A Distributed Runtime for Java: Yesterday and Today

Combining transparency with portability

Michael Factor	**IBM**
Assaf Schuster	**Technion**
Konstantin Shagin	**Technion**

Outline

- Background and motivation
- Existing systems
  - Cluster-aware virtual machines
  - Compiler-based DSM systems
  - Systems using standard JVMs
- The JavaSplit runtime
  - Features
  - Implementation overview
  - Performance evaluation

Background and Motivation

- Need a convenient programming paradigm for distributed systems
  - The average programmer tends to prefer shared memory over message passing
- Java is popular, comfortable, and “well defined”
  - Can extend it with libraries for efficient support for parallel computing (e.g., barriers)
- Servers are written in Java (development cycle! Portability! Effciency?)
- Existing base of multithreaded code

The goal: create a runtime environment for distributed execution of multithreaded Java programs

Portability, Transparency, Efficiency.

1. Distributed nonstandard JVMs

- Require that each node install a custom JVM
  - Not portable
  - Cannot use a native just-in-time compiler (JIT)
- Can access the system resources, *e.g.*, memory and network interface directly
- Since there is no need to preserve portability, allow use of nonstandard but more efficient networking hardware

  - Java/DSM (1997)
  - Cluster VM for Java (formerly cJVM) (1999)
  - JESSICA (1999)

2. Compiler-based DSM systems

- Translate Java sources or bytecode to machine dependent assembler while adding DSM capabilities
  - Do not need a JIT
- The use of a dedicated compiler allows performing various compiler optimizations
  - Access check elimination and batching
- Have the same portability issues as cluster-aware JVMs

  - Hyperion (2001)
  - Jackal (2001)

3. Systems using standard JVMs

- Each node carries out its part of the execution using a standard JVM
  - Portable across any Java-enabled platform
  - Can use a native JIT
  - Given certain security permissions, nodes can join the system using a Java-enabled browser
- Access machine resources through the JVM
- Not transparent
  - Introduce unorthodox programming constructs and style: JSDM 2001 (SPMD), JavaParty 1997 (remote, RMI hooks)
  - Require non-standard libraries: ProActive 1998
  - Need user assistance: Addistant 2001 (class-based distribution, non/modifiable), jOrchestra 2002 (user-defined class partition, must co-locate a system class with its referenced code)

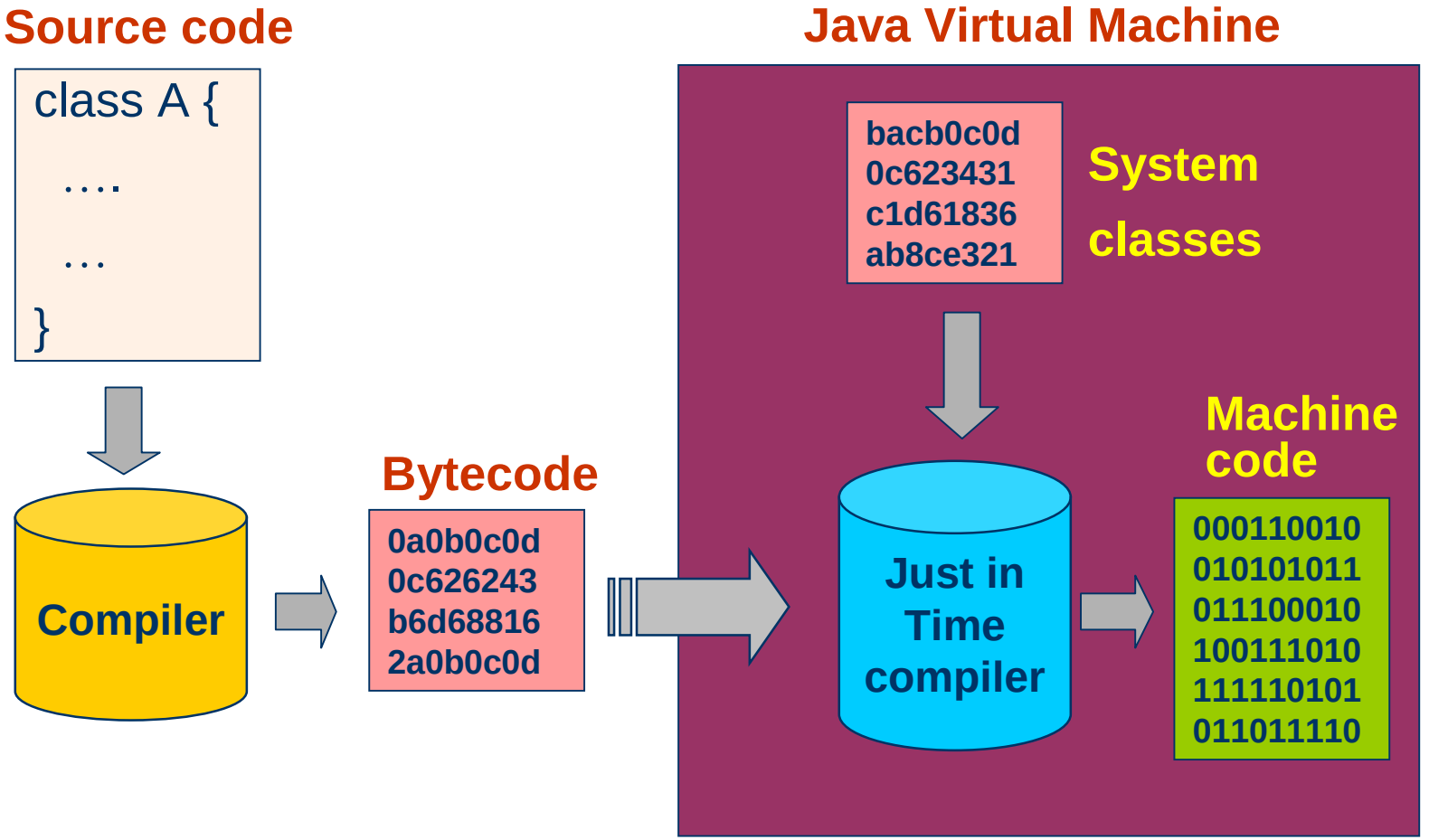
The JavaSplit runtime

- **Combines transparency with portability**
- Executes standard Java applications
  - Can automatically execute preexisting applications
    - No nonstandard libraries
    - No unconventional programming constructs or style
  - Does not require user hints
- Uses standard JVMs and therefore:
  - Portable across any Java-enabled platform
  - Can use a native JIT
  - Given certain security permissions, nodes can join the system using a Java-enabled browser
- Designed to efficiently support a large number of nodes

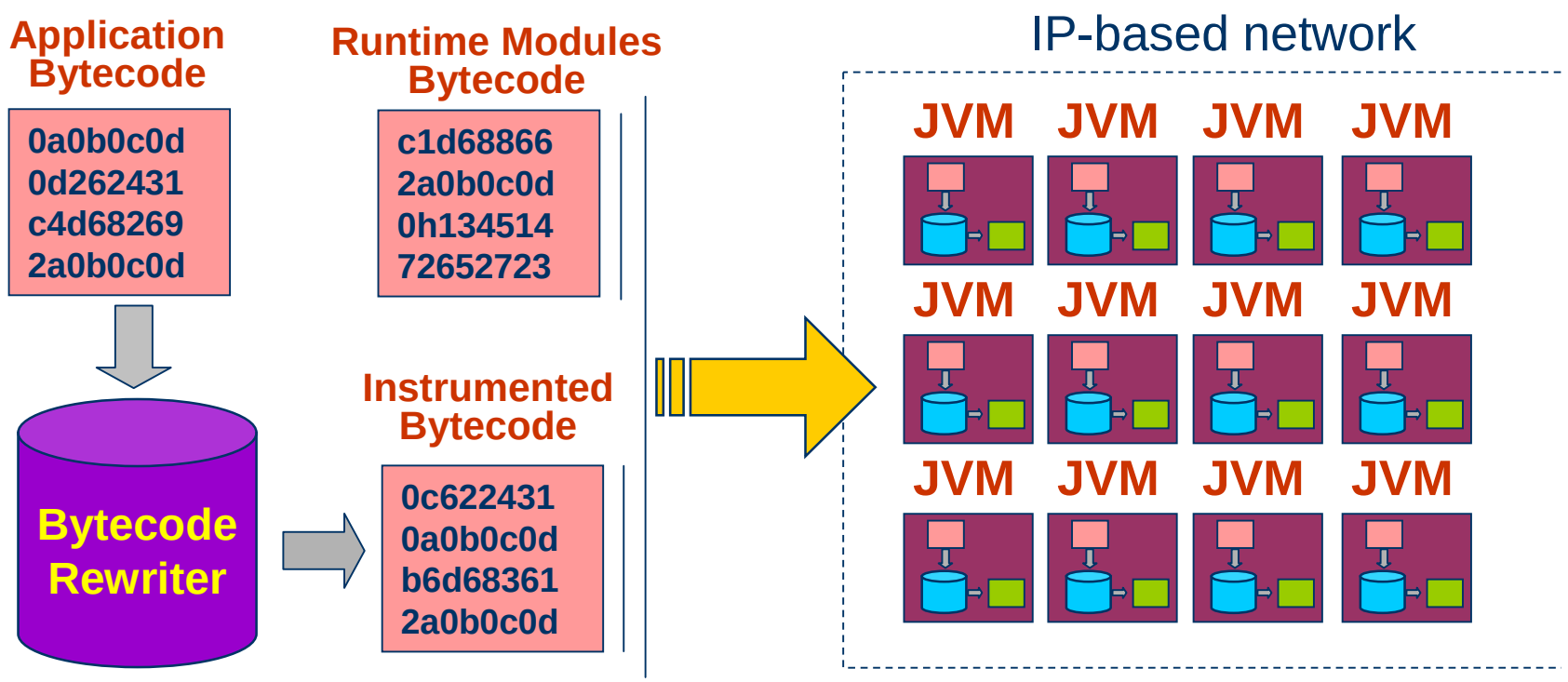
Employment of JavaSplit

- High-performance computing
- Rapid development of low-priced distributed systems composed of commodity hardware
- Cycle stealing in large non-dedicated environments
  - Need to augment the system with fault tolerance

Java Basics


Source code
class A {
….
…
}
Compiler
Bytecode
0a0b0c0d
0c626243
b6d68816
2a0b0c0d
Java Virtual Machine
bacb0c0d
0c623431
c1d61836
ab8ce321
System classes
Just in Time compiler
Machine code
000110010
010101011
011100010
100111010
111110101
011011110

JavaSplit Overview



- Rewriting intercepts synchronization, accesses to shared data etc.
- Threads and objects are distributed among the machines

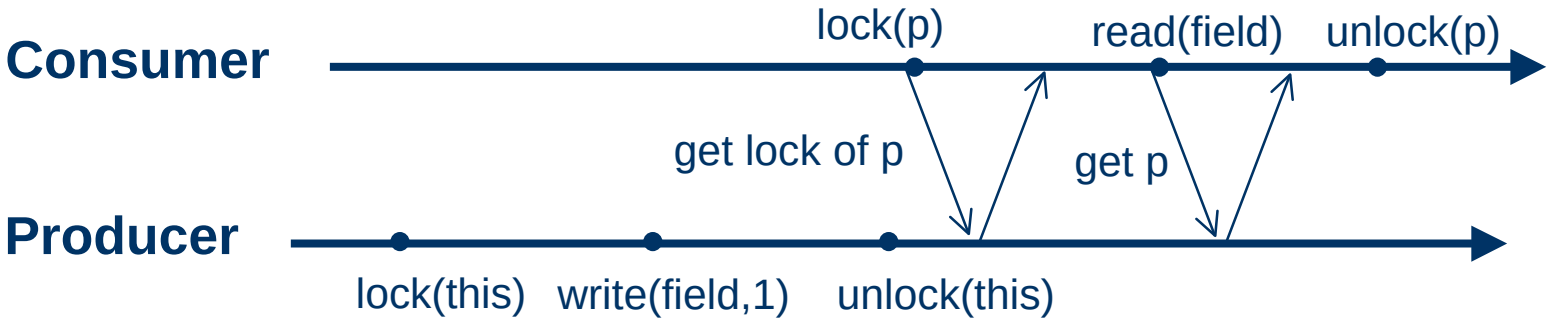
Example

```
class Producer extends Thread {
   public int field = 0;

   public void run(){
      synchronized(this){
        field = 1;
      }
  }
}
```

```
class Consumer extends Thread {
   public Producer p;

   public void run(){
      synchronized(p){
          System.out.println(p.field);
      }
  }
}
```



Distributed Shared Memory (DSM)

- Object-based
  - More suitable for Java
  - Few false-sharing
- Designed to be scalable
  - No global operations
  - Allows multiple simultaneous writers
- Implements Lazy Release Consistency
  - Consistent with the proposed revisions to the Java Memory Model (JMM)
- Only objects accessed by more than one thread are managed by the DSM
  - Detected at runtime

Treatment of system classes

- jOrchestra and Addistant treat system classes as *unmodifiable code*
- This restricts the placement of data
- requires user intervention to find a correct and efficient placement

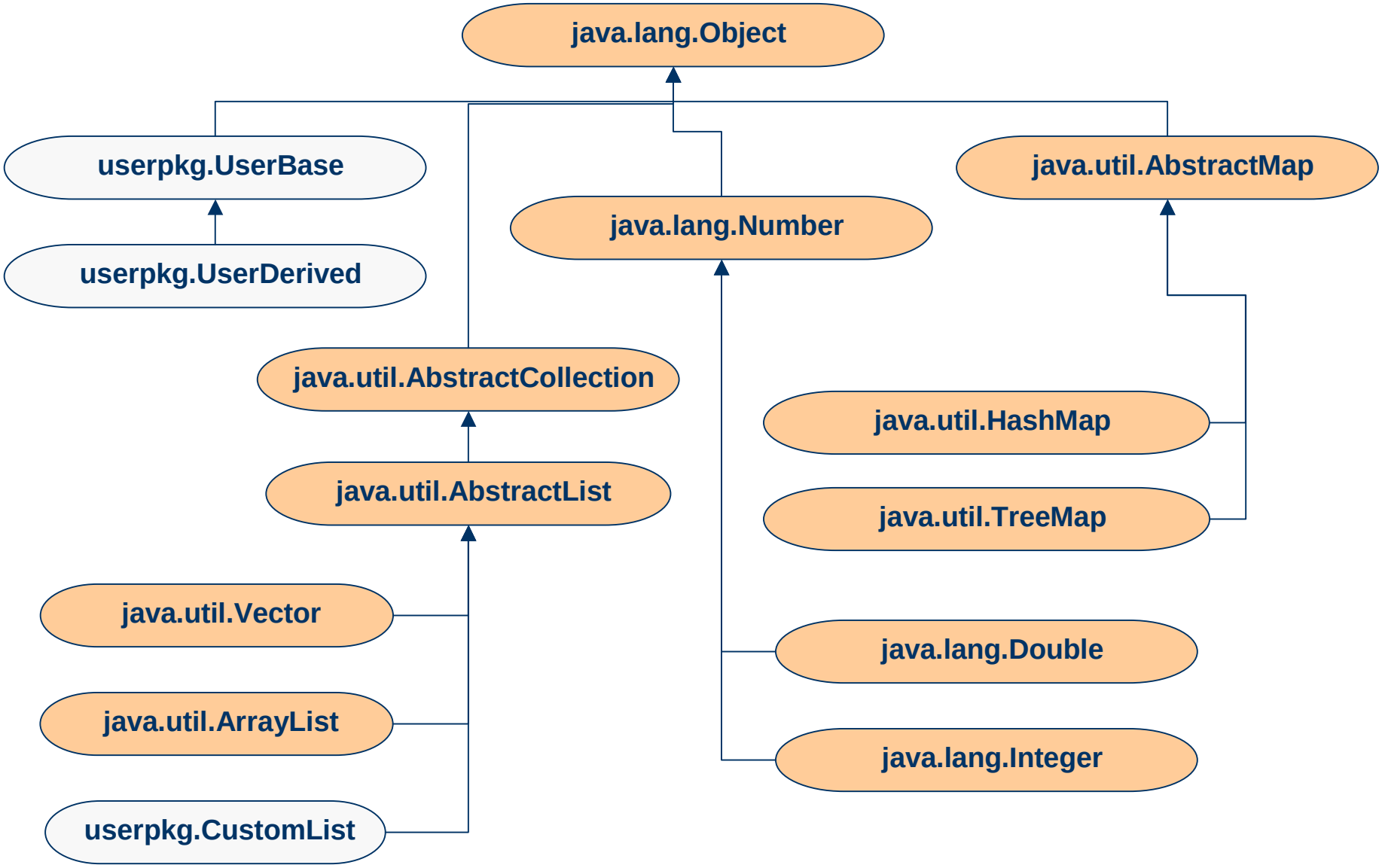
java.util.Calendar

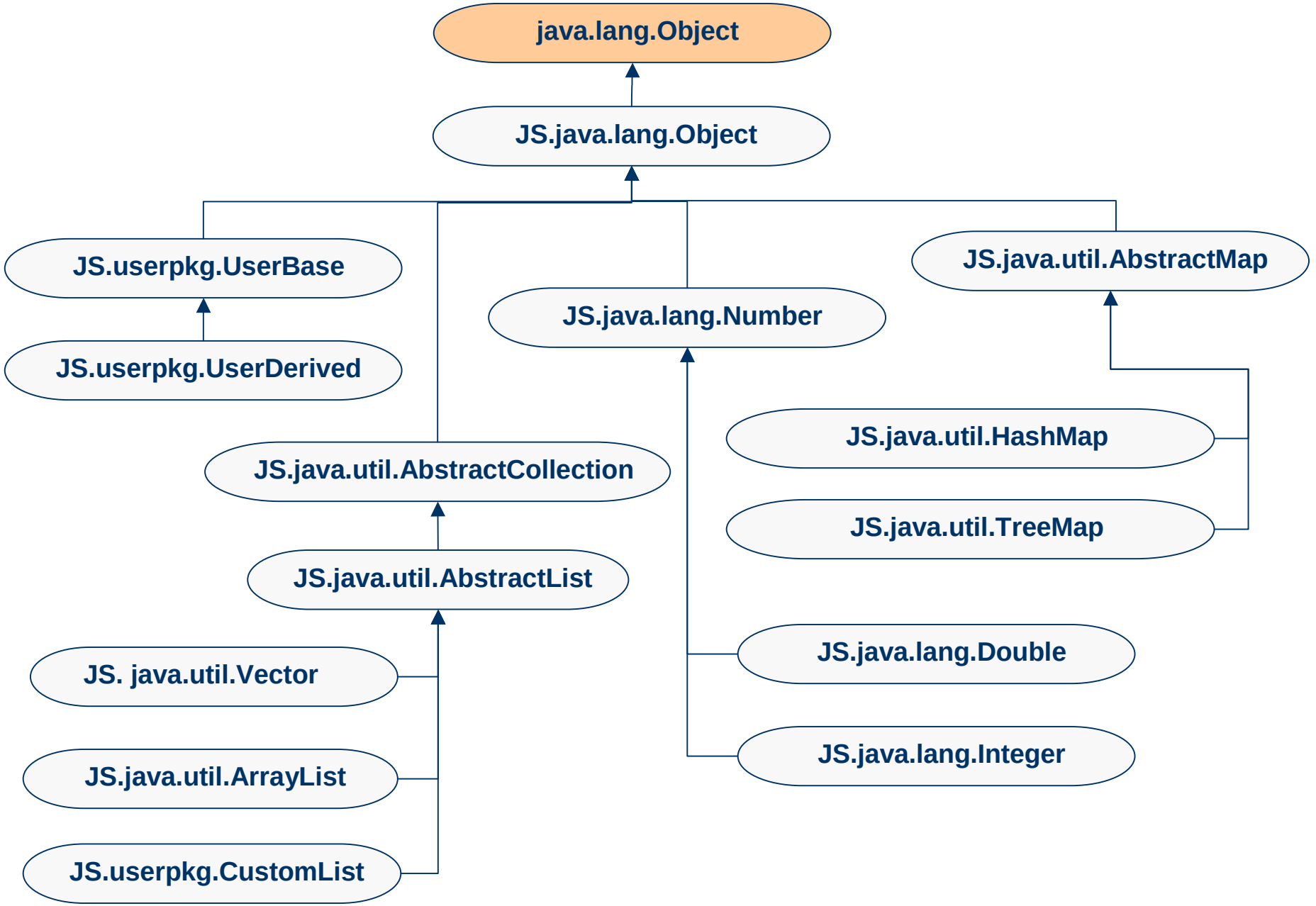
```
public Object clone() {
        …
        other.zone = (java.util.TimeZone) zone.clone();
        return other;
}
```

The code of Calendar cannot be updated to access the distribution-aware proxy of the *zone* object, therefore the zone object and the calendar instance pointing to it must be located on the same node

Bytecode Instrumentation

- JavaSplit instruments all classes used by the original application, including *system classes*
- To instrument system classes we use a novel technique, called *Twin Class Hierarchy (TCH)*
  - All instrumented classes are renamed
  - In a rewritten class, all referenced class names are replaced with the new names
  - All rewritten system classes become user classes, which are much easier to instrument


java.lang.Object
userpkg.UserBase
userpkg.UserDerived
java.lang.Number
java.util.AbstractMap
java.util.AbstractCollection
java.util.HashMap
java.util.AbstractList
java.util.TreeMap
java.util.Vector
java.lang.Double
java.util.ArrayList
java.lang.Integer
userpkg.CustomList


java.lang.Object
JS.java.lang.Object
JS.userpkg.UserBase
JS.userpkg.UserDerived
JS.java.lang.Number
JS.java.util.AbstractMap
JS.java.util.HashMap
JS.java.util.TreeMap
JS.java.util.AbstractCollection
JS.java.util.AbstractList
JS. java.util.Vector
JS.java.util.ArrayList
JS.userpkg.CustomList
JS.java.lang.Double
JS.java.lang.Integer

Original class

```
class A extends somepackage.C {
    // fields
    private int myIntField;
    public B myRefField;
    public java.util.Vector myVectorField;
    // methods
    protected void doSomething(B b, int n) {
        if(b instanceof java.util.List){ ... }
        java.lang.Class vecClass =
            java.lang.Class.forName("java.util.Vector");
        ...
    }
    public B doSomethingElse(java.lang.String str)  {
        java.lang.System.out.println(str);
        java.io.File f = new java.io.File(str);
        ...
    }
}
```

Instrumented class

```
class JS.A extends JS.somepackage.C {
    // fields
    private int myIntField;
    public JS.B myRefField;
    public JS.java.util.Vector myVectorField;
    // methods
    protected void doSomething(JS.B b, int n) {
        if(b instanceof JS.java.util.List){ ... }
        JS.java.lang.Class vecClass =
            JS.java.lang.Class.forName("java.util.Vector");
        ...
    }
    public JS.B doSomethingElse(JS.java.lang.String str)  {
        JS.java.lang.System.out.println(str);
        JS.java.io.File f = new JS.java.io.File(str);
        ...
    }
}
```

Implementing native methods

JS.java.lang.System

```
public static long currentTimeMillis(){
        return java.lang.System.currentTimeMillis();
}
```

JS.java.net.Inet4AddressImpl

```
public JS.java.lang.String getLocalHostName() {
        // origImpl_ is a private field of type java.net.Inet4AddressImpl
        java.lang.String name = origImpl_.getLocalHostName();
        // convert the name into a JS.java.lang.String and return it
        return JS.java.lang.String.__JS__convertFromJavaString(name);
}
```

Implementing native methods (2)

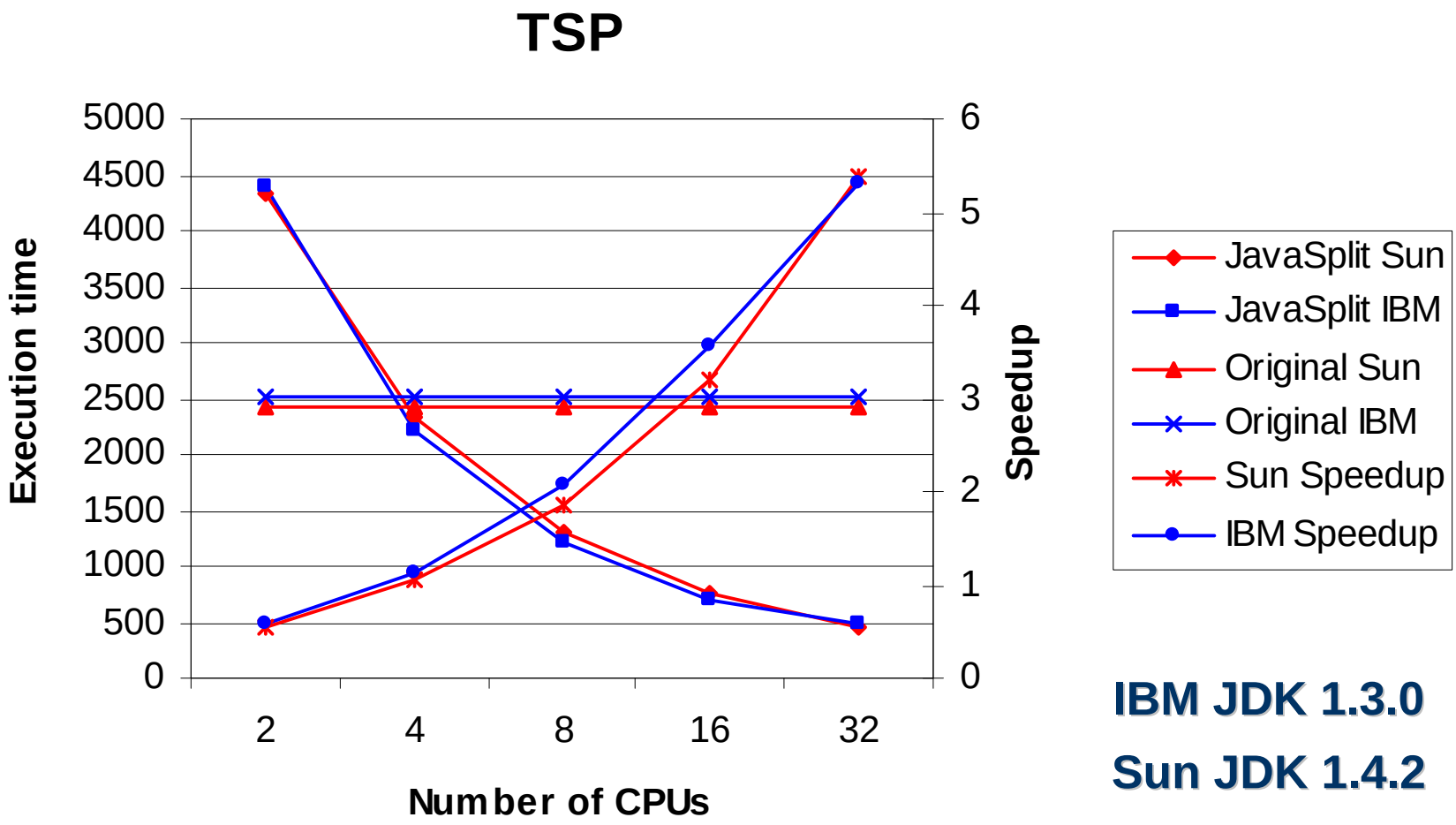
JS.java.math.StrictMath

```
public static strictfp double sqrt(double arg){
        return java.lang.StrictMath.sqrt(arg);
}
```

JS.java.lang.Inet4AddressImpl

```
public boolean isPrimitive(){
        // origImpl_ is a private field of type java.lang.Class
        return origImpl_.isPrimitive();
}
```

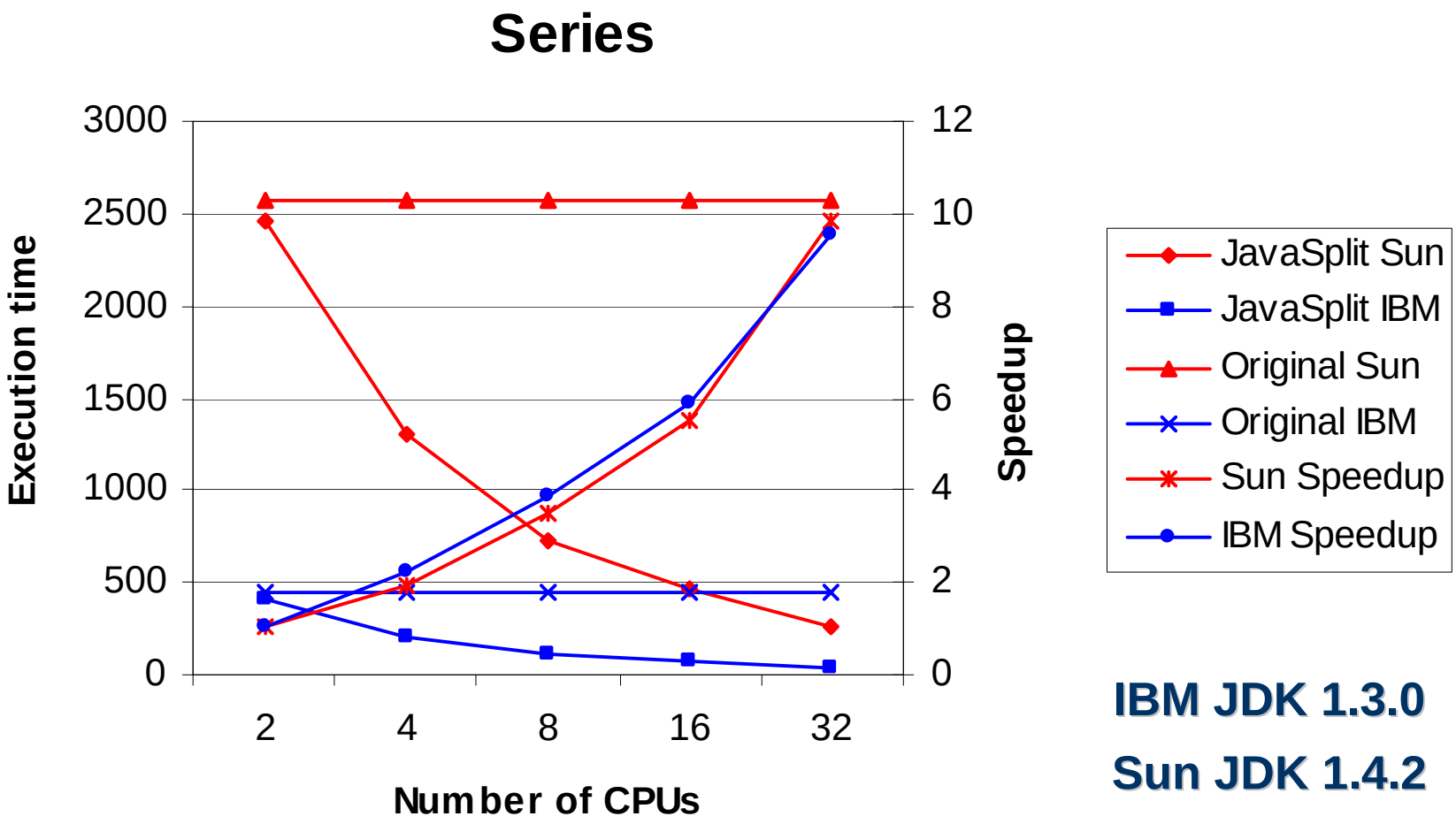
Performance



IBM JDK 1.3.0

Sun JDK 1.4.2

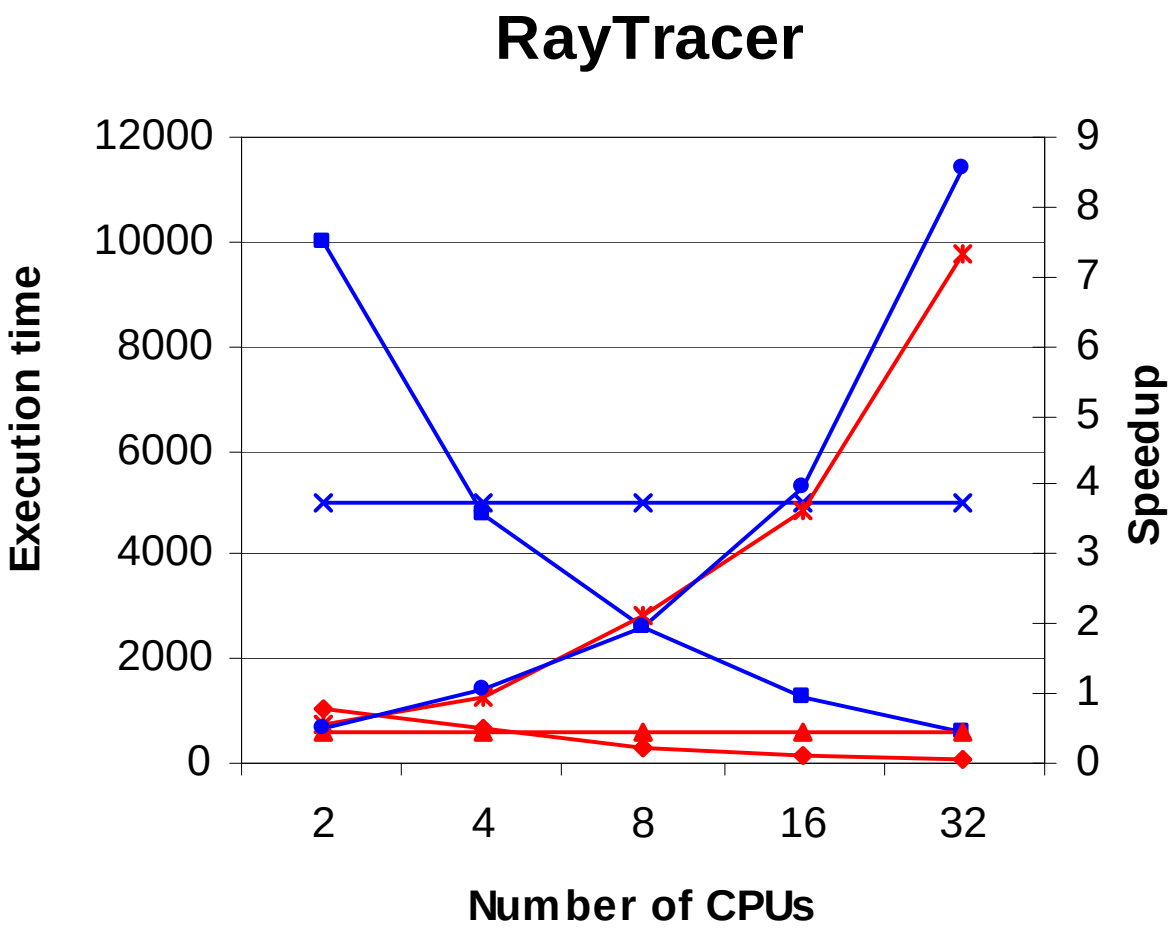
Performance (2)



IBM JDK 1.3.0

Sun JDK 1.4.2

Performance (3)



IBM JDK 1.3.0

Sun JDK 1.4.2

Conclusion

- JavaSplit is a first step towards creating a convenient and portable infrastructure for distributed computing
  - Provides shared memory abstraction
  - Can be used by any Java developer
  - Any platform with a JVM can participate
- Achieves scalable speedups executing computation-intensive applications
  - Despite relatively slow access to the network
  - With few simple optimizations

The End

Questions?

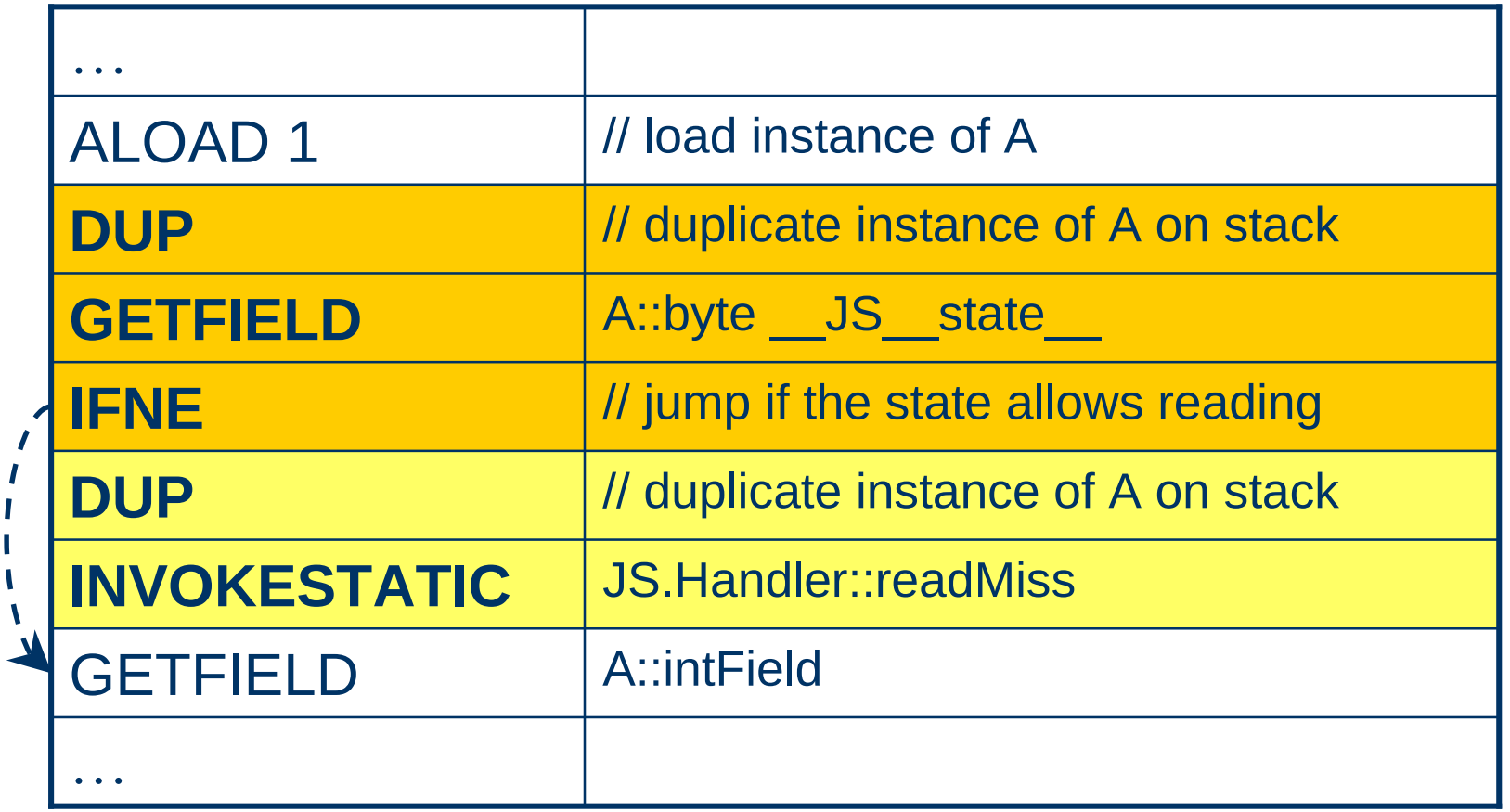
Instrumentation Details

- Classes are augmented with utility fields and methods
- The fields indicate the state of an object
  - Inserted at the topmost hierarchy classes
  - The state data can be quickly accessed and easily disposed.
- Implementation of the utility methods is class-specific
  - Perform the same operation on each field of the class

```
class A extends C {
  …
  // inherited utility fields
  public byte  __JS__state;
  public int   __JS__version;
  public long  __JS__globalID;

  public void _JS_pack
  (OutputStream out)
  {…}
  public void _JS_unpack
  (InputStream in)
  {…}
  public _JS_Diff _JS_compare
  (JS.A other)
  {…}
}
```

Read Access Check Example



Access Check Elimination

```
A aObject = new A();
…
<WRITE ACCESS CHECK of aObject>
aObject.intField = 2003;
        … // no lock acquires
<READ ACCESS CHECK of aObject>
for(int k=0; k<N; k++){
            … // no lock acquires
        <READ ACCESS CHECK of aObject>
            System.out.println(k+aObject.intField);
            … // no lock acquires
}
```

Efficient Synchronization

- Java applications contain a great amount of unneeded synchronization [Choi et. al., OOPSLA'99]
  - May cause significant performance degradation in instrumented classes
- We distinguish between synchronization operations on local and shared objects
  - Lightweight synchronization for local objects (similar to [Bacon et. al., PLDI'98])
  - Synchronization of local objects is cheaper than in original Java

[nanosec.]	Original	Local	Shared
Sun 1.4.1	90.6	19.6	281
IBM 1.3.0	93.4	54.7	327

Classification of existing systems

1. Distributed nonstandard JVMs
   - Java/DSM (1997), Cluster VM for Java (formerly cJVM) (1999), JESSICA(1999)
2. Compilation to native code combined with a distributed shared memory
   - Hyperion (2001), Jackal (2001)
3. Systems built on top of standard JVMs
   - JavaParty(1997), ProActive (1998), JSDM (2001), Addistant (2001), jOrchestra (2002)