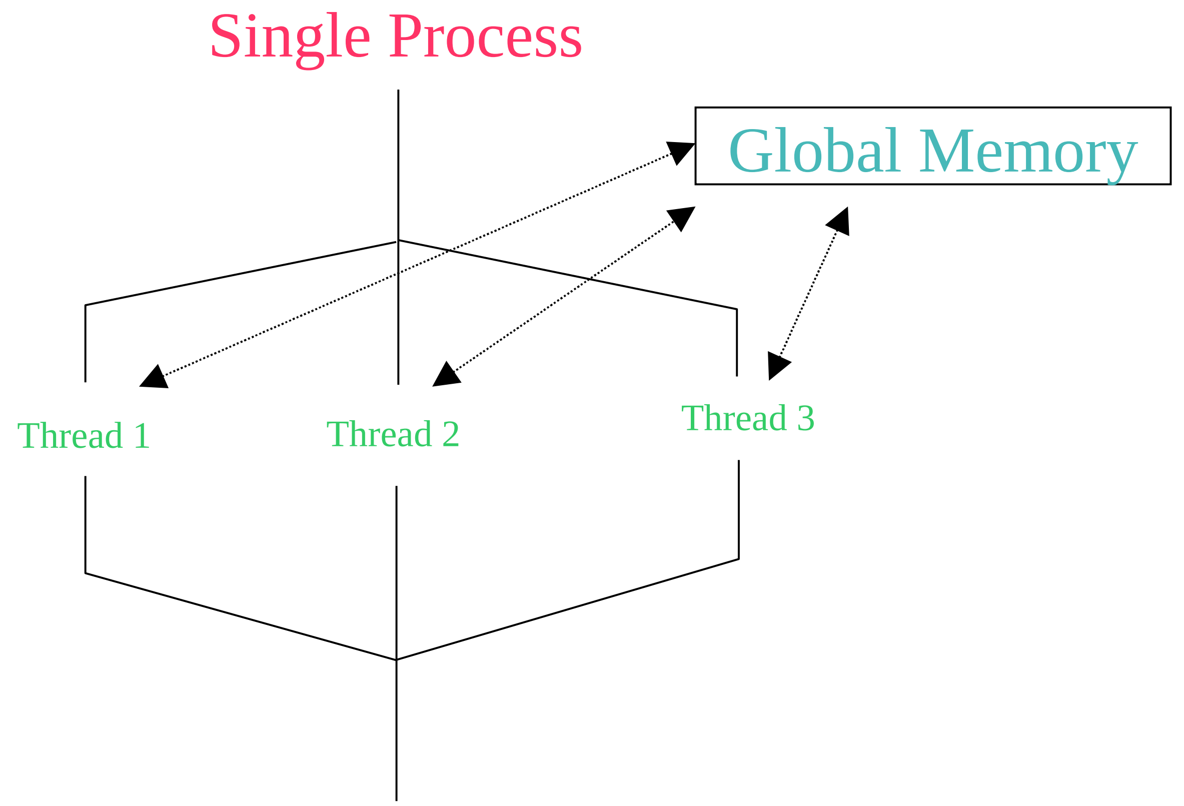
Collective Communication

- Synchronization - processes wait until all members of the group have reached the synchronization point.
- Data Movement - broadcast, scatter/gather, all to all.
- Collective Computation (reductions) - one member of the group collects data from the other members and performs an operation (min, max, add, multiply, etc.).

Virtual Topologies

- Allows the user to specify the topology of the interconnection network.
- This may allow certain features to be implemented more efficiently.

OpenMP/Threads



OpenMP Implementation

- OpenMP is implemented through compiler directives.
- User is responsible for indicating what code segments should be performed in parallel.
- The user is also responsible for eliminating potential memory conflicts, etc.
- The compiler is responsible for inserting platform-specific function calls, etc.

OpenMP Features

- Capabilities are dependent on the compiler.
  - Primarily used on shared-memory architectures
  - Can work in distributed-memory environments (TreadMarks)
- Explicit synchronization
- Locking functions
- Critical regions
- Private and shared variables

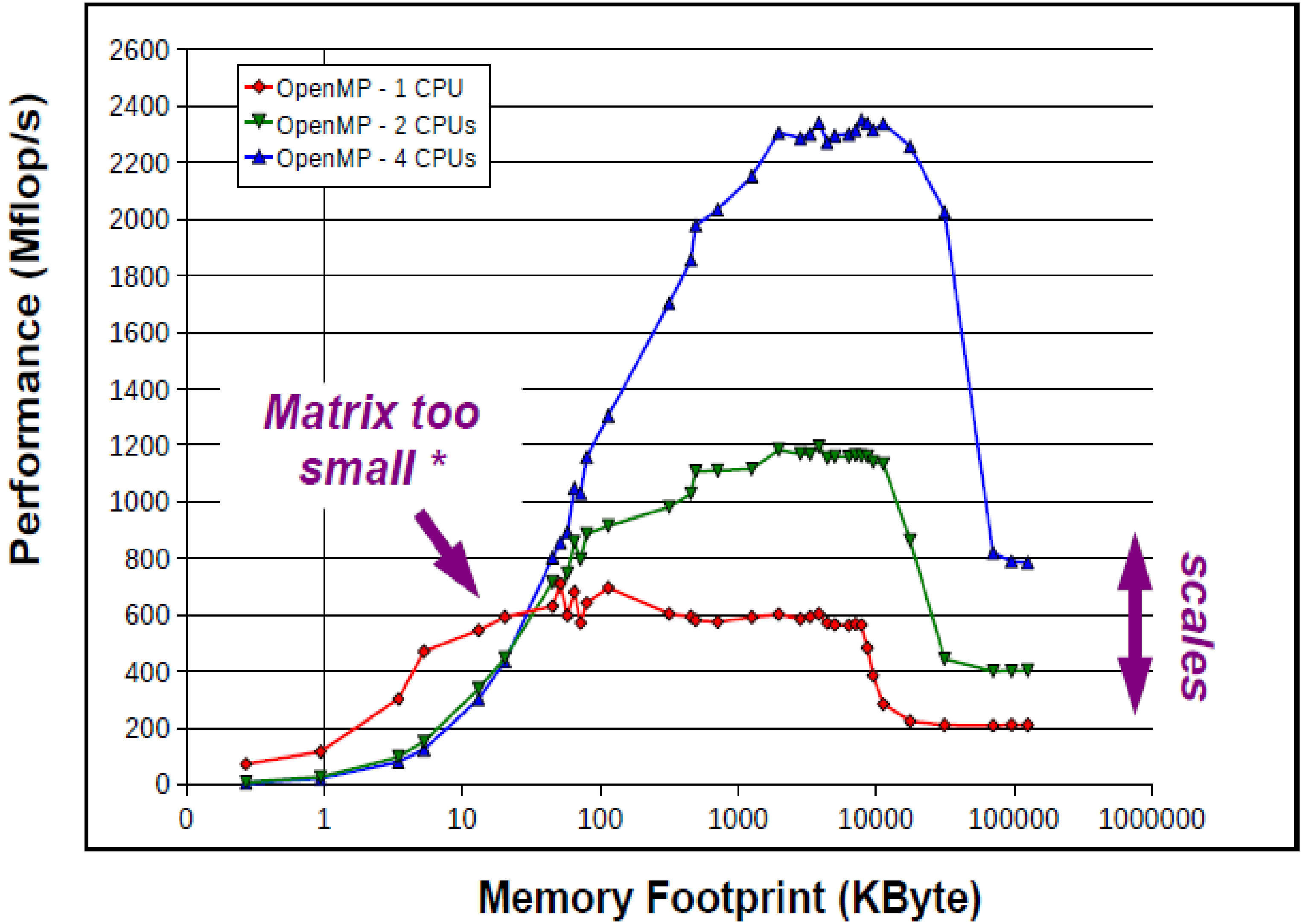
Using OpenMP

- Compiler directives
  - `parallel`
  - `parallel for`
  - `parallel sections`
  - `barrier`
  - `private`
  - `critical`
- Shared library functions
  - omp_get_num_threads()
  - omp_set_lock()

OpenMP Example

```
#praga omp parallel for default(none) private(i,j,sum) \
                                      shared(m,n,a,b,c)
for (i=0; i<m; i++){
  sum = 0.0;
  for (j=0; j<n; j++)
    sum += b[i][j]*c[j];
  a[i] = sum;
}
```

OpenMP Performance



OpenMP Concepts and Issues

- Race Conditions
  - Conflicts between processes in updating data.
- Deadlocks
- Critical regions
- Locking functions