Java for High Performance Computing: Assessment of Current Research and Practice

Guillermo L. Taboada*, Juan Touriño, Ramón Doallo

Computer Architecture Group
University of A Coruña (Spain)
{taboada,juan,doallo}@udc.es

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Outline

Java is an Alternative for HPC in the Multi-core Era

Interesting features:

- Built-in networking
- Built-in multi-threading
- Portable, platform independent
- Object Oriented
- Main training language

Many productive parallel/distributed programming libs:

- Java shared memory programming (high level facilities: Concurrency framework)
- Java Sockets
- Java RMI
- Message-Passing in Java (MPJ) libraries

Java Adoption in HPC

- HPC developers and users usually want to use Java in their projects.
- Java code is no longer slow (Just-In-Time compilation)!
- But still performance penalties in Java communications:

Pros and Cons:

- high programming productivity.
- but they are highly concerned about performance.

Java Adoption in HPC

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- But still performance penalties in Java communications:

JIT Performance:

- Like native performance.
- Java can even outperform native languages thanks to the dynamic compilation.

Java Adoption in HPC

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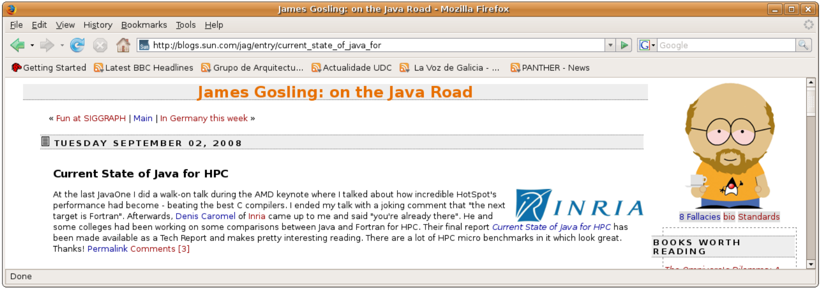
- But still performance penalties in Java communications:

High Java Communications Overhead:

- Poor high-speed networks support.
- The data copies between the Java heap and native code through JNI.
- Costly data serialization.
- The use of communication protocols unsuitable for HPC.

Emerging Interest in Java for HPC



Current State of Java for HPC

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Current State of Java for HPC

Brian Amedro [1], Vladimir Bodnartchouk [2], Denis Caromel [1, 3], Christian Delbe [1], Fabrice Huet [1], Guillermo L. Taboada [a, 4]

(2008)

Access to full text: PDF

Abstract: About ten years after the Java Grande effort, this paper aims at providing a snapshot of the current status of Java for High Performance Computing. Multi-core chips are becoming mainstream, offering many ways for a Java Virtual Machine (JVM) to take advantage of such systems for critical tasks such as Just-In-Time compilation or Garbage Collection. We first perform some micro benchmarks for various JVMs, showing the overall good performance for basic arithmetic operations. Then we study a Java implementation of the Nas Parallel Benchmarks, using the ProActive middleware for distribution. Comparing this implementation with a Fortran/MPI one, we show that they have similar performance on computation intensive benchmarks, but still have scalability issues when performing intensive communications. Using experiments on clusters and multi-core machines, we show that the performance varies greatly, depending on the Java Virtual Machine used (version and vendor) and the kind of computation performed.

a – Faculty of Informatics, University of A Coruna, Spain
1: OASIS (INRIA Sophia Antipolis / Laboratoire I3S)
INRIA – Université de Nice Sophia-Antipolis – CNRS : UMR6070
2: ActiveEon
ActiveEon
3: SLOOP (INRIA Sophia Antipolis)
INRIA
4: University of A Coruna - Computer Architecture Group
University of A Coruna

Done

Java for HPC

Current options in Java for HPC:

- Java Shared Memory Programming
- Java Sockets
- Java RMI
- Message-Passing in Java (MPJ)

Java for HPC

Java Shared Memory Programming:

- Java Threads
- Concurrency Framework (ThreadPools, Tasks ...)
- Parallel Java (PJ)
- Java OpenMP (JOMP and JaMP)

JOMP

Listing 1: JOMP example

```
public static void main (String argv[]) {
  int myid;
   //omp parallel private(myid)
   {
      myid = OMP.getThreadNum();
      System.out.println(``Hello from'' + myid);
   }

   //omp parallel for
   for (i=1;i<n;i++) {
       b[i] = (a[i] + a[i-1]) * 0.5;
   }
}
```

Java Communication Libraries Overview

Java HPC Applications

Java Message-passing libraries

Java RMI / Low-level messaging libraries

Java Sockets libraries

HPC Communications Hardware

HPC Communications Hardware

Performance of current HPC networks (Theoretical/C/Java):

	Startup latency (microseconds)	Bandwidth (Mbps)
Gig. Ethernet	50/55/60	1000/920/900
10G Ethernet	5/10/50	10000/9000/5000
10G Myrinet	1/2/30	10000/9300/4000
InfiniBand	1/2/20	16000/12000/6000
SCI	1.4/3/50	5333/2400/800

Java Sockets

Standard and widely extended low-level programming interface for networked communications.

Current implementations:

- IO sockets
- NIO sockets
- Ibis sockets
- Java Fast Sockets

Pros and Cons:

- easy to use.
- but only TCP/IP support.
- lack non-blocking communication.
- lack HPC tailoring.

Java Sockets

Standard and widely extended low-level programming interface for networked communications.

Current implementations:

- IO sockets
- NIO sockets
- Ibis sockets
- Java Fast Sockets

Pros and Cons:

- provides non-blocking communication.
- but only TCP/IP support.
- lack HPC tailoring.
- difficult use.

Java Sockets

Standard and widely extended low-level programming interface for networked communications.

Current implementations:

- IO sockets
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- easy to use.
- with Myrinet support.
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- lack HPC tailoring.

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Standard and widely extended low-level programming interface for networked communications.

Current implementations:

- IO sockets
- NIO sockets
- Ibis sockets
- Java Fast Sockets

Pros and Cons:

- easy to use.
- efficient high-speed networks support.
- efficient shared memory protocol.
- with HPC tailoring.
- but lack non-blocking support.

Remote Method Invocation

RMI (Remote Method Invocation)

- Widely extended
- RMI-based middleware (e.g., ProActive)
- RMI Optimizations:
    - KaRMI
    - Manta
    - Ibis RMI
    - Opt RMI

Java Message-Passing Libraries

Message-passing is the main HPC programming model.

- Implementation approaches in Java message-passing libraries.

Implementation approaches

- RMI-based.
- Wrapping a native library (e.g., MPI libraries: OpenMPI, MPICH).
- Sockets-based.

Listing 2: MPJ example

```
import mpi.* ;

public class Hello {

  public static void main (String argv[]) {
    MPI.Init(args);
    int rank = MPI.COMM_WORLD.Rank() ;

    if (rank == 0){
      String[] msg = new String[1];
      msg[0] = new String("Hello");
      MPI.COMM_WORLD.Send(msg, 0, 1, MPI.OBJECT, 1, 13);
    } else if (rank == 1) {
      String[] message = new String[1];
      MPI.COMM_WORLD.Recv(message, 0, 1, MPI.OBJECT, 0, 13);
      System.out.println(message[0]);
    }
    MPI.Finalize() ;
  }
}
```

	Pure Java Impl.	Socket impl.		High-speed network support			API		
		Java IO	Java NIO	Myrinet	InfiniBand	SCI	mpiJava 1.2	JGF MPJ	Other APIs
MPJava	✓		✓						✓
Jcluster	✓	✓							✓
Parallel Java	✓	✓							✓
mpiJava				✓	✓	✓	✓		
P2P-MPI	✓	✓	✓				✓		
MPJ Express	✓		✓	✓			✓		
MPJ/Ibis	✓	✓		✓				✓	
JMPI	✓	✓							✓
F-MPJ	✓	✓		✓	✓	✓	✓		

Java Communication Libraries Overview

Java HPC Applications (Develop Efficient Codes)
Java Message-passing libraries (Scalable Algorithms)
Low-level messaging libraries (MPJ Devices)
Java Sockets libraries (Java Fast Sockets)
HPC Hardware

Java Fast Sockets (JFS)

High Performance Java Fast Sockets (JFS):

- Provides efficient high-speed cluster interconnects support (SCI, Myrinet and InfiniBand).
- Optimizes Java IO sockets, more popular and extended than NIO sockets.
- Avoids the need for primitive data type array serialization.
- Significantly reduces buffering and unnecessary copies.
- Implements an optimized shared memory protocol.
- It is user and application transparent, no source code modification is necessary to use JFS.

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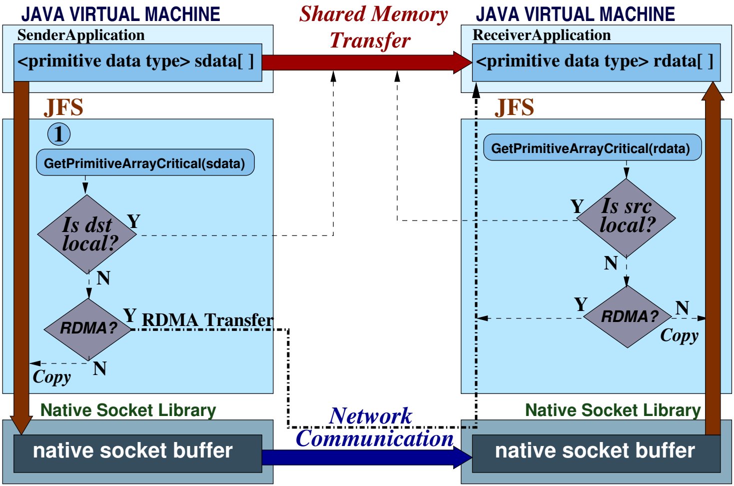
JFS Transparency

```
SocketImplFactory factory = new jfs.net.JFSImplFactory();
Socket.setSocketImplFactory(factory);
ServerSocket.setSocketFactory(factory);

Class cl = Class.forName(className);
Method method = cl.getMethod("main",parameterTypes);
method.invoke(null, parameters);
```

JFS optimized protocol



JFS Serialization Avoidance Feature

JFS extended API for communicating primitive data type arrays directly.

```
jfs.net.SocketOutputStream.write(byte buf[], int offset, int length);
jfs.net.SocketOutputStream.write(int buf[], int offset, int length);
jfs.net.SocketOutputStream.write(double buf[], int offset, int length);
  ...
jfs.net.SocketInputStream.read(byte buf[], int offset, int length);
jfs.net.SocketInputStream.read(int buf[], int offset, int length);
jfs.net.SocketInputStream.read(double buf[], int offset, int length);
  ...
```

JFS Portability and Performance (direct send of part of an integer array)

```
int int_array[] = new int[20];

// Writing the first ten elements of int_array
if (os instanceof jfs.net.SocketOutputStream) {
      ((jfs.net.SocketOutputStream) os).write(int_array,0,10);
else {
      int[] ints = (int[])Array.newInstance(int.class, 10);
      System.arraycopy(int_array, 0, ints, 0, 10);
      oos = new ObjectOutputStream(os);
      oos.writeUnshared(ints);
}
```

JFS High-speed Networks Support

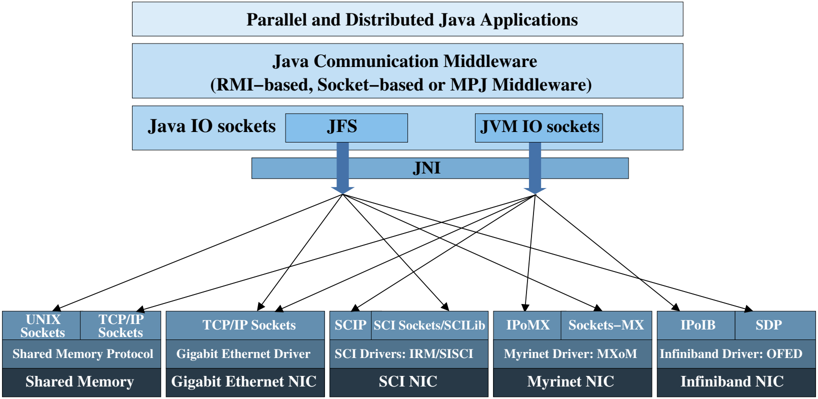


Figure: Java communication middleware on high-speed multi-core clusters

JFS Micro-Benchmarking

JFS performance improvement compared to Sun JVM sockets

	JFS start-up reduction	JFS bandwidth increase
SCI	up to 88%	up to 1305%
Myrinet	up to 78%	up to 412%
InfiniBand	up to 65%	up to 860%
Gigabit Ethernet	up to 10%	up to 119%
Shared memory	up to 50%	up to 4411%

iodev: Low-level Message-Passing Library

The use of pluggable low-level communication devices is widely extended in message-passing libraries.

Message-passing Low-level Devices:

- MPICH/MPICH2 ADI/ADI3 (GM/MX for Myrinet, IBV/VAPI for InfiniBand, and shared memory).
- OpenMPI BTL (GM/MX for Myrinet, IBV/VAPI for InfiniBand, and shared memory).
- MPJ Express xdev (NIO sockets, MX for Myrinet, and shared memory).

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xxdev API. Public interface of the *xxdev.Device* class

```
public abstract class Device {
 static public Device newInstance(String deviceImpl);
 public int[] init(String[] args);
 public int id();
 public void finish();

 public Request isend(Object buf, int dst, int tag);
 public Request irecv(Object buf, int src, int tag, Status stts);

 public void send(Object buf, int dst, int tag);
 public Status recv(Object buf, int src, int tag);

 public Request issend(Object buf, int dst, int tag);
 public void ssend(Object buf, int dst, int tag);

 public Status iprobe(int src, int tag, int context);
 public Status probe(int src, int tag, int context);
 public Request peek();
}
```

Low-Level Java Communication Devices

xdev implementations

- Current: niodev (Java NIO sockets), iodev (Java IO sockets, and hence JFS) and mxdev (Myrinet)
- Ongoing: smpdev (Shared memory) and ibdev (InfiniBand)

Low-Level Java Communication Devices

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Fast MPJ (F-MPJ)

Fast MPJ (F-MPJ) is the scalable and efficient Java message-passing library implemented on top of the low-level message-passing middleware iodev.

F-MPJ:

- shows efficient non-blocking communication (iodev) and high-speed multi-core clusters support (JFS).
- presents lower communication overhead through an extensive use of communications overlapping.
- achieves high scalability as it implements several algorithms per collective primitive, allowing their selection at runtime.

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MPJ Collective Algorithms

The design, implementation and runtime selection of efficient collective communication operations have been extensively discussed in the context of native message-passing libraries, but not in MPJ.

F-MPJ focuses on developing scalable MPJ collective primitives.

MPJ Collective Algorithms

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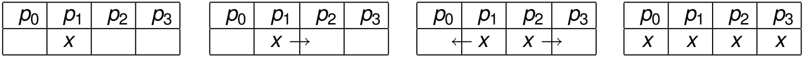
Collective Algorithms:

- Flat Tree (FT)
- Minimum-Spanning Tree (MST)
- Binomial Tree (BT)
- Four-ary Tree (Four-aryT)
- Bucket (BKT) or cyclic
- BiDirectional Exchange (BDE) or recursive doubling

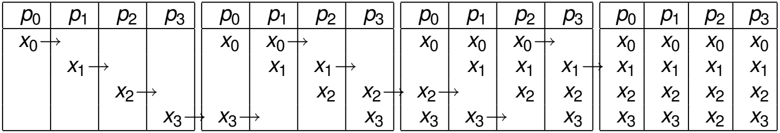
MPJ Collective Algorithms. MST



(a) Initial state (b) 1^{st} Step (c) 2^{nd} Step (d) Final state

Figure: Minimum-spanning tree algorithm for Broadcast

MPJ Collective Algorithms. BKT



(a) 1^{st} Step (b) 2^{nd} Step (c) 3^{rd} Step (d) Final state

Figure: Bucket algorithm for Allgather (BKTAllgather)

MPJ Collective Algorithms. BDE

p_0	p_1	p_2	p_3
x_0			
	x_1		
		x_2	
			x_3

(a) Initial state

p_0	p_1	p_2	p_3
$x_0 \rightarrow$			
	$\leftarrow x_1$		
		$x_2 \rightarrow$	
			$\leftarrow x_3$

(b) 1^{st} Step

p_0	p_1	p_2	p_3
x_0	$x_0 \rightrightarrows$		
x_1	$x_1 \rightrightarrows$		
		$\leftleftarrows x_2$	x_2
		$\leftleftarrows x_3$	x_3

(c) 2^{nd} Step

p_0	p_1	p_2	p_3
x_0	x_0	x_0	x_0
x_1	x_1	x_1	x_1
x_2	x_2	x_2	x_2
x_3	x_3	x_3	x_3

(d) Final state

Figure: Bidirectional exchange algorithm for Allgather (BDEAllgather). In the 2^{nd} step, bidirectional exchanges occur between the two pairs of processes p_0 and p_2, and p_1 and p_3

Collective	F-MPJ	MPJ Express
Barrier	MST	nbFTGather+ bFour-aryTBcast
Bcast	MST[1] MSTScatter+BKTAllgather[2]	bFour-aryT
Scatter	MST[1] nbFT[2]	nbFT
Scatterv	MST[1] nbFT[2]	nbFT
Gather	MST[1] nbFT[2]	nbFT
Gatherv	MST[1] nbFT[2]	nbFT
Allgather	MSTGather+MSTBcast[1] BKT[2] / BDE[3]	nbFT
Allgatherv	MSTGatherv+MSTBcast	nbFT
Alltoall	nbFT	nbFT
Alltoallv	nbFT	nbFT
Reduce	MST[1] BKTReduce_scatter+ MSTGather[2]	bFT
Allreduce	MSTReduce+MSTBcast[1] BKTReduce_scatter+ BKTAllgather[2] / BDE[3]	BT
Reduce_-scatter	MSTReduce+MSTScatterv[1] BKT[2] / BDE[3]	bFTReduce+ nbFTScatterv
Scan	nbFT	nbFT

NPB-MPJ Characteristics (10,000 SLOC (Source LOC))

Name	Operation	SLOC	Communicat. intensiveness	Kernel	Applic.
CG	Conjugate Gradient	1000	Medium	✓	
EP	Embarrassingly Parallel	350	Low	✓	
FT	Fourier Transformation	1700	High	✓	
IS	Integer Sort	700	High	✓	
MG	Multi-Grid	2000	High	✓	
SP	Scalar Pentadiagonal	4300	Medium		✓

NPB-MPJ

NPB-MPJ Optimization:

- JVM JIT compilation of heavy and frequent methods with runtime information
- Structured programming is the best option
  - Small frequent methods are better.
    - mapping elements from multidimensional to one-dimensional arrays (array flattening technique: arr3D[x][y][z]→arr3D[pos3D(lenghtx,lengthy,x,y,z)])
  - NPB-MPJ code refactored, obtaining significant improvements (up to 2800% performance increase)

Experimental Configuration:

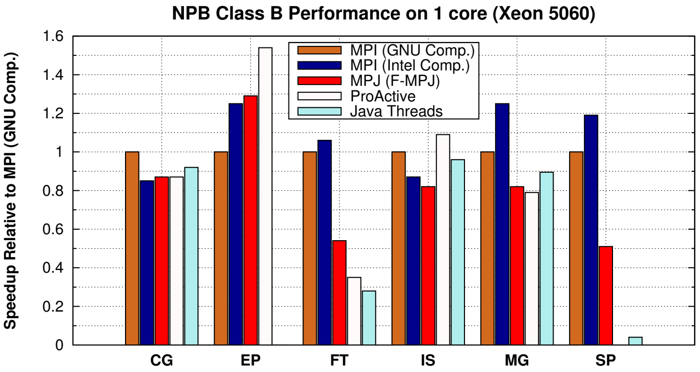
Departmental cluster (8 nodes)

- Intel Xeon 5060 dual dual-core CPU (4 cores with hyper-threading per node)
- 4 GB RAM
- InfiniBand network (16 Gbps)
- Linux, OFED-1.4, Intel MPI/C Compiler
- Sun JDK 1.6, ProActive, F-MPJ, MPJ Express, mpiJava

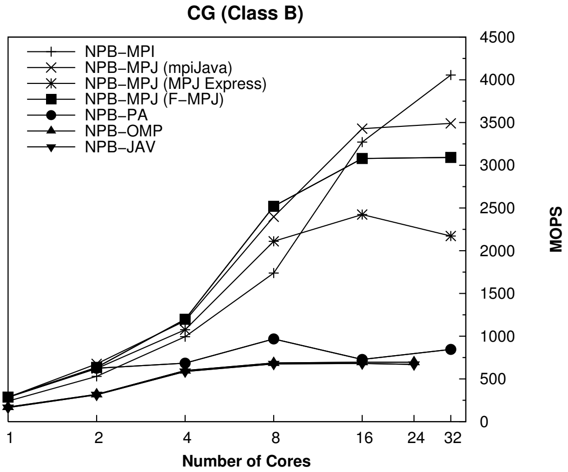
24-core machine

- Quad Intel Xeon 7450 hexa-core CPU (24 cores)
- 32 GB RAM
- Linux, Sun JDK 1.6, Intel Open Compiler

Experimental Results on One Core (relative perf.)



NPB-MPJ Performance



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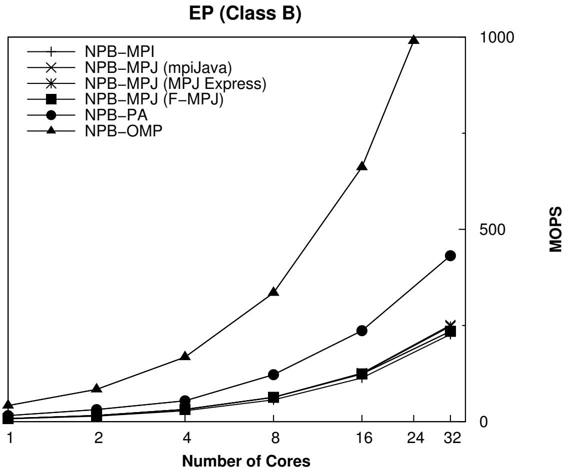

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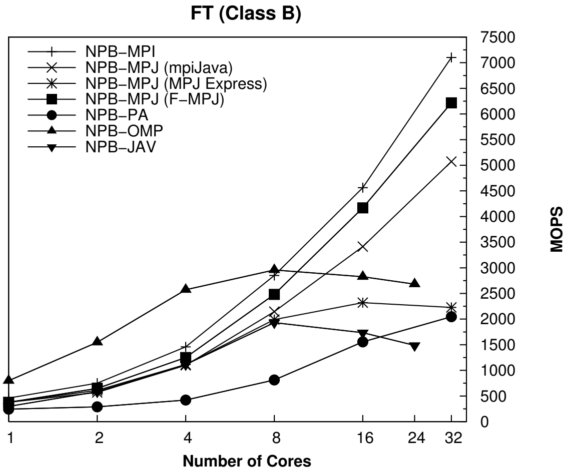

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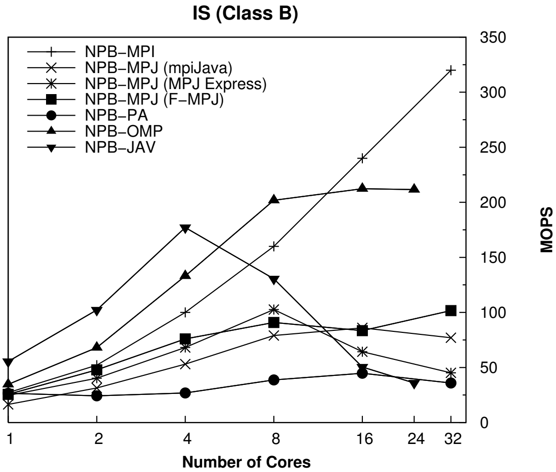

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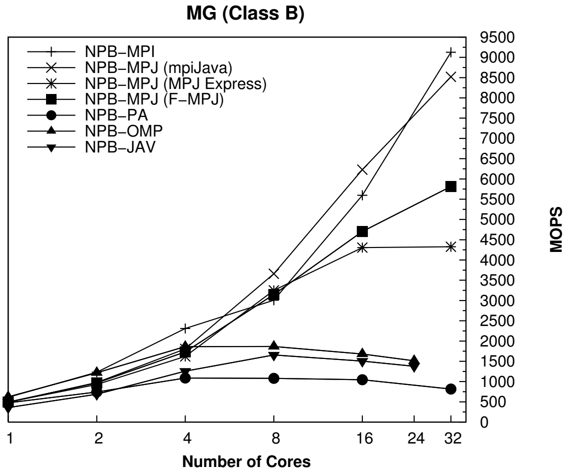

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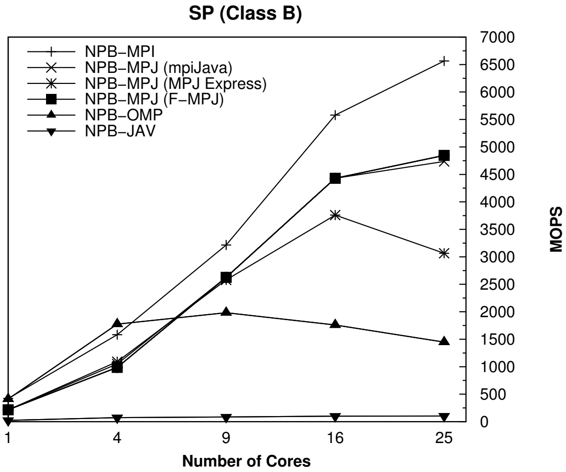


Finis Terrae Supercomputer Configuration

Finis Terrae (142 HP Integrity rx7640 nodes).

Hybrid shared/distributed memory (up to 8 cores per node and up to 32 nodes).

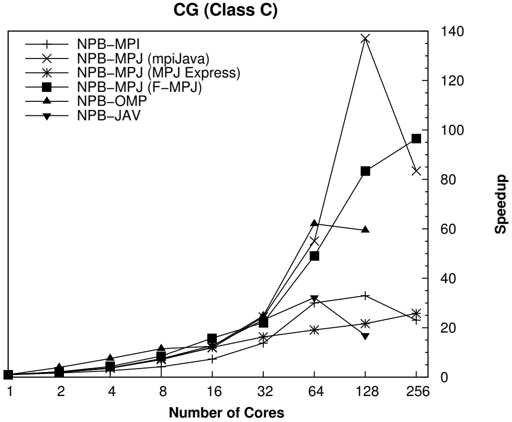
- 16 Montvale Itanium2 (IA64) cores at 1.6 GHz (used 8 cores per node).
- 128 GB RAM
- Interconnected via InfiniBand (16 Gbps)

Finis Terrae Integrity Superdome

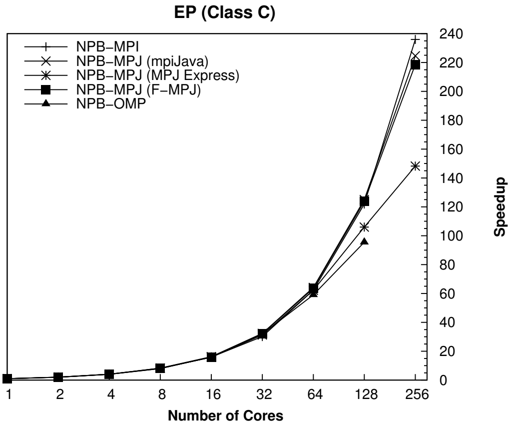
Shared memory performance evaluation of up to 64 cores:

- 128 Montvale Itanium2 (IA64) cores at 1.6 GHz
- 1 TB RAM

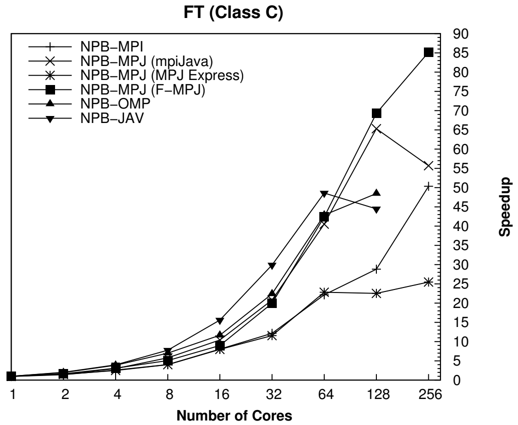
NPB-MPJ Performance Evaluation (Finis Terrae)



NPB-MPJ Performance Evaluation (Finis Terrae)



NPB-MPJ Performance Evaluation (Finis Terrae)



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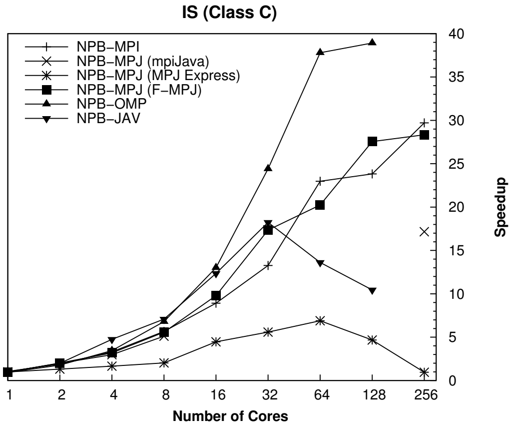

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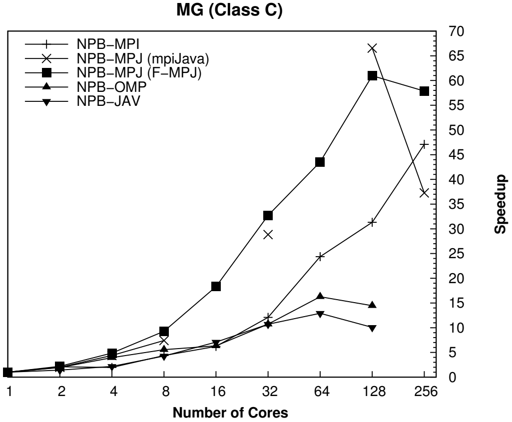
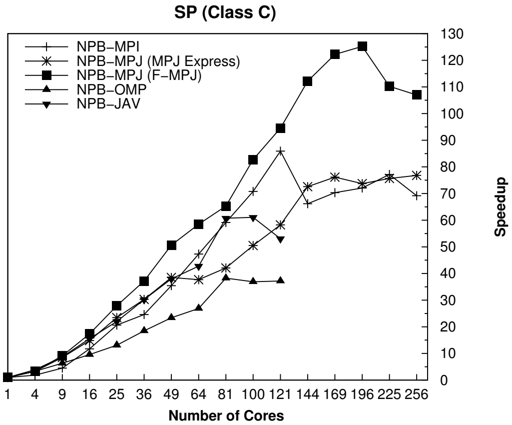
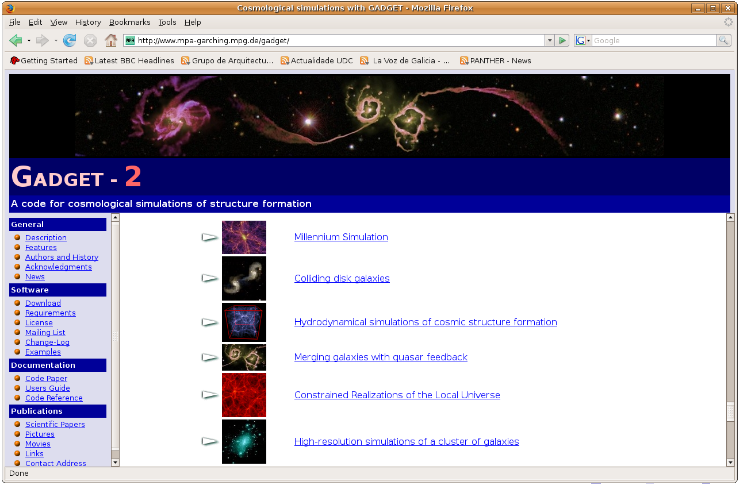


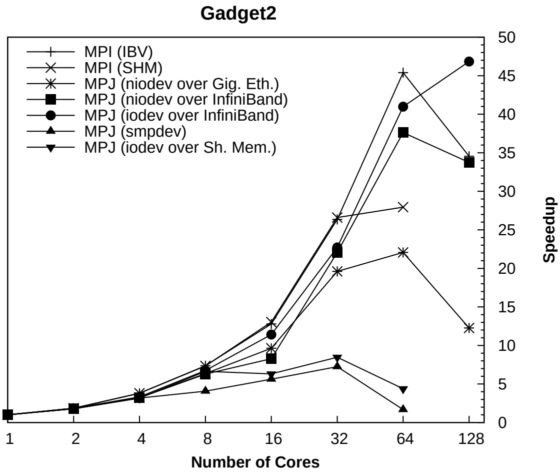
NPB-MPJ Performance Evaluation (Finis Terrae)



Gadget Cosmological Simulation Project Webpage



Gadget Cosmological Simulation Speedup



Summary

- Current state of Java for HPC (interesting/feasible alternative)
- Available programming models in Java for HPC:
  - Shared memory programming
  - Distributed memory programming
  - Distributed shared memory programming
- Active research on Java for HPC (>30 projects)
- ...but still not a mainstream language for HPC
- Adoption of Java for HPC:
  - It is an alternative for programming multi-core clusters (tradeoff some performance for appealing features)
  - Performance evaluations are highly important
  - Analysis of current projects (promotion of joint efforts)

Questions?

JAVA FOR HIGH PERFORMANCE COMPUTING:

ASSESSMENT OF CURRENT RESEARCH AND PRACTICE

PPPJ'09

Guillermo López Taboada
Computer Architecture Group, University of A Coruña

For Further Reading I

- G. L. Taboada, and J. Touriño, and R. Doallo, "Java Fast Sockets: Enabling High-speed Java Communications on High Performance Clusters," *Computer Communications*, vol. 31, no. 17, pp. 4049–4059, 2008.
- G. L. Taboada, J. Touriño, and R. Doallo, "F-MPJ: Scalable Java Message-passing Communications on Parallel Systems," *Journal of Supercomputing*, vol. In press, 2009.
- G. L. Taboada, J. Touriño, and R. Doallo, "Performance Analysis of Message-Passing Libraries on High-Speed Clusters," *Intl. Journal of Computer Systems Science & Engineering*, 2009 (In press).

For Further Reading II

- B. Amedro, V. Bodnartchouk, D. Caromel, C. Delbé, F. Huet, and G. L. Taboada. "Current State of Java for HPC", *INRIA Technical Report RT-0353*, pages 1–24, INRIA Sophia Antipolis, Nice, France, 2008, http://hal.inria.fr/inria-00312039/en/

- A. Shafi, B. Carpenter, and M. Baker. "Nested Parallelism for Multi-core HPC Systems using Java", *Journal of Parallel and Distributed Computing*, 2009 (In press).

- A. Shafi, B. Carpenter, M. Baker, and A. Hussain. "A Comparative Study of Java and C Performance in two Large-scale Parallel Applications", .*Concurrency and Computation: Practice and Experience*, In press, 2009.

Opt RMI

RMI Layers:

- Transport Protocol Optimization.
- Serialization Overhead Reduction.
- Object Manipulation Improvements.

Optimization:

- High Performance Sockets Support (JFS).
- Reduction of Data Block Information.

Opt RMI

RMI Layers:

- Transport Protocol Optimization.
- Serialization Overhead Reduction.
- Object Manipulation Improvements.

Optimization:

- Native Array Serialization.

Opt RMI

RMI Layers:

- Transport Protocol Optimization.
- Serialization Overhead Reduction.
- Object Manipulation Improvements.

Optimization:

- Versioning Information Reduction.
- Class Annotation Reduction.
- Array Processing Improvements.

Gadget Cosmological Simulation Runtime