M-JavaMPI:
A Java-MPI Binding with Process Migration Support

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Introduction: Why Java+MPI ?

- **Java**
  - Emerging as a major language for distributed and parallel programming.
  - Almost for all platforms: Sun's J2SE, J2EE, J2ME.
  - But…Client-Server Model, No SPMD
    - Sockets and the Remote Method Invocation (RMI)
    - Both communication models are optimized for client-server programming, whereas the parallel computing world is mainly concerned with ``symmetric'' (peer-to-peer) communication, occurring in groups of interacting peers.

Introduction: Why Java+MPI?

- **Message Passing Interface (MPI)**
  - **Standard message-passing communication library** (Has been implemented on many parallel machines).
  - Directly supports the **Single Program Multiple Data (SPMD)** model of parallel computing.
  - **Natural model** on distributed-memory machines such as clusters
  - Possible to do **special problem partitioning**, **initial assignment of application data to machines**, and **intelligent runtime data movement** to achieve high performance.

Java MPI Binding: Existing Solutions

- **Direct bindings to the native MPI library**
  - **mpiJava** [Baker, *et. al.,* 1998] :
    - through JNI wrappers to native MPI software
  - **JavaMPI** [Mintchev: 1997] :
    - through JNI wrappers to native MPI software (wrappers were automatically generated by a special-purpose code generator)

Java MPI Binding: Existing Solutions

- **MPI libraries entirely written in Java.**
  - **JMPI :** [MPI Software Technology :1997]
  - **Jmpi :** [Dincer: 1998]
  - **MPIJ :** [DOGMA project : 1999]
  - **PJMPI:** [Tong *et. al.:* 2000]
  - **MPJ :** [MPI Software Technology : 2000]

Discussion: Java MPI Binding

- **Direct Java-MPI binding**
  - (O) Efficient MPI communication through calling native MPI methods
  - (X) Low-level conflicts between the Java runtime and the interrupt mechanisms used in MPI implementations
- **Pure Java implementation**
  - (O) Provides a portable MPI implementation
  - (X) MPI communication is less efficient

Our Research Objectives

- **Application Fault-tolerant:**
  - Many scientific applications run for a very long time (days or even months at a time).
  - System failures (e.g., hardware or network failures) can be expected to occur during the run of applications.
  - The system aborts the job early because of a planned downtime.
- **Dynamic Load Balancing:**
  - Computation patterns of irregularly structured problems can not be expected in the algorithm design phase.
  - Most programmers are lack of skills to design efficient algorithms in message passing programming.
  - Time-shared computing environment.

Our Approach

- **Fault Tolerance and Dynamic Load-balancing**
  - Transparent Java process migration without programmer's involvement or modification of their codes.
  - Automatic message redirection and communication handoff
- **High Portability**
  - **No modification of OS, JVM, and MPI**
  - **Java Virtual Machine Debugger Interface (JVMDI)**
- **Efficient Messaging Support (MPI) for Java**
  - Minimize the overheads for binding MPI with Java
  - Avoid low-level resource conflicts between MPI and JVM

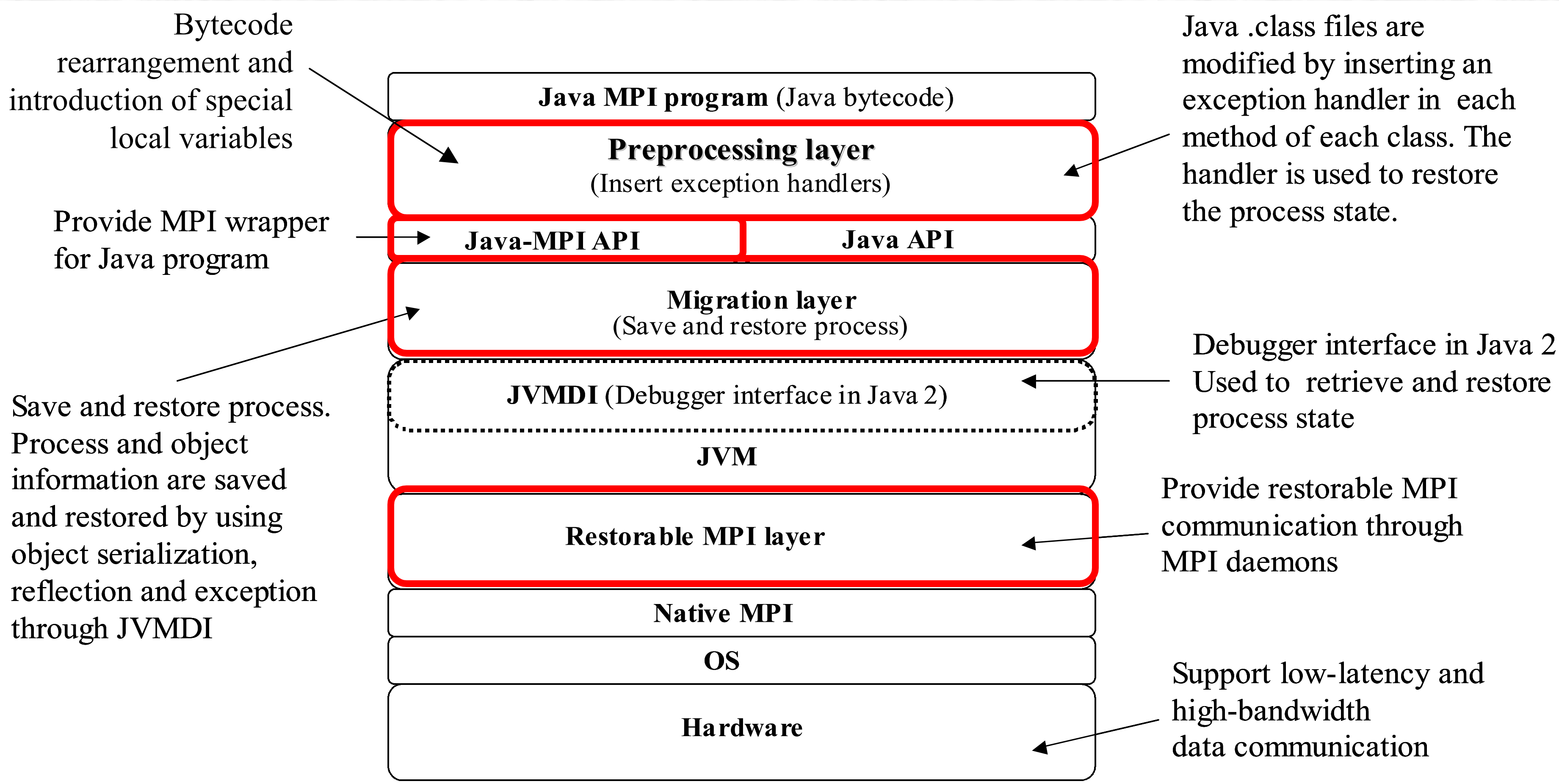
Java Virtual Machine Debugger Interface (JVMDI)

- **Standard interface for JVM:**
  - Define standard services that a JVM must provide for debugging.
  - Available since Java 2.
- **Enough support to capture Java process state:**
  - Able to obtain runtime information of threads, stack frames, local variables, classes, objects and methods.
  - It can be used to control threads, set local variables, receive notification of events.

M-JavaMPI Overview

- **Java Debugger Interface (JVMDI)**
  - Used to capture execution context
  - Eager(all) strategy to reduce residual dependency
- **Object serialization**
  - Java process context is saved in a platform-independent format
- **Exception handler inserted at pre-processing**
  - Cope with the migration layer to restore the processes
- **Client-server based Java-MPI interface**
  - Provides restorable MPI communications

A Layered View of M-JavaMPI



Migration Granularity

- **At the Java source code level**
  - Migration can only happen after the complete execution of all Java bytecode corresponding to a single Java source code line.
    - Migration is postponed until the end of the executing Java source line
    - Similarly for a migration request that is received in the middle of the execution of a native method

State Capturing and Restoring

1. **Program code:** re-used in the destination nodes.
2. **Data**: captured and restored using the object serialization mechanism.
3. **Execution context**: captured by using JVMDI and restored by the exception handlers which are inserted during the pre-processing of bytecode.

- **Eager(all) strategy** : For each frame, local variables, referenced objects, the name of the class and class method, and program counter are saved using object serialization

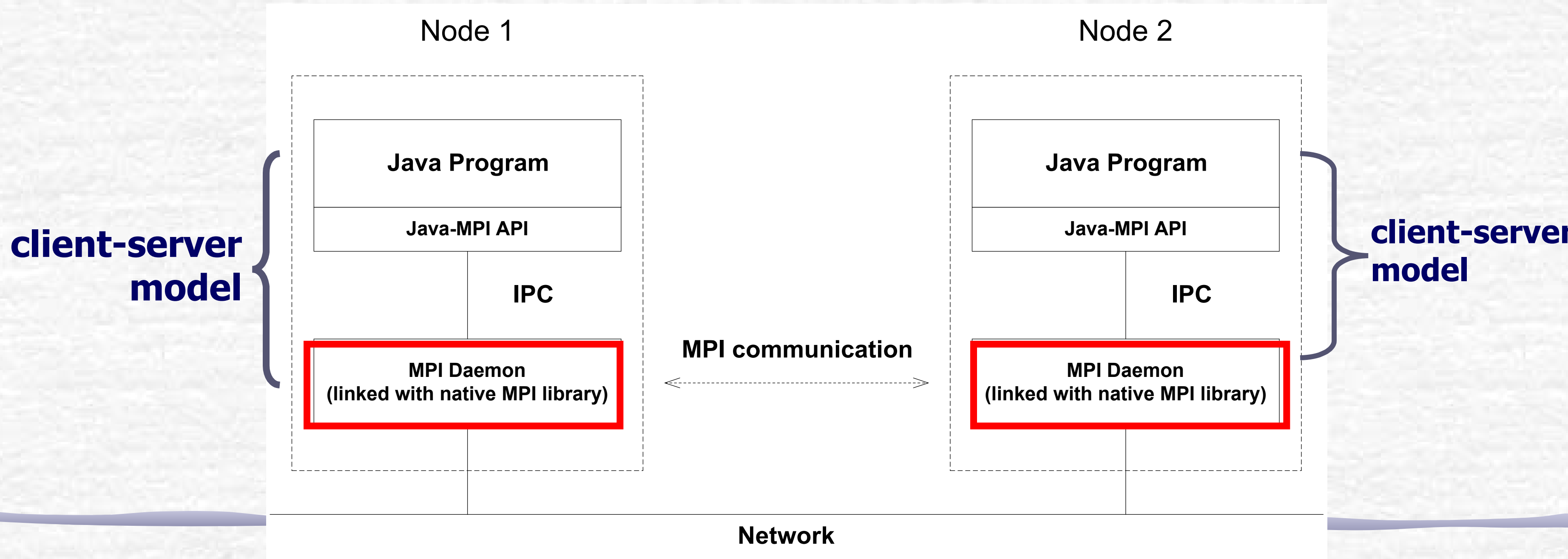
State Capturing using JVMDI

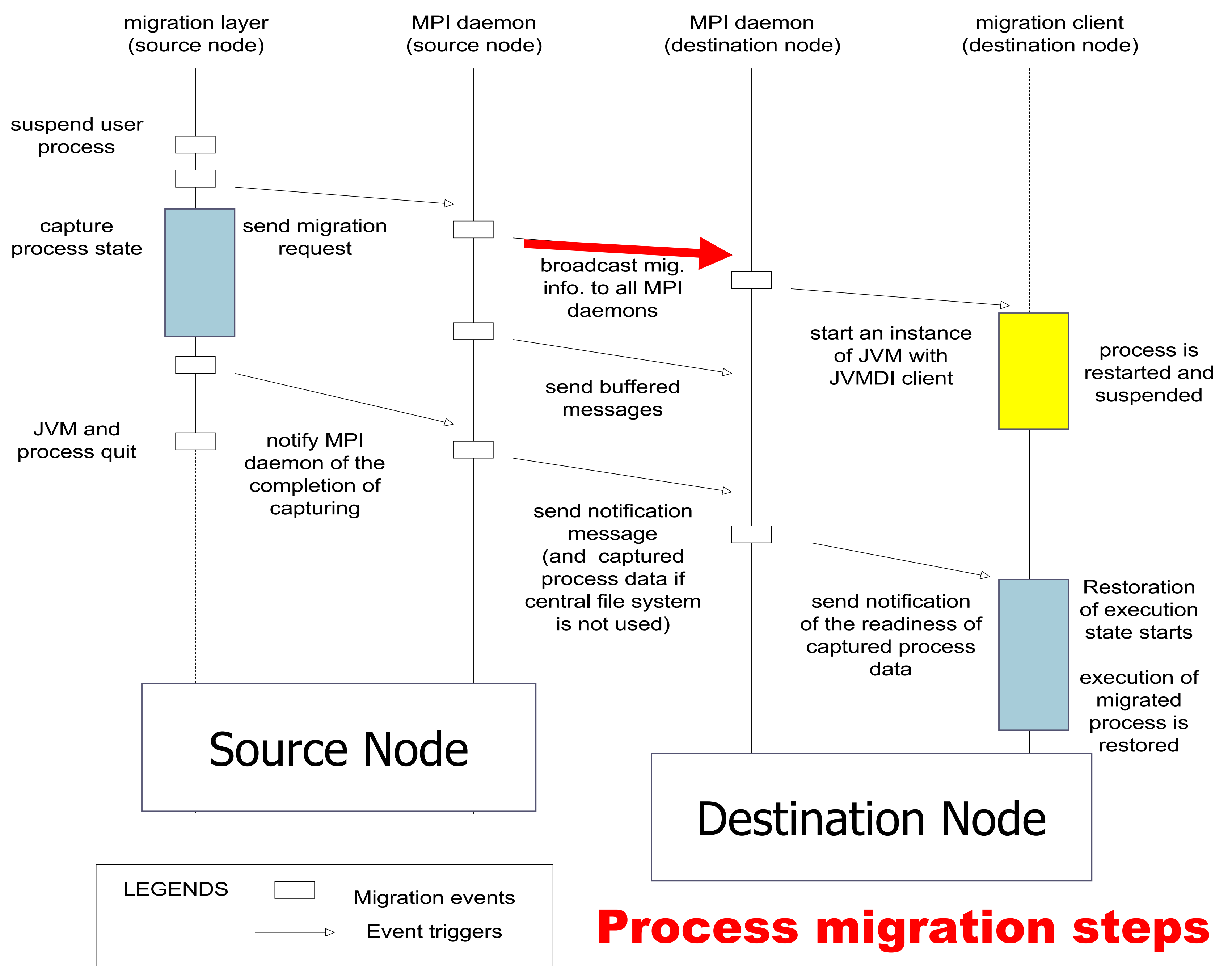
```
public class A {
   int a;
   char b;
  ...
}
```

```
public class A {
   try {
      ...
   } catch (RestorationException e) {
      a = saved value of local variable a;
      b = saved value of local variable b;
     pc = saved value of program counter
           when the program is suspended
      jump to the location where the program
     is suspended
   }
}
```

Restorable MPI Layer

- **MPI daemon run on each node of the cluster to support message passing between distributed java processes.**
- **IPC between Java program and MPI daemon in the same node is done through *shared memory* and *semaphores*.**





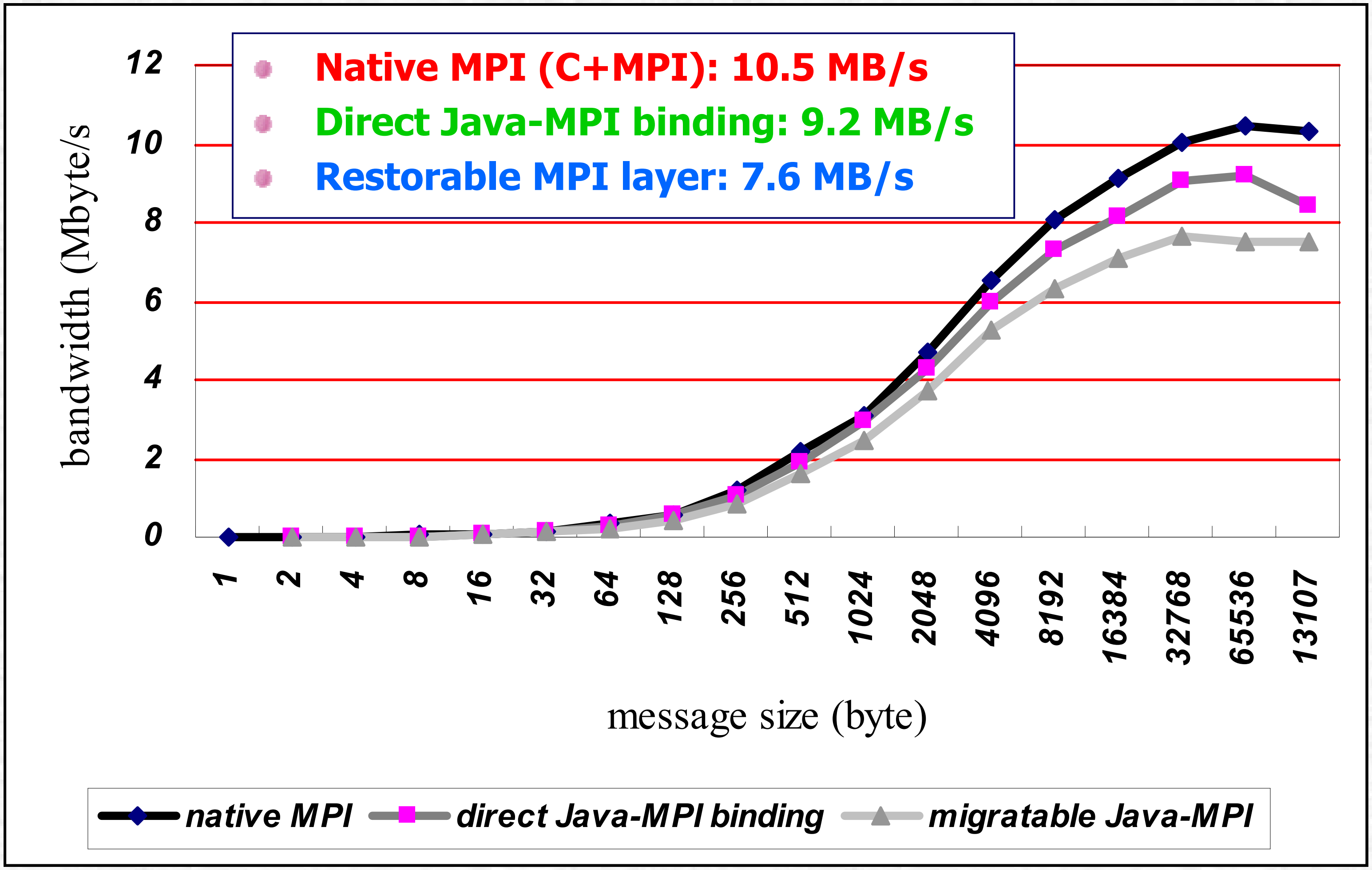
Process migration steps

Performance Evaluation

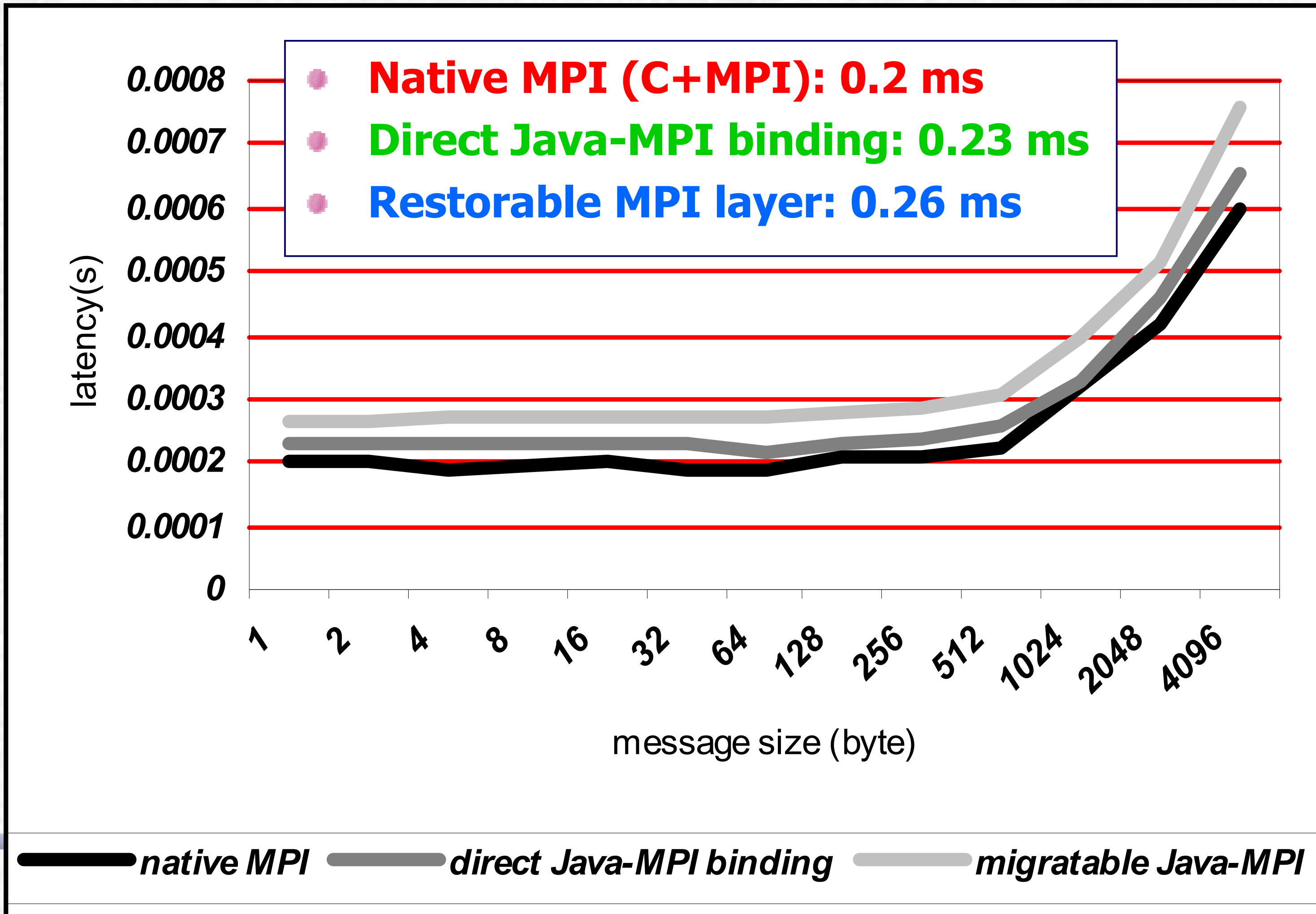
Experimental Setting

- PC Cluster
  - 16-node cluster
  - Pentium II 300 MHz with 128MB of memory
  - Linux 2.2.14 with Sun JDK 1.3.0 + MPICH
  - Connected by 100Mb/s fast Ethernet
- All Java programs were executed without JIT compilation mode enabled

Bandwidth: PingPong Test



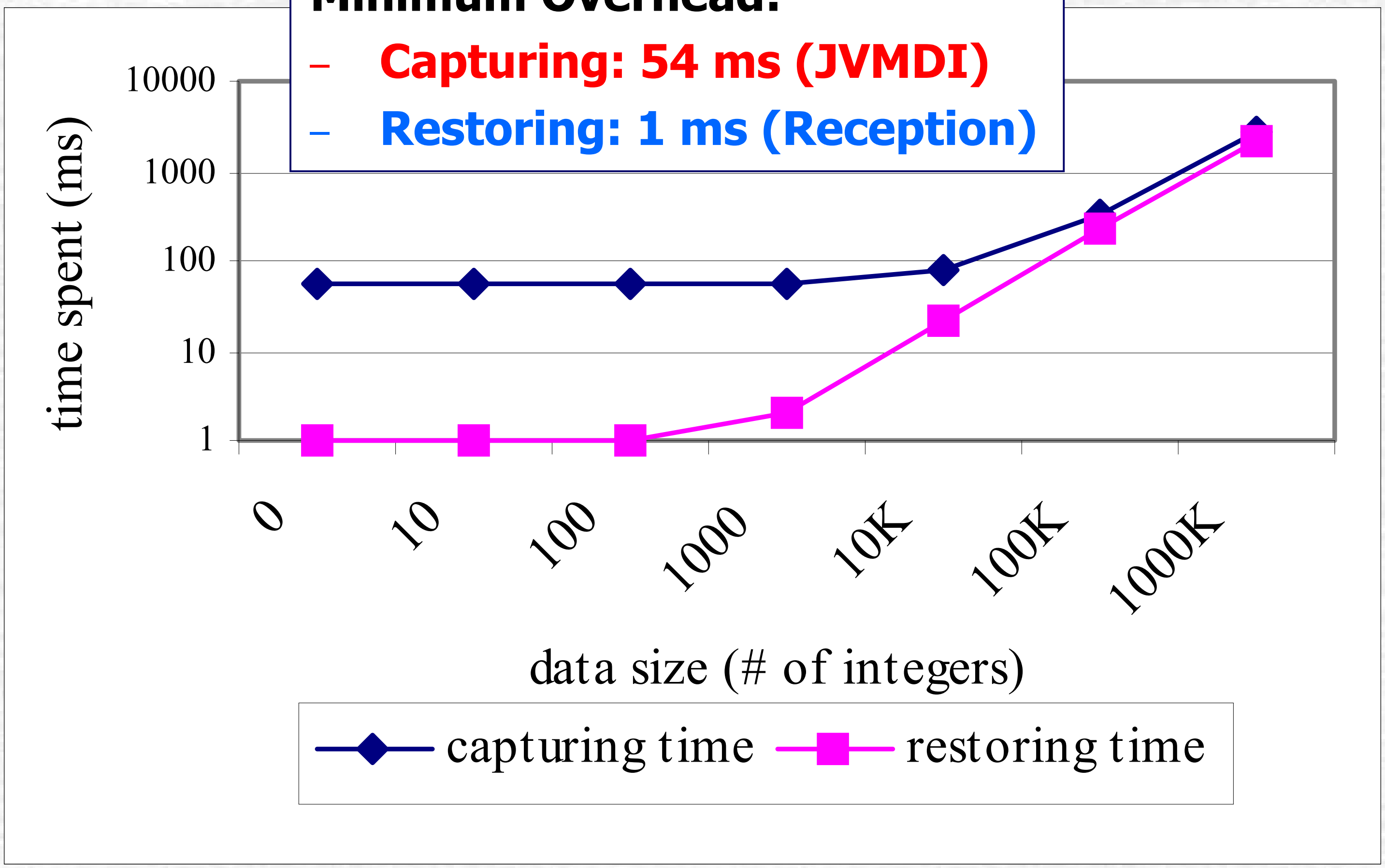
Latency: PingPong Test



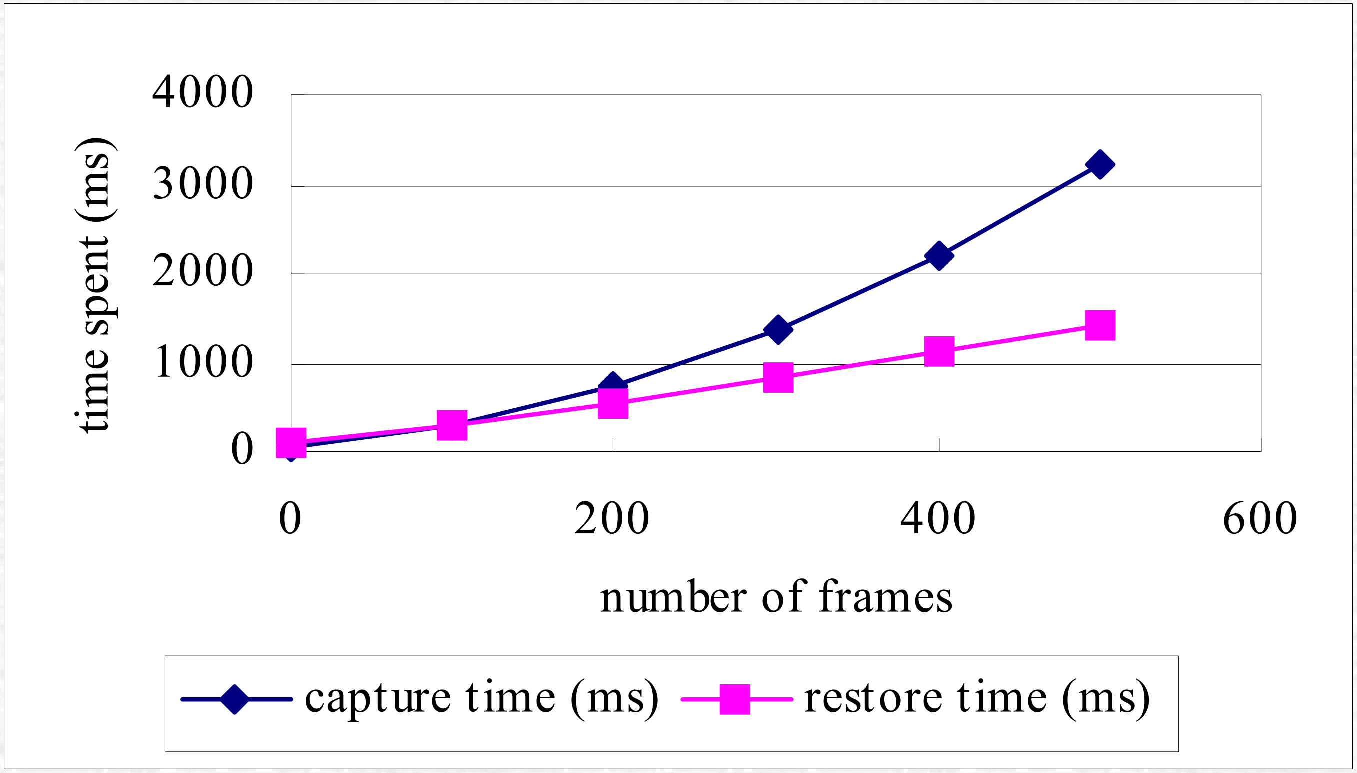
Migration Cost : capturing and restoring objects

Minimum Overhead:

- **Capturing: 54 ms (JVMDI)**
- **Restoring: 1 ms (Reception)**



Migration Cost : capturing and restoring frames



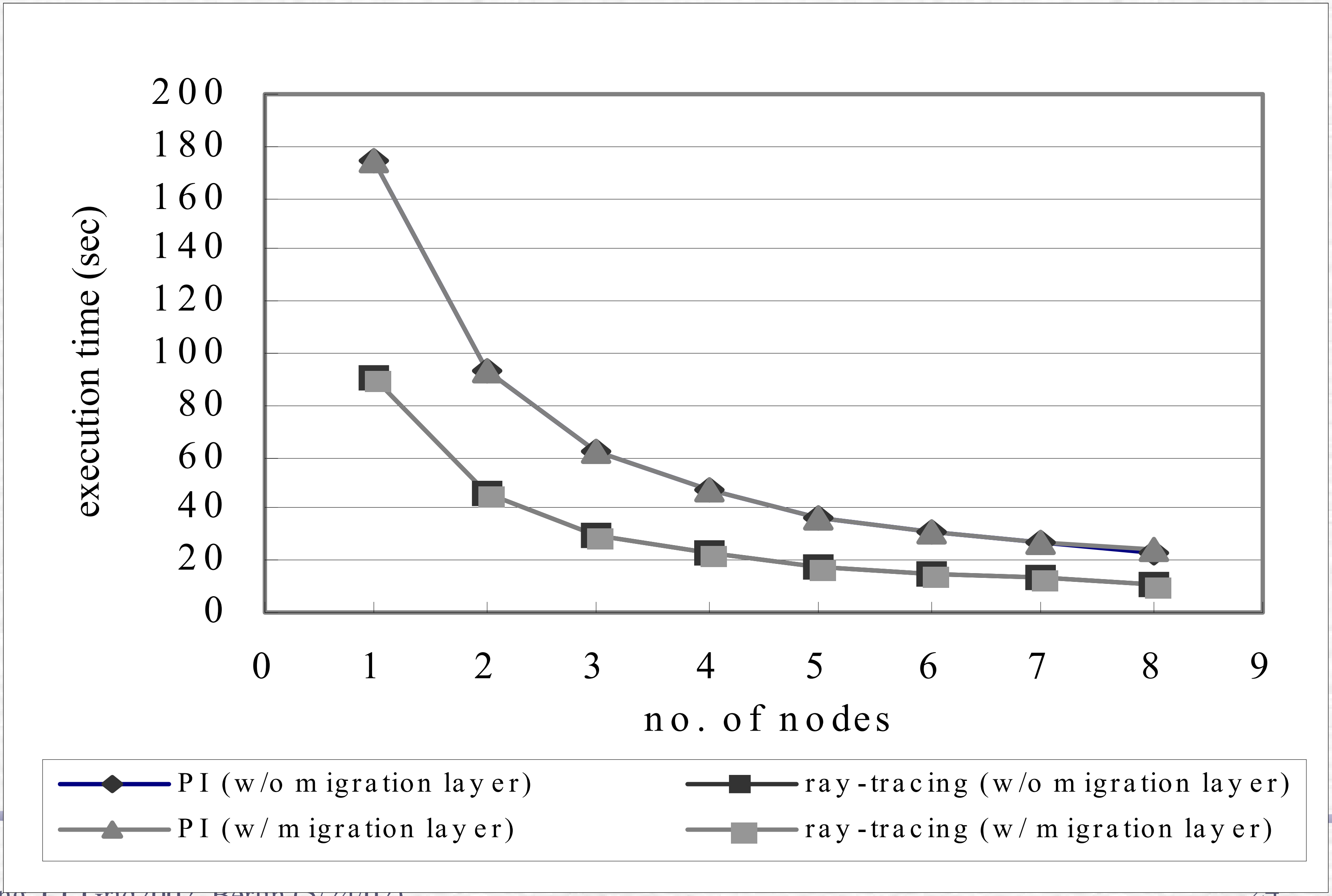
(Empty Java frame: No local variables are defined in each frame)

Performance Evaluation

- Application Performance
  - **PI Calculation** (computational intensive)
  - **Recursive ray-tracing** (computational intensive)
  - **NAS integer sort** (comp. + comm. intensive)
  - **Parallel SOR** (comp. + comm. intensive)

Execution Time of PI and Ray-tracing with and without migration layer

(Debugging Mode vs. Interpretation Mode; Binding Overhead)



Execution time of NAS program with different problem sizes

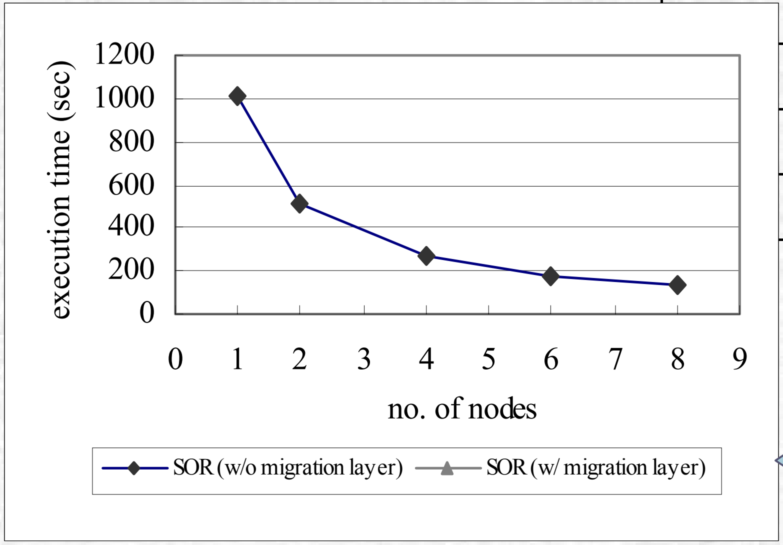
Problem size (no. of integers)	Time (sec) : Direct Java-MPI Binding (Interpretation Mode)			Time (sec) : M-JavaMPI (Debugging Mode)			Slowdown introduced by M-JavaMPI (in %)	
	Total	Comp	Comm	Total	Comp	Comm	Total	Comm
Class S: 65536	0.023	0.009	0.014	0.026	0.009	0.017	13%	21%
Class W:1048576	0.393	0.182	0.212	0.424	0.182	0.242	7.8%	14%
Class A: 8388608	3.206	1.545	1.66	3.387	1.546	1.840	5.6%	11%

No noticeable overhead introduced in the computation part when running in debugging mode using 2 nodes; while in the communication part, an overhead of about 10-20% was induced.

Execution time of SOR

Execution time of SOR on an array of size 256x256 (Process migration adds extra 2-3 sec).

No. of nodes	No migration (sec)	One migration (sec)
1	1013	1016
2	518	521
4	267	270
6	176	178
8	141	144



- **Execution time of SOR using different numbers of nodes with and without migration layer (No Migration)**

Average Process Migration Time

Applications	Average migration time
PI	2 sec
Ray-tracing	3 sec
NAS	2 sec
SOR	3 sec

**** Mainly dominated by the startup time of JVM and loading time of the Java process in the destination node**

Dynamic Load Balancing

- **A Simple Test:**
  - SOR program was executed using **6 nodes** with one of the nodes executing a computationally intensive program.
- Without migration : **319s.**
- With migration: **180s.**

Related Works : Fault Tolerance Support for MPI

- **CoCheck MPI** (Technische Universität München) :
  - Restart the virtual machine every time a node failure occurs (Heavy Penalty)
- **MPI-TM** (Mississippi State U.):
  - MPI with task migration.
- **LA-MPI** (ACL at LANL):
  - Support end-to-end network fault-tolerant message passing without aborting the application.
- **MPI/FT** (MPI Software Technology: 2000)

Related Works : Java Process/Thread Migration

- **JESSICA (HKU:1999):**
  - Java Thread Migration in interpretation mode. Modification of JVM.
- **JESSICA2 (HKU:2002):**
  - Java Thread Migration in JIT compiler mode. Modification of JVM.
- **MERPATI :**
  - entire run-time information of the Java virtual machine (JVM)
- **Checkpointing Java (University of Tennessee)**
- **Jthread (Utah) :**
  - thread migration based on the Voyager framework
- Mobile Agent related : Brakes, JavaGo, Class File Translation (U. of Tokyo), MOBA, MobileThread (Inria), etc.

Java Process/Thread Migration

- **Bytecode instrument**:
  - Insert code into programs, which can be done manually, or via some pre-processors.
- **JVM Extension**:
  - Make thread state accessible from Java programs. Non-transparent to applications. Modifications of JVM are required
- **Checkpoint the whole JVM process**:
  - Very powerful but heavy penalty
- **Modification of JVM** :
  - Totally transparent to the applications, efficient but very difficult to implement -- JESSICA and JESSICA2

Conclusions

- M-JavaMPI's Main Features:
  - JVMDI is used to capture execution states
  - Exception handler is used to restore process state
  - Restorable MPI is provided for transparent message redirection and communication handoff.
- Acceptable migration overheads for long-run scientific applications.
- Dynamic load balancing with the support of process migration -- Good for inexperienced programmers
- A good base for achieving fault tolerance
- Simple!! No need to modify OS, JVM and MPI

Future Works

1. M-JavaMPI in JIT compiler mode
2. Develop system modules for automatic dynamic load balancing
3. Develop system modules for effective fault-tolerant supports
4. M-JavaMPI on the Grid ??