Language Tools for Distributed Computing (II)

J-Orchestra:
Automatic Java Application Partitioning

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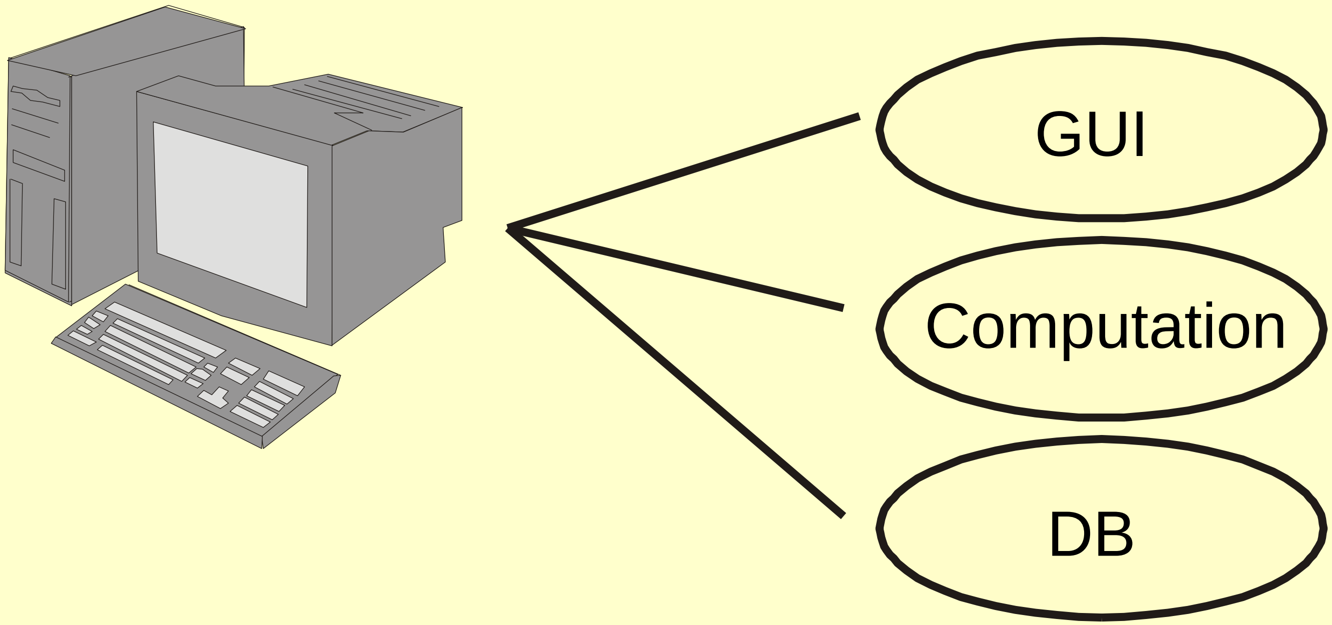
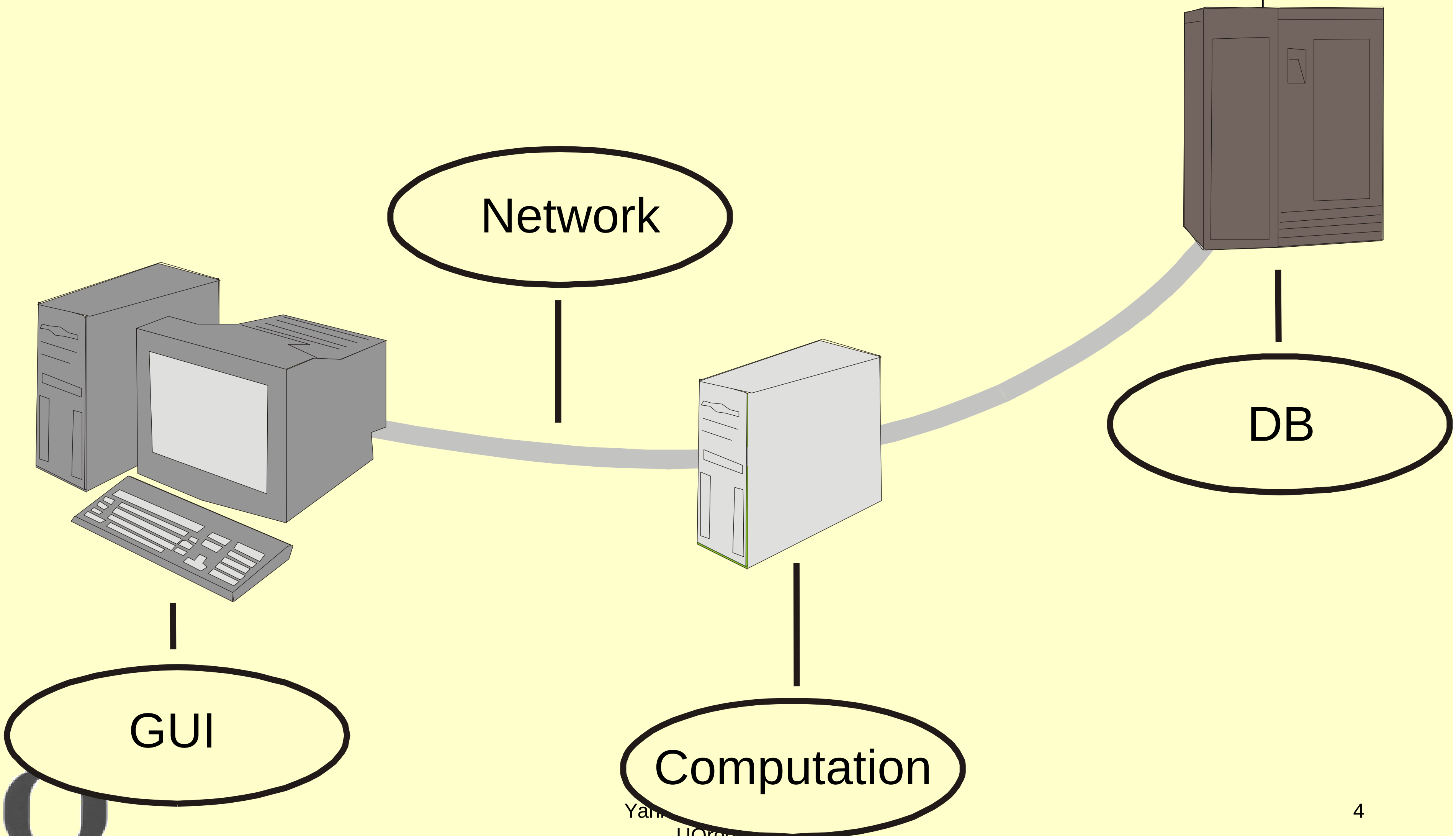
These Lectures

- NRMI: middleware offering a natural programming model for distributed computing
  - solves a long standing, well-known open problem!
- J-Orchestra: execute unsuspecting programs over a network, using program rewriting
  - led to key enhancements of a major open-source software project (JBoss)
- Morphing: a high-level language facility for safe program transformation
  - "bringing discipline to meta-programming"

Partitioning: Start with a Centralized Application



Convert it to a Distributed Application

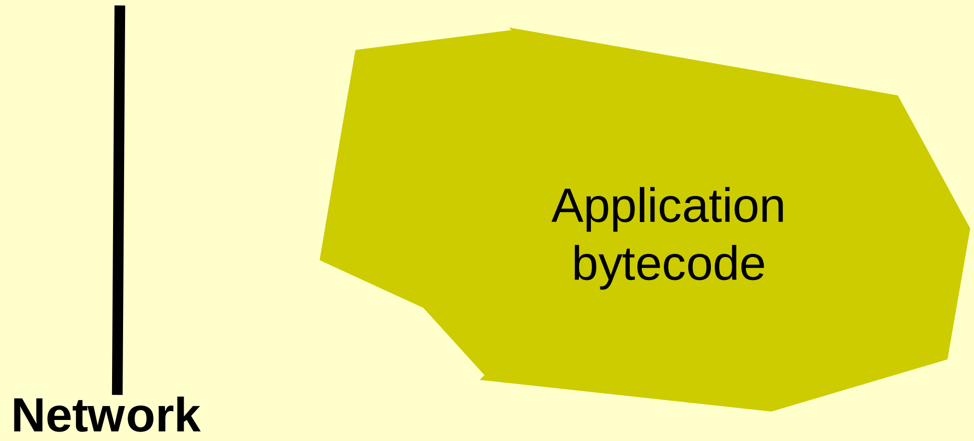


Automatic Program Partitioning

- How can we do this with tools instead of manually?
  - write a centralized program
  - select elements (at some granularity) and assign them to network locations
  - let an automatic tool (compiler) transform the program so that it runs over a network, using a general purpose run-time system
    - correctness and efficiency concerns addressed by compiler—though not always possible

J-Orchestra

- For the past 5 years, J-Orchestra has been one of my major research projects
  - an automatic partitioning system for Java
  - works as a bytecode compiler
  - think of result as “applets on steroids”
    - “code near resource”



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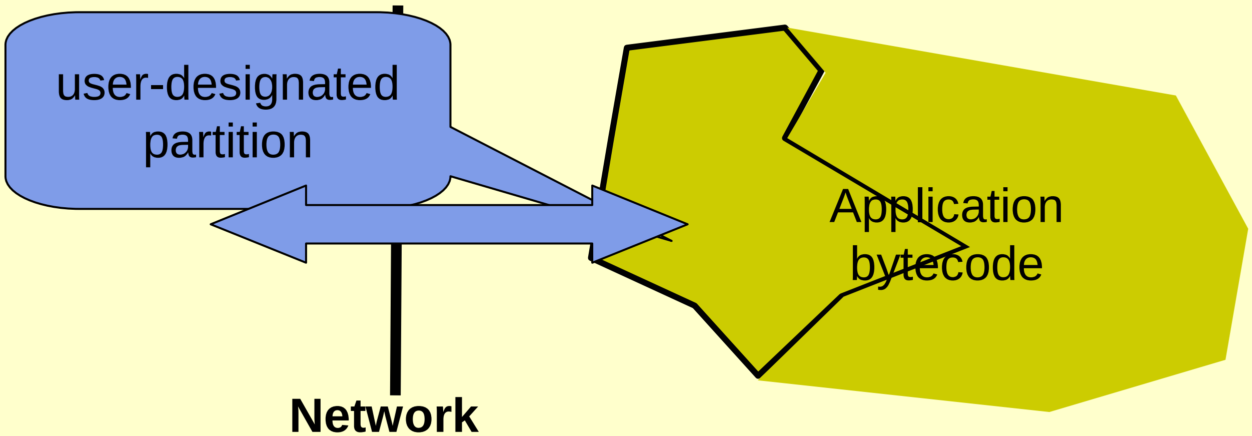
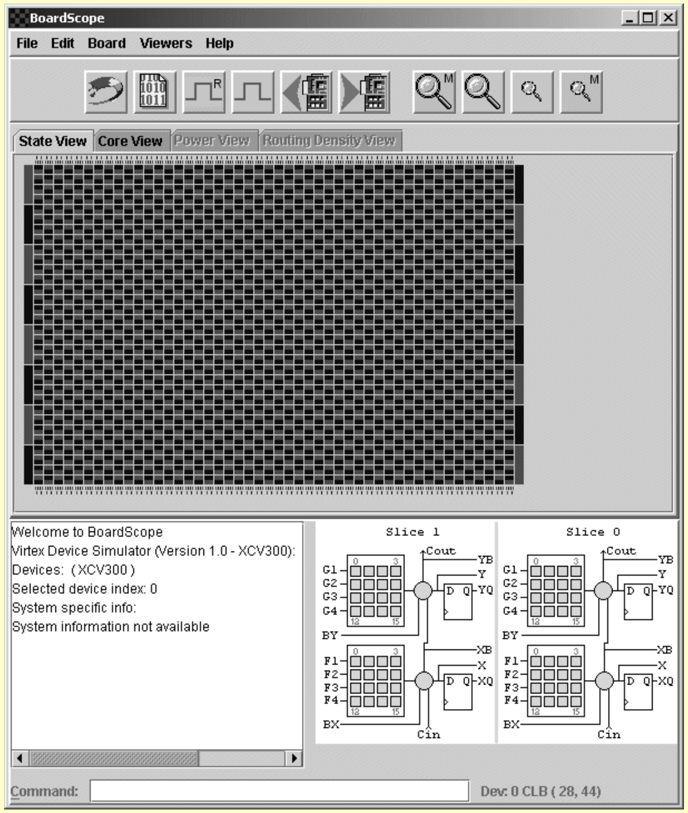


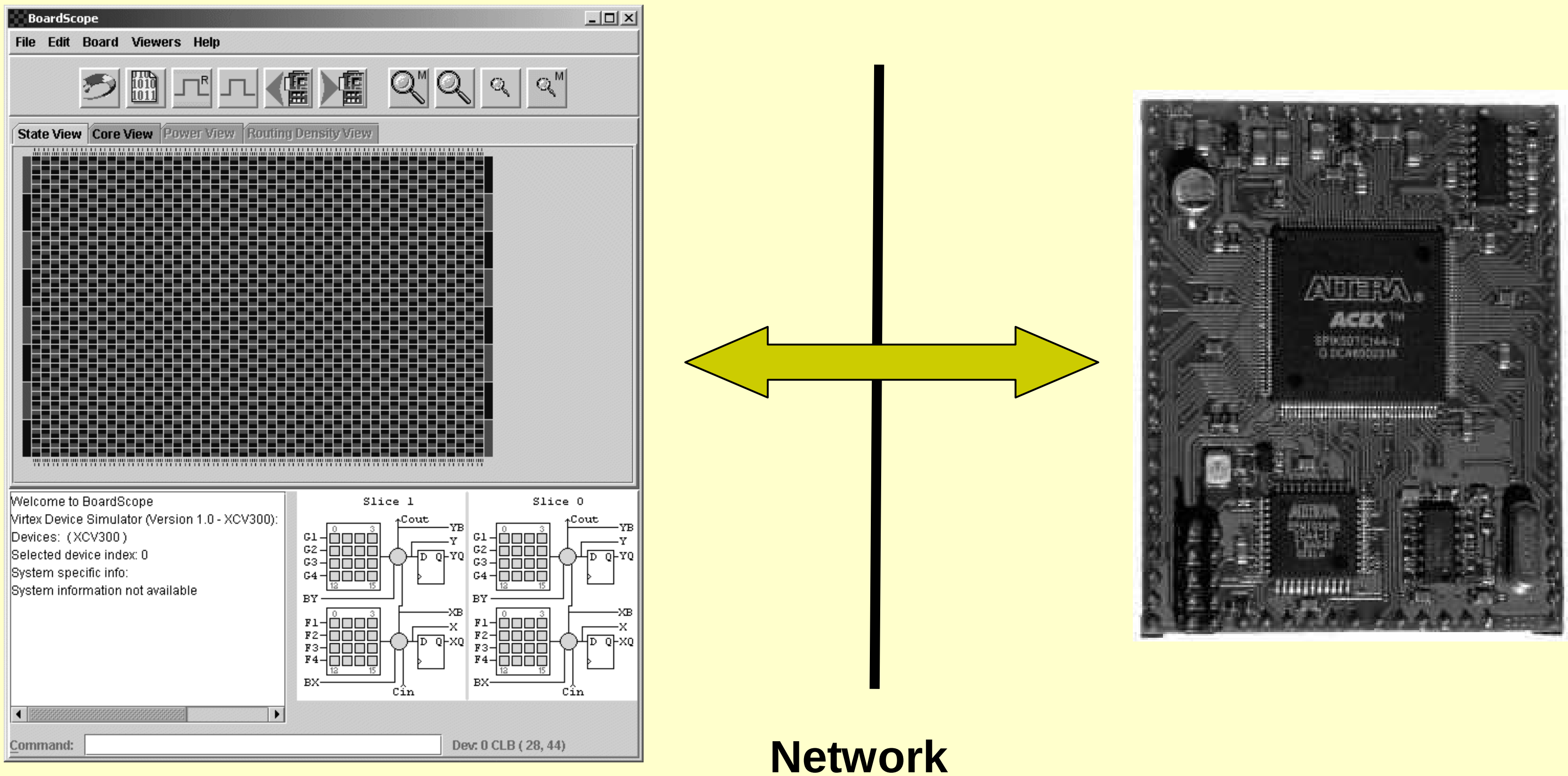
J-Orchestra Executive Summary

- Partitioned program is *equivalent* to the original centralized program for a very large subset of Java.
  - we handle synchronization, all OO language features, object construction, ...
  - nice analysis and compilation technique for dealing with native code
  - result: *most scalable automatic partitioning system in existence*
  - have partitioned many unsuspecting applications
    - including 8MB third-party bytecode only (JBits)

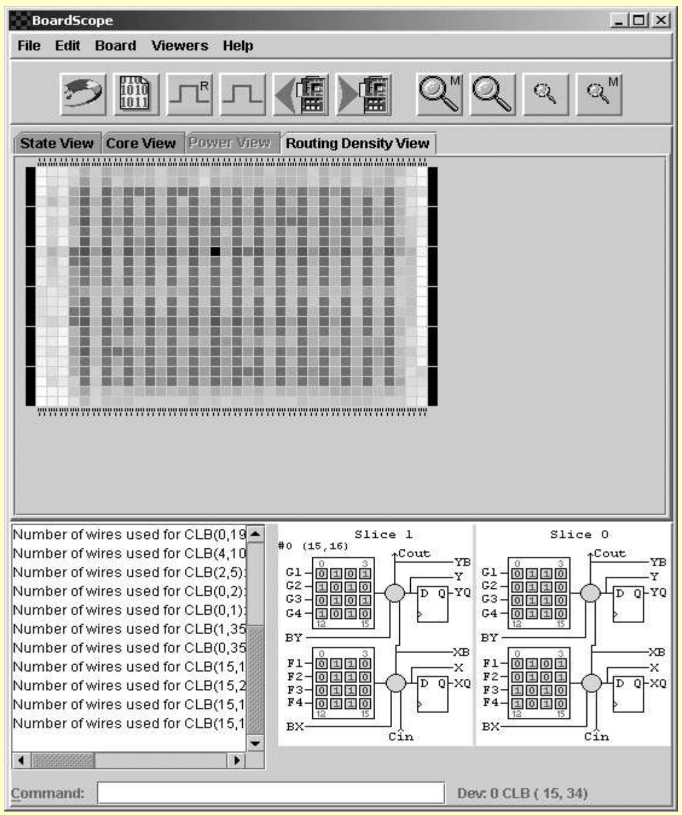
Example Partitioning



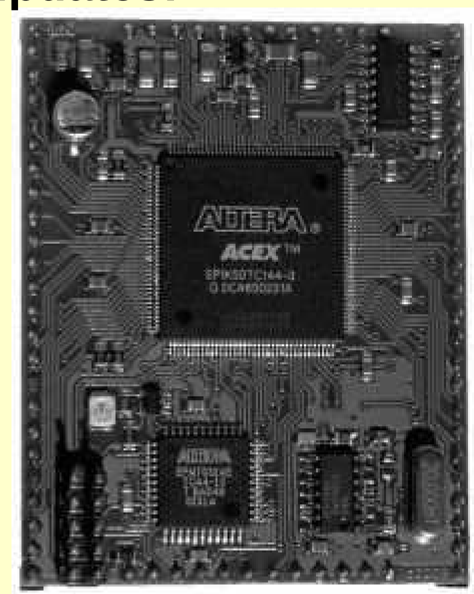
Example Partitioning



Example Partitioning



Benefit: 3.4MB + 1.8MB + 3.5MB transfers eliminated for view updates!



Network

Benefit: 1.28MB vs, 1.68MB per simulation step!

J-Orchestra Techniques Summary

- Program generation and program transformation at the bytecode level
  - “virtualizing” execution through bytecode transformation
    - creating a “virtual” virtual machine
  - existing classes get transformed into RMI remote objects
  - client code is redirected through proxies
  - for each class, about 8 different proxy types (for mobility, access to native code, etc.) may need to be generated
  - user input is at class level, but how objects are passed around determines where code executes

J-Orchestra Program Transformation Techniques

Neo: Programs hacking programs. Why?

[Matrix Reloaded]

The Problem Technically

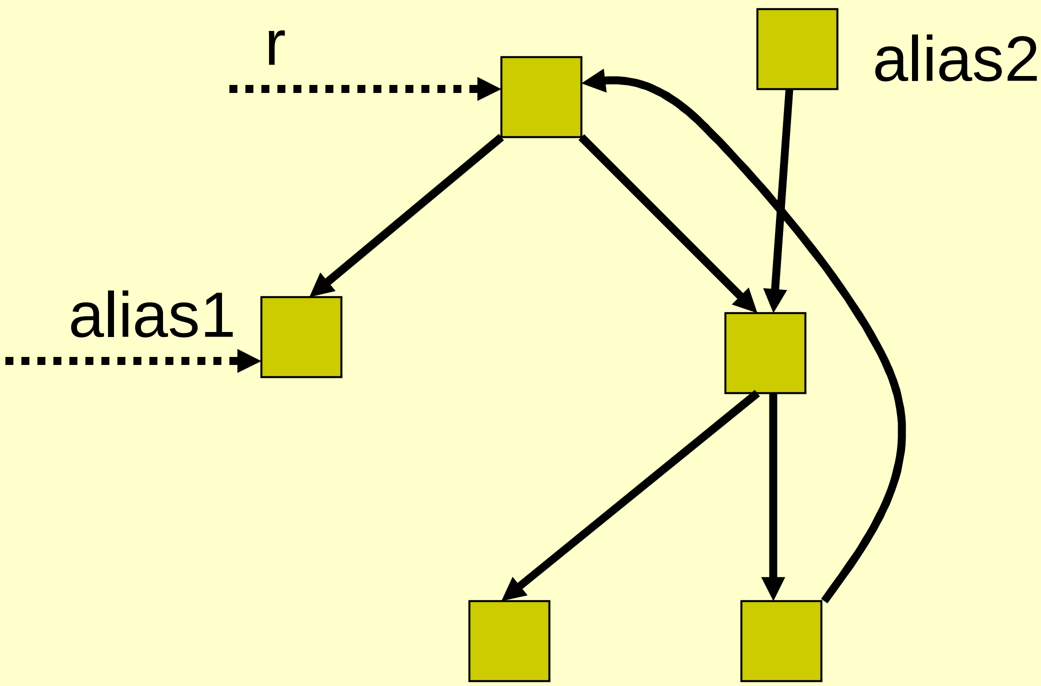
- Emulate a *shared memory* abstraction for unsuspecting applications *without changing the runtime system.*
  - Complicating assumption: a pointer-based language.
  - Resembles DSM but different in objectives.
    - DSM – distribution for parallelism.
    - Auto Partitioning – functional distribution.

The Approach: User Level Indirection

- We cannot change the VM to change the notion of "pointer"/"reference"
- Can we do it by careful rewriting of the entire program?
  - any reference, method call, etc. is through a proxy
    - where an original program reference would be to an object of type A, the same reference will now be to a proxy for As
  - For example:
    - "**new A()**" creates proxy for A instead of instance of original class A
    - **a.field** becomes **a.getField()** or **a.putField()**

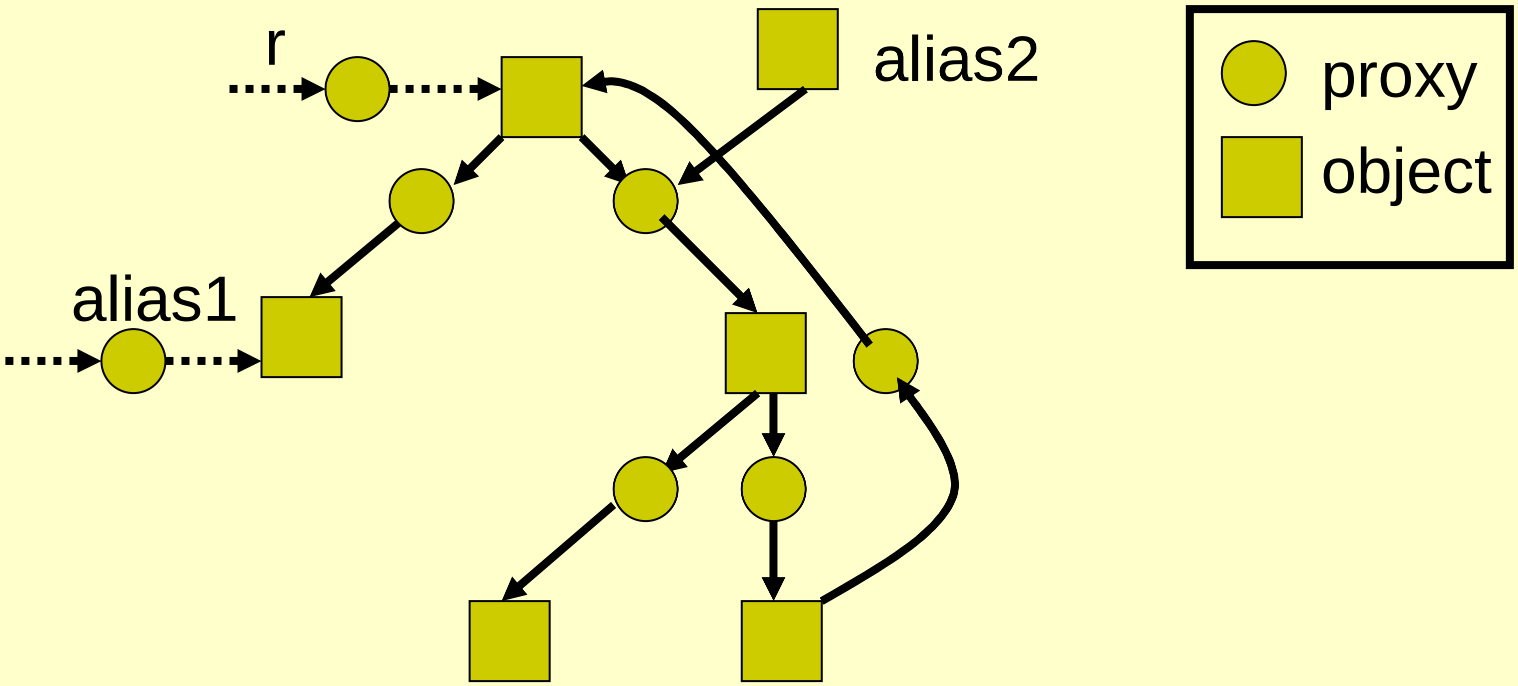
User Indirection (Proxy) Approach

- All clients (aliases) should view the same object regardless of location
- Change all references from direct to indirect



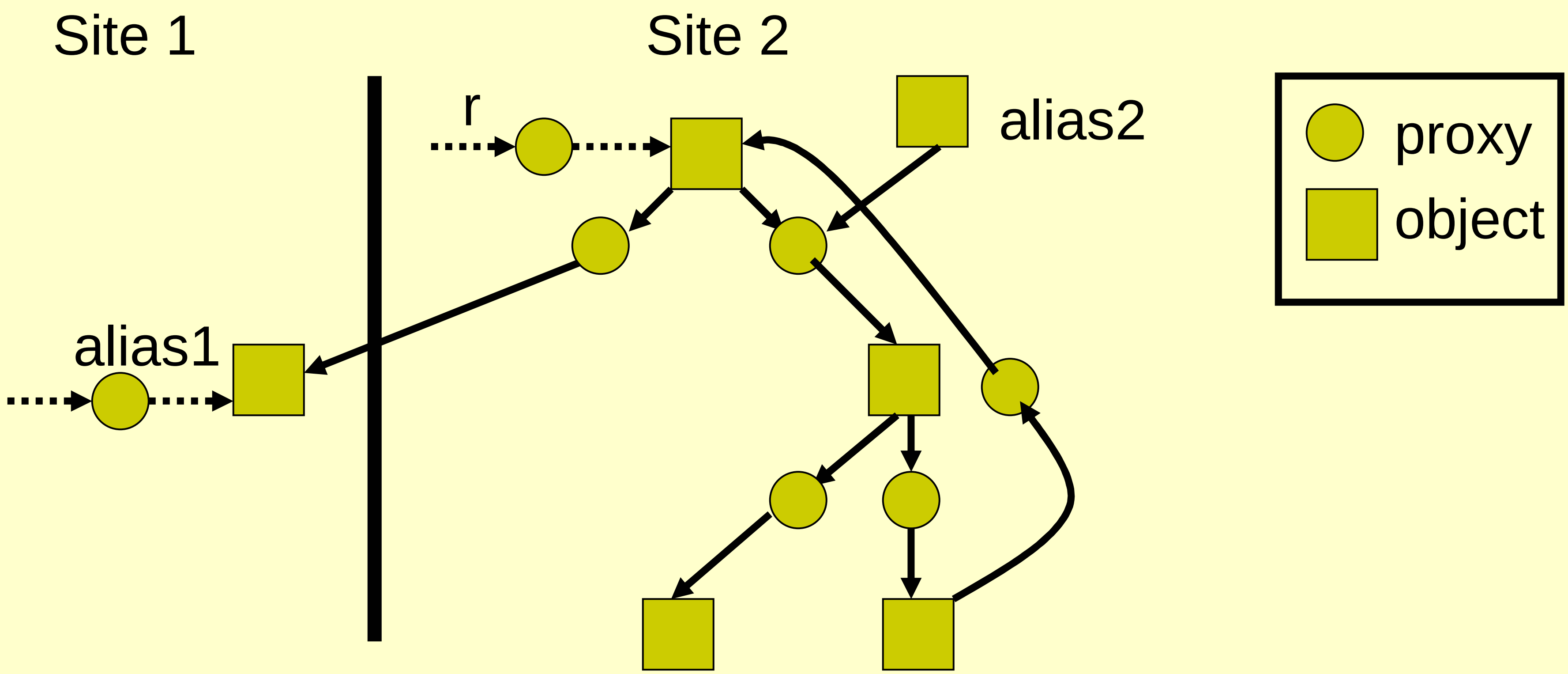
The Proxy Approach

- Changing all references from direct to indirect ensures correct behavior in the presence of aliases
- A remote object can have several proxies on different network sites



The Proxy Approach

- Proxies hide the location of the actual object: objects can move at will to exploit locality



J-Orchestra Sample Transformations

For each original class A

class A becomes a proxy

Remote class A__remote

Local class A__local

Interface A__iface

class A__static_delegator

Interface A__static_iface

Generated Code

For each original class A:

```
class A {
  java.io.File _file;

  public void foo(A p) {
        _file.read();
        p._file.read();
  }
}
```

A__interface is generated:

```
interface A__iface
 extends java.rmi.Remote
{
  public void foo(A p)
  throws Remote Exception;

  public proxy.io.File get_file()
     throws RemoteException;
}
```

Generated Code

For each original class A:

```
class A {
  java.io.File _file;

  public void foo(A p) {
        _file.read();
        p._file.read();
  }
}
```

proxy is generated:

```
class A {
  A__iface _ref;

  public void foo(A p) {
        _ref.foo(p);
  }
}
```

Generated Code

For each original class A:

```
class A {
  java.io.File _file;

  public void foo(A p) {
        _file.read();
        p._file.read();
  }
}
```

class A is binary-modified:

```
class A__remote
extends UnicastRemoteObject
implements A__iface
{
    proxy.java.io.File _file;

    public void foo(A p) {
        _file.read();
        p.get_file().read();
    }
   public proxy.java.io.File
   get_file() { return _file; }
}
```

Complexities

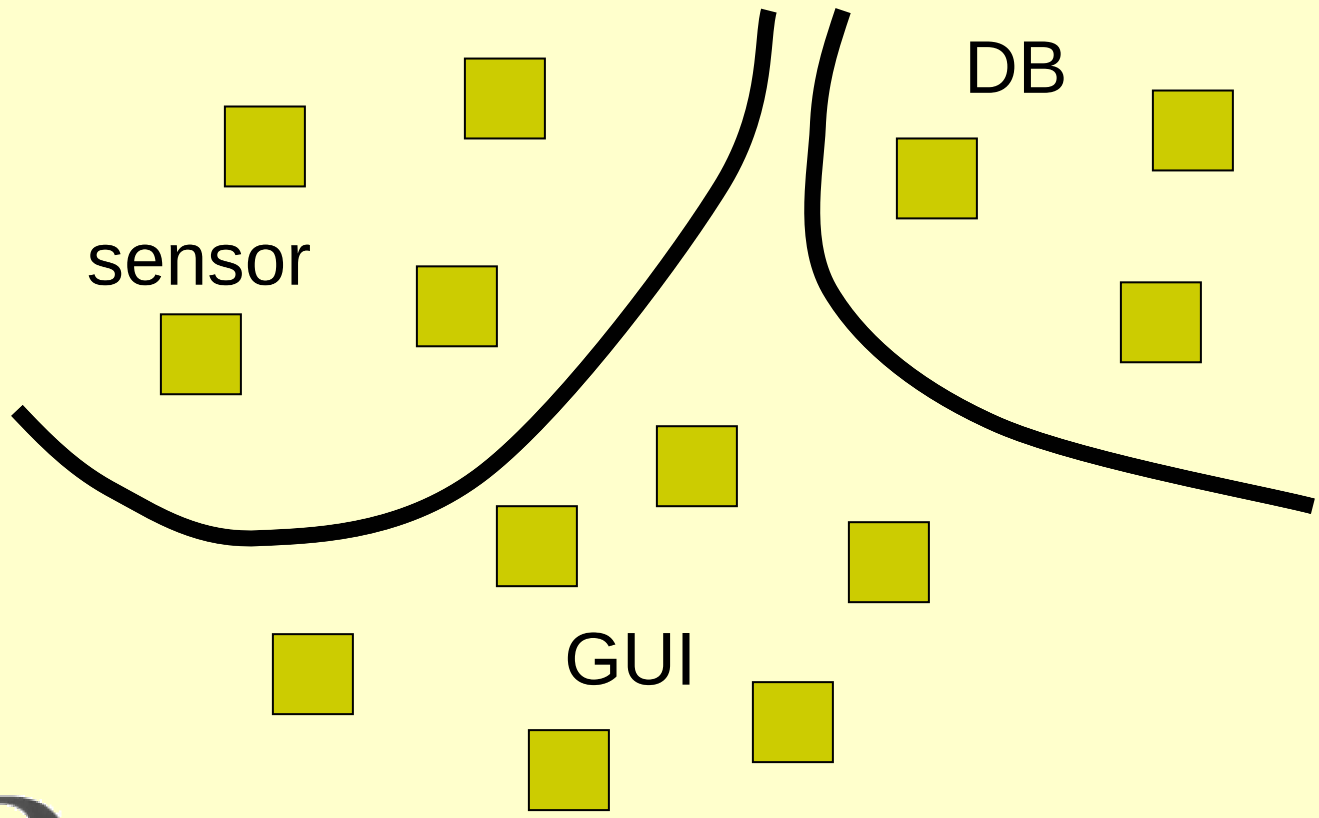
Overheads, Grouping Objects,
System Code

Proxy Indirection Overhead

Work (test, multiply, increment)	Original Time	Rewritten Time	Overhead
2	35.17s	47.52s	35%
4	42.06s	51.30s	22%
10	62.50s	73.32s	17%

- Micro benchmark
- A function of average work per method call
- 1 billion calls total

Optimizing Proxy Indirection



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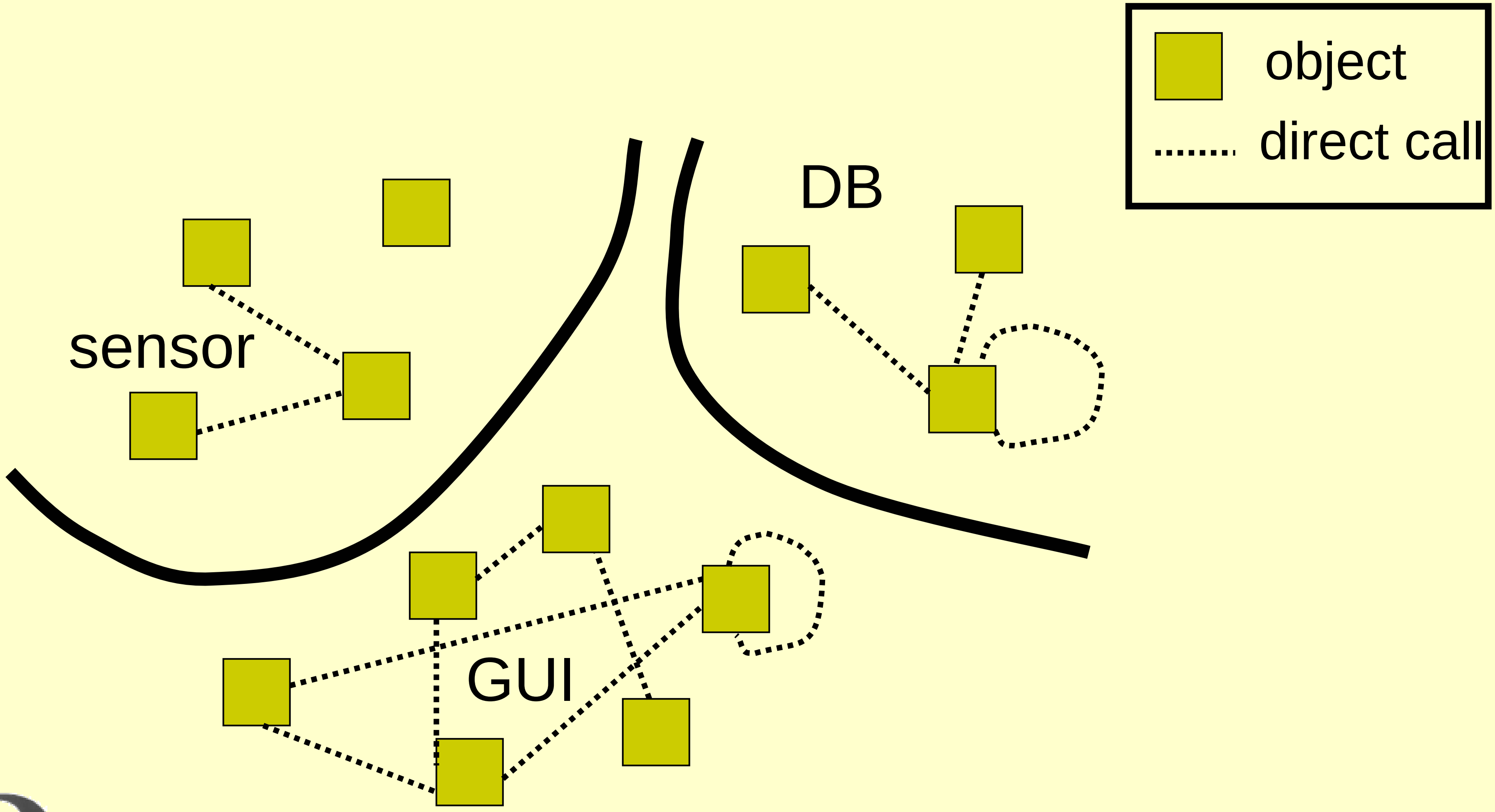

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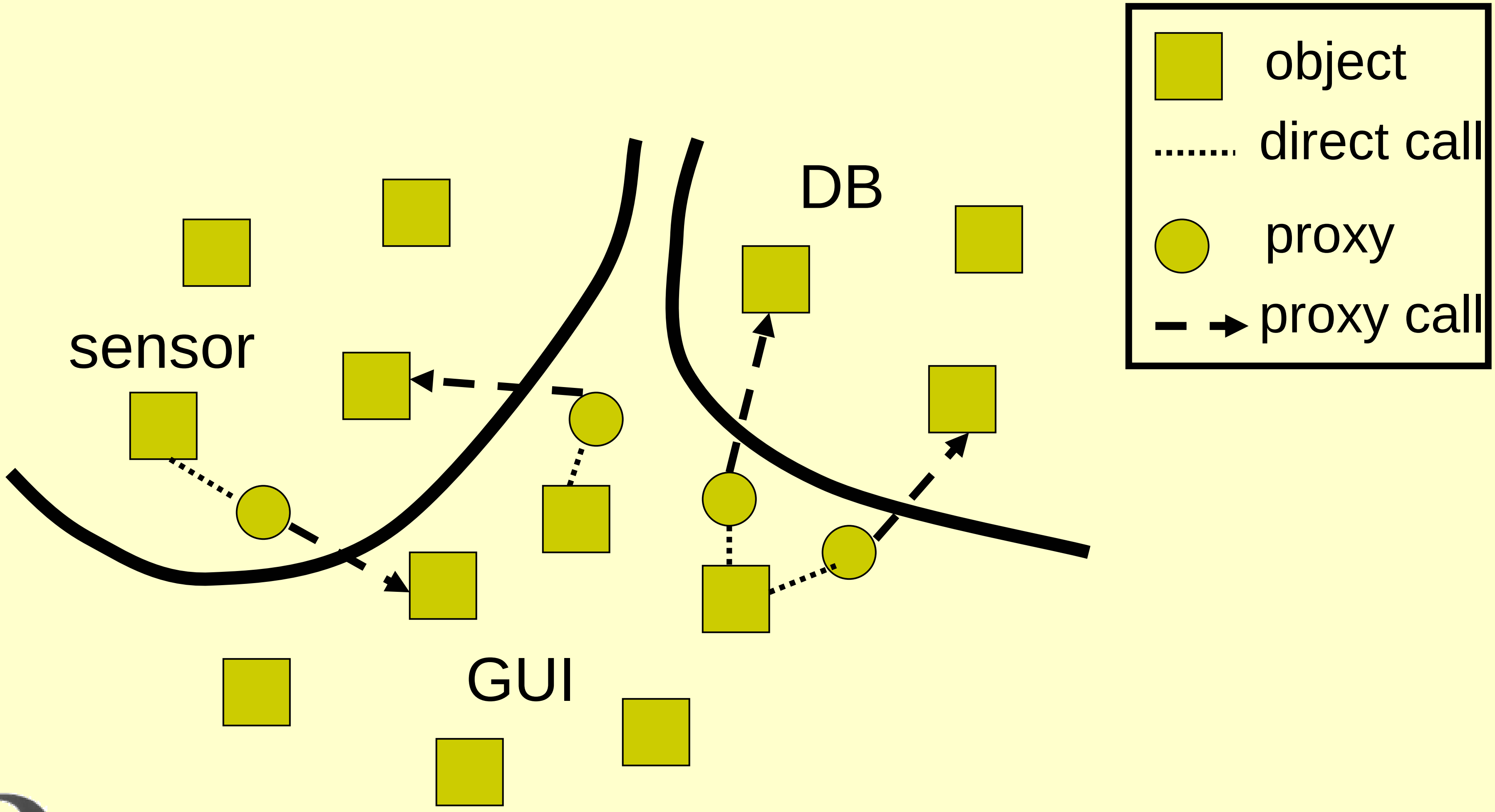

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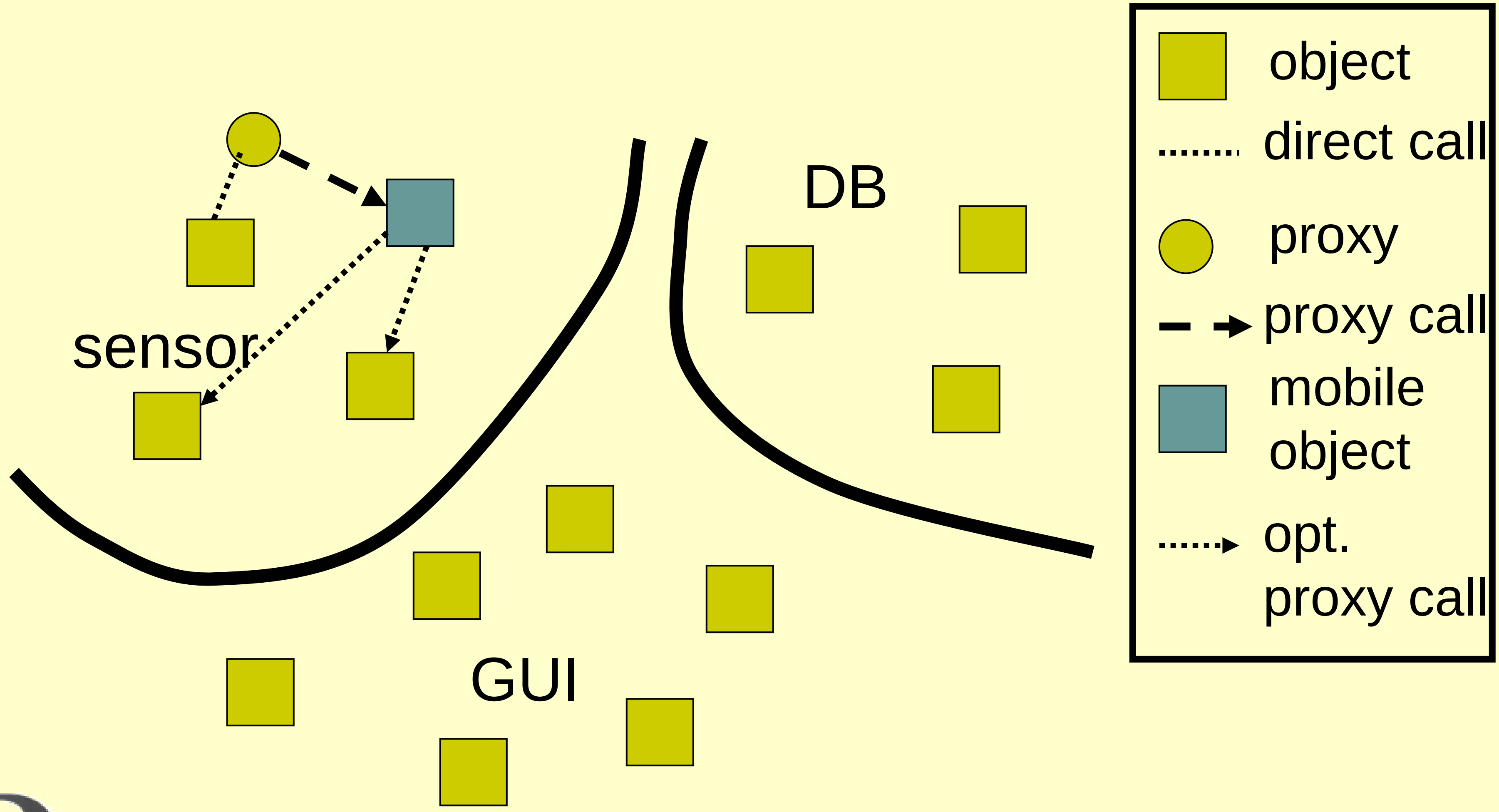

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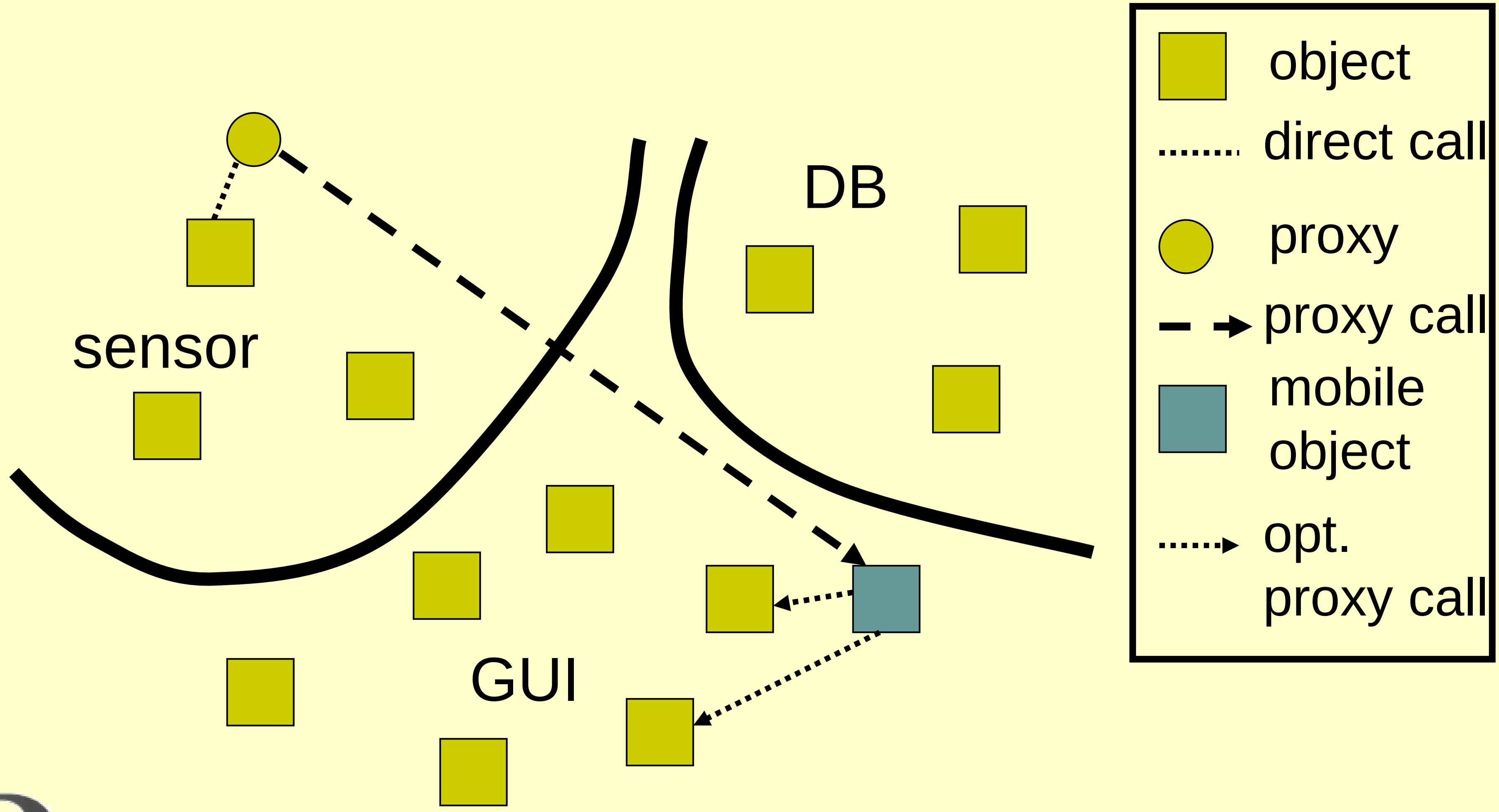


How is This Implemented?

- Two kinds of references: direct and indirect
- Direct: for code statically guaranteed to refer to the object itself
  - i.e., object on the same site
- Indirect: maybe we are calling a method on the object, maybe on a proxy

System Code

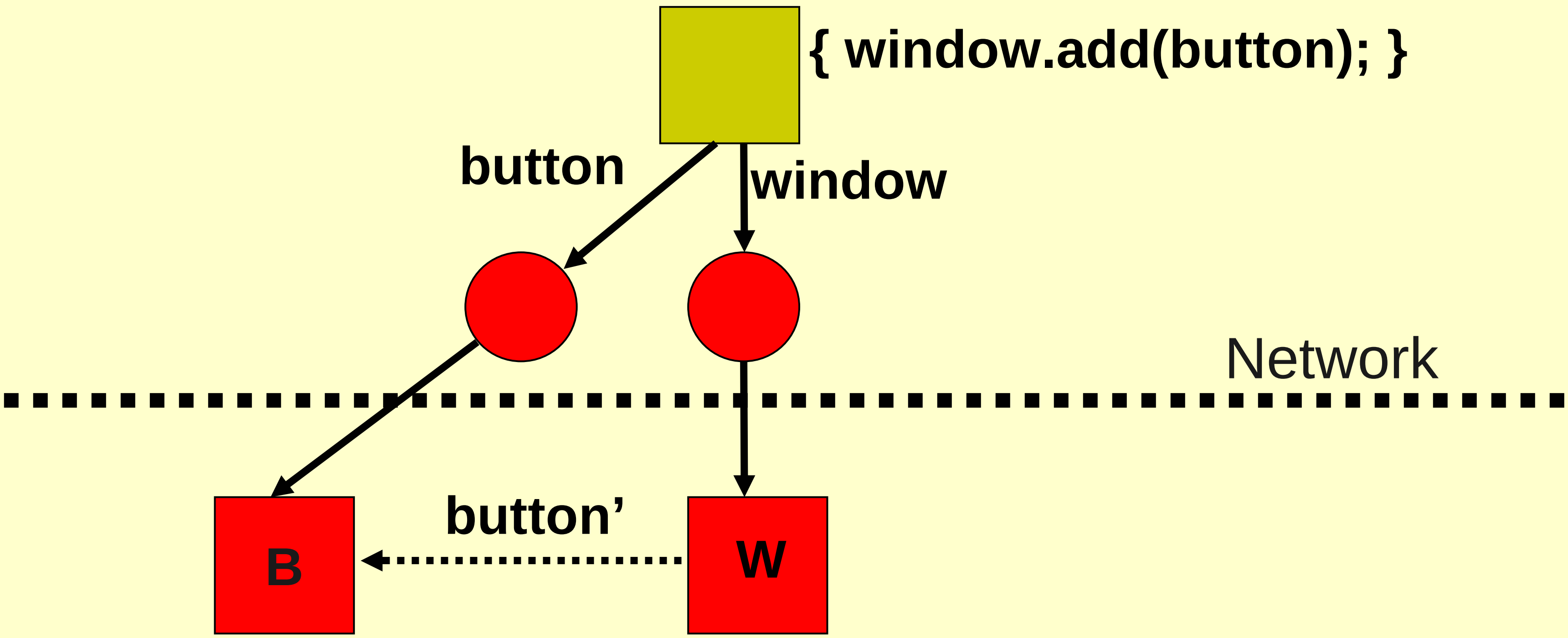
- The same idea applies to dealing with system classes
  - system classes are split in groups
    - we assume that groups are consistent with what native code does (more later)
  - code accesses objects in the same group directly
  - other objects accessed indirectly

Wrapping / Unwrapping

- For this approach to work, we need to inject code in many places to convert direct references to indirect and vice-versa
  - dynamic “*wrapping/unwrapping*”
  - code injected at compile time, wrapping/unwrapping takes place at run time

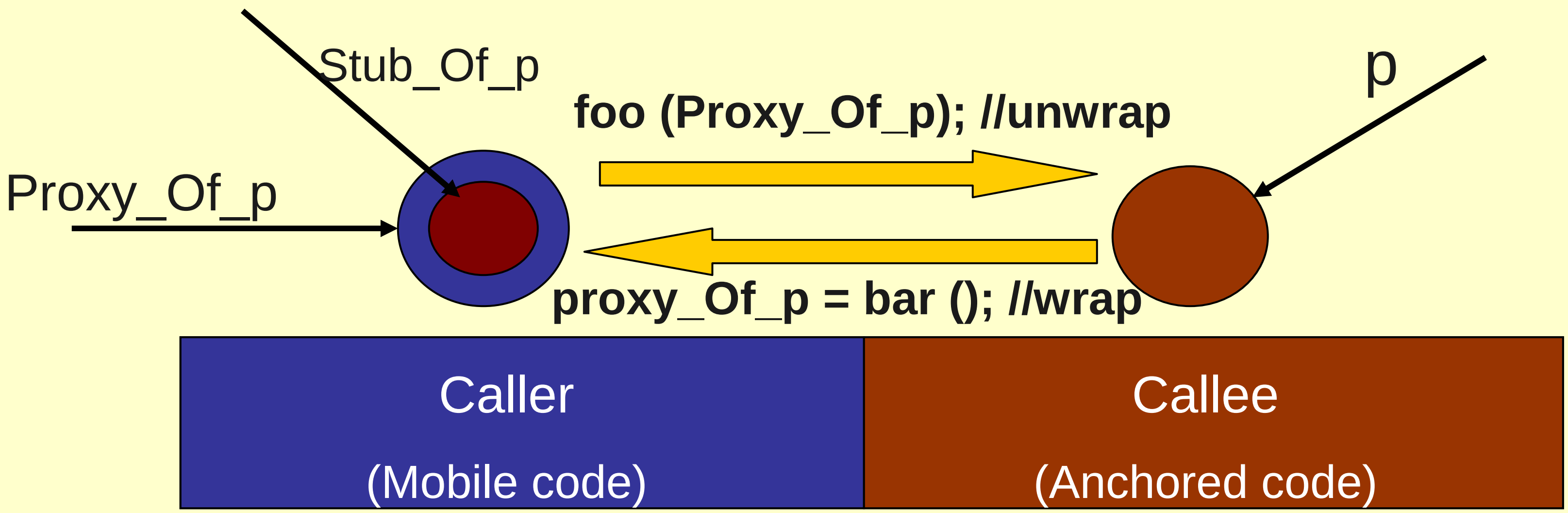
Example: Pass a Reference to System Code

- What if a system object is passed from user code to system code?



Wrapping/Unwrapping at the Proxy

- The easy case: callee can tell wrapping is needed
  - applies to system code



Wrapping/Unwrapping at Call Site

- The harder case: sometimes we need to wrap/unwrap at call site
  - either to keep proxy simple, or because we'd end up with overloaded methods only differing in return type
    - a problem since our proxies are generated in source, although the rest of the transforms are in bytecode
  - need to reconstruct call stack, inject code

Example: “this”

```
//original code
class A { void foo (B b) { b.baz (this); } }
class B { void baz (A a) {...} }
//generated remote object for A
class A__remote {
  void foo (B b) { b.baz (this); }     //”this” is of type A__remote!
}

//rewritten bytecode for foo
aload_0                        //pass “this” to locateProxy method
invokestatic Runtime.locateProxy
checkcast “A”                  //locateProxy returns Object, need a cast to “A”
astore_2                       //store the located proxy object for future use
aload_1                        //load b
aload_2                        //load proxy (of type A)
invokevirtual B.baz
```

“How Do You Handle...?”

Native code,
Synchronization

Handling Java Language Features

- Many language features need explicit handling, but most complexities are just engineering
  - static methods and fields
  - inheritance hierarchies
  - remote object creation
  - inner classes
  - System.in, System.out, System.exit, System.properties
- Some require more thought
  - native code
  - synchronization

Native Code

- Recall how we split system classes into groups
- These groups have to respect native code behavior
- But we don't know what native code does!
- The problem: we may let a proxy escape into native code, and the native code will try to access it directly
  - e.g., read fields from the original object

Heuristic Type-Based Analysis: Group Based on Types

- class **C** extends **S** {
  F f;
  public native **R** meth (**A** a);
  }
- Conservative, but still not safe
  - nothing can be!
  - type information can be disguised at the native code interface level
    - i.e., native code can do type casts

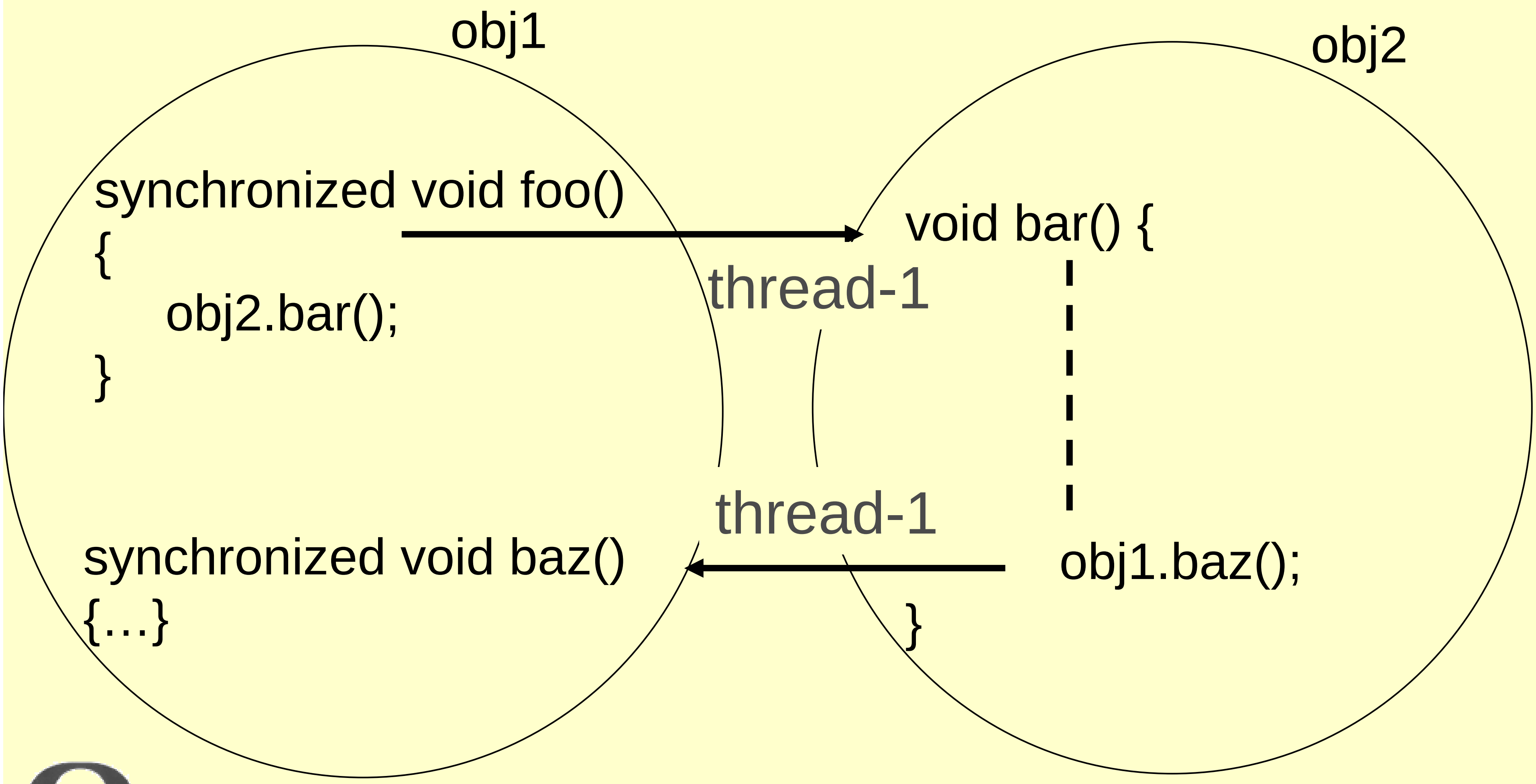
How Safe?

- Studied native code in JDK 1.4.2 for Solaris
- Two analyses:
  - 13 applications, dynamic analysis of execution
  - code inspection of native code for **Object**, **IsInstanceOf**
- Overall, fairly safe—few violations
  - PlainSocketImp.socketGetOption casts Object to InetAddress
  - GlyphVector assumed to be StandardGlyphVector, Composite assumed to be AlphaComposite
  - native code respects types more than library code!
    - JNI **IsInstanceOf** : 69 occurrences
Java **instanceof** : 5900 occurrences
- In practice, J-Orchestra works without (much) intervention

Synchronization

- We only handle monitor-style synchronization: synchronized blocks and methods, wait/notify/notifyAll
  - not volatile variables, concurrent data structures, atomic operations, etc.
- Two problems:
  - thread identity is not maintained over the network
  - synchronization operations (synchronized, wait, notify, etc.) do not get propagated by RMI

Thread Identity Is Not Maintained
(The Zigzag Deadlock Problem)



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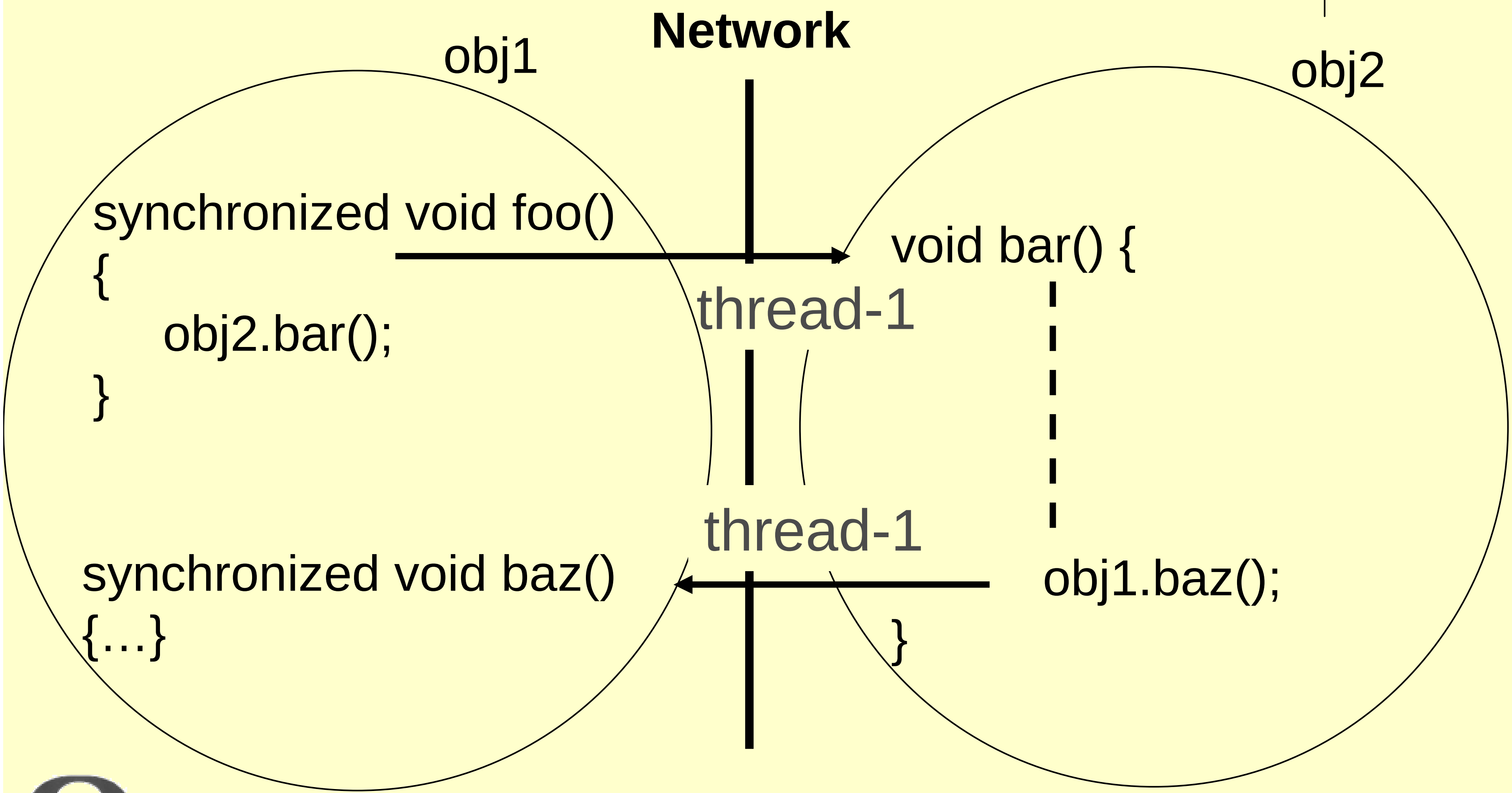

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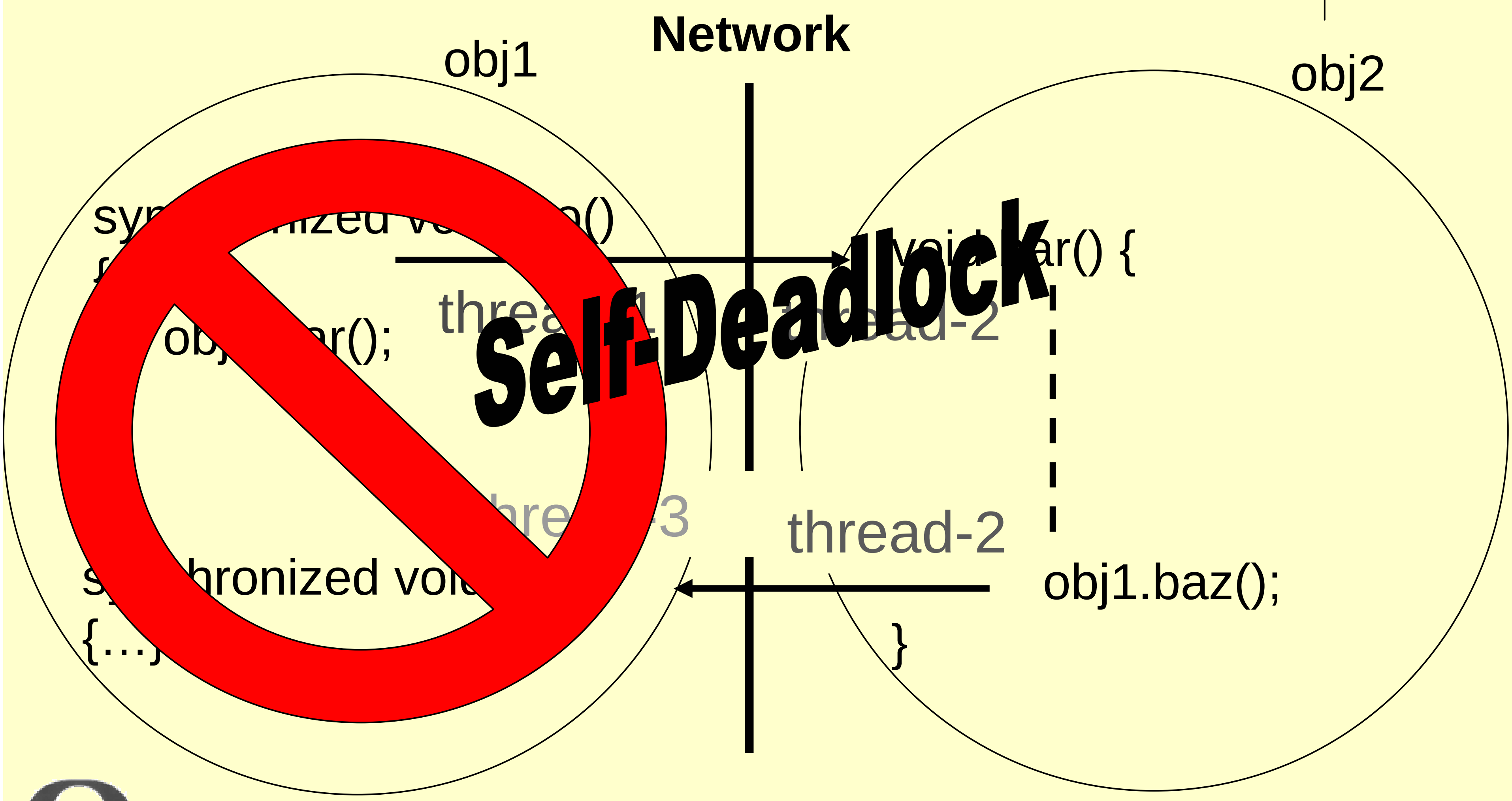
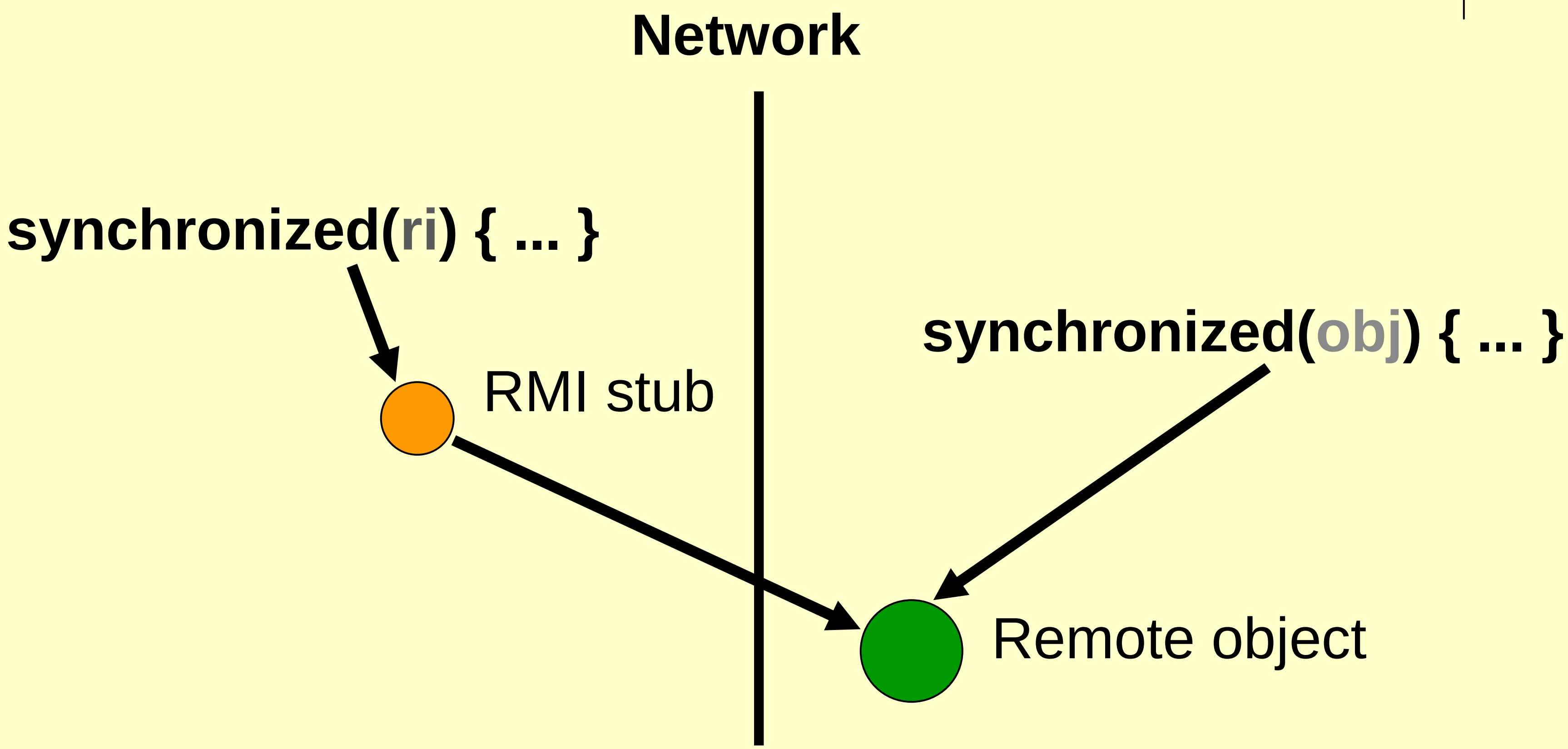


Synchronization Operations Don't Get Propagated Over the Network

- *obj* – a remote object, implementing interface *RI* and remotely accessible through it
- *RI ri* – points to a local RMI "stub" object
- ri.foo(); //will be invoked on obj on a remote machine
- The stub serves as an intermediary, propagating method calls to the *obj* object
- Only *synchronized* methods are propagated correctly
- *Synchronized* blocks might not work correctly

Synchronized Blocks



- Even if obj and ri point to the same object, synchronization will be on stub vs. true object.

Synchronization Operations Don’t Get Propagated Over the Network

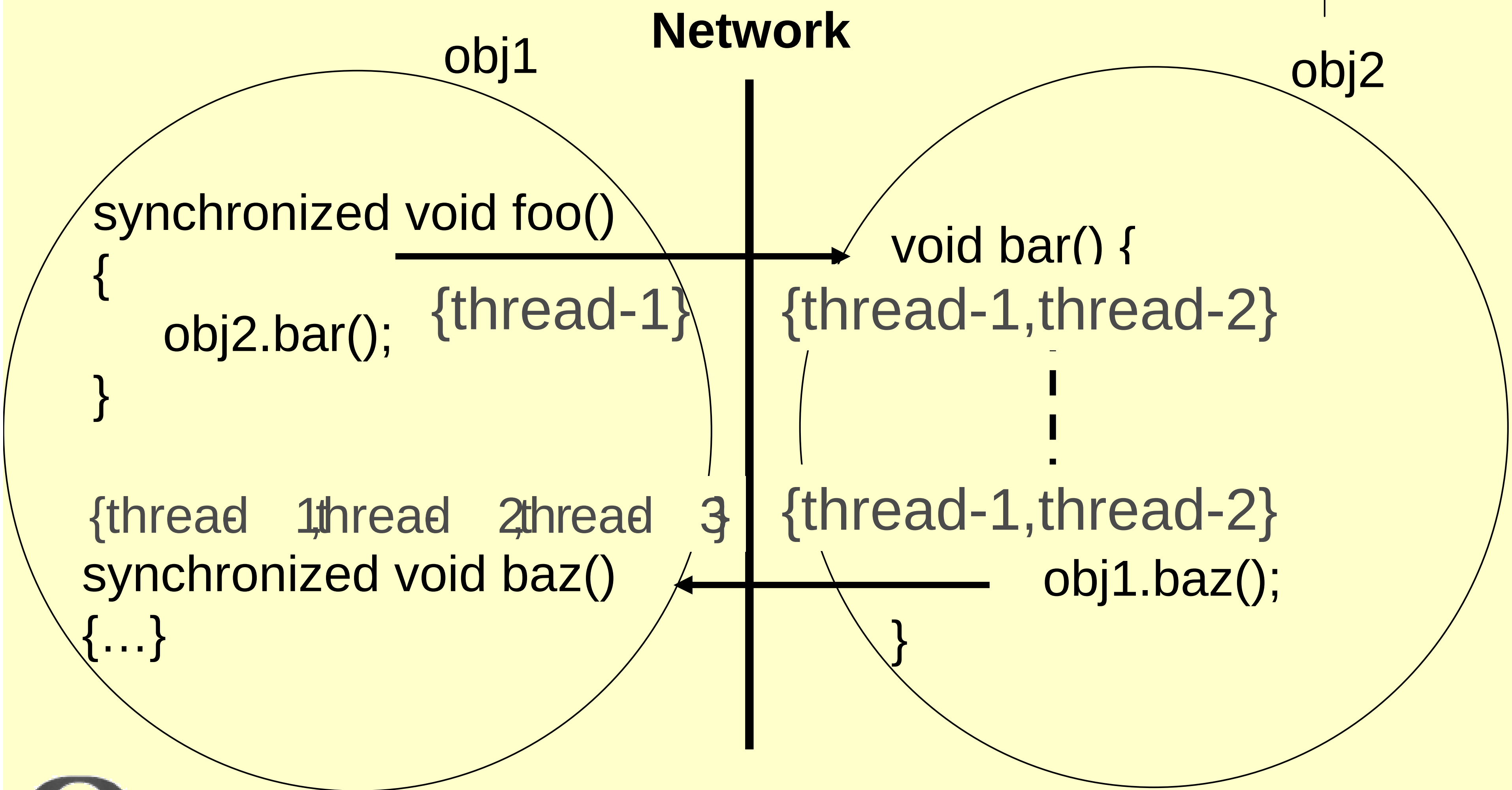
- Monitor operations: **Object.wait**, **Object.notify**, **Object.notifyAll** don’t work correctly
- They are declared *final* in class *Object* and cannot be overridden in subclasses
- Calling any of them on an RMI stub does not get propagated over the network

J-Orchestra Synchronization

- Maintain per-site “thread id equivalence classes”
- Replace all the standard synchronization constructs (**monitorenter**, **Object.wait**, **Object.notify**) with the corresponding calls to a per-site synchronization library

Thread Identity Is Not Maintained

(The Zigzag Deadlock Problem)



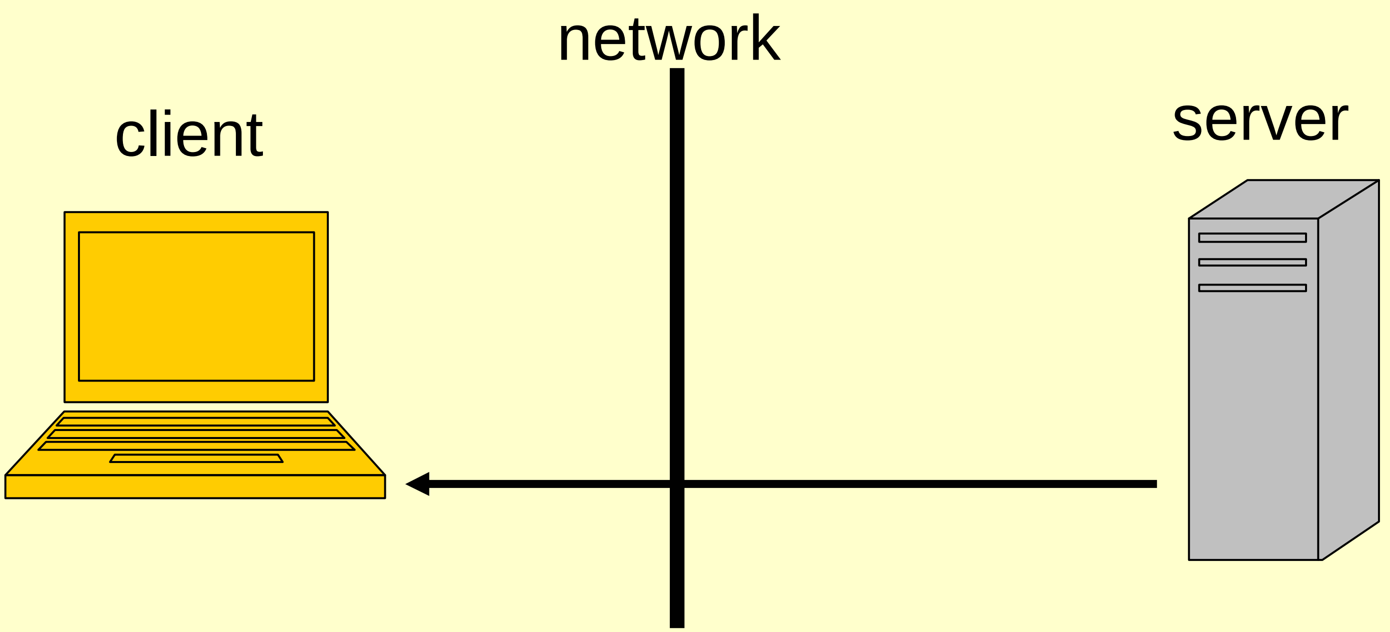
Maintaining Thread Id Equivalence Classes *Efficiently*

- Updating thread equivalence classes *only* when the execution of a program crosses the network boundary
- This happens only after it enters a method in an RMI stub
- Use bytecode instrumentation on standard RMI stubs
- Equivalence classes' representation is very compact (encoded into a *long int*). Imposes virtually no overhead on remote calls

A Specialized Application

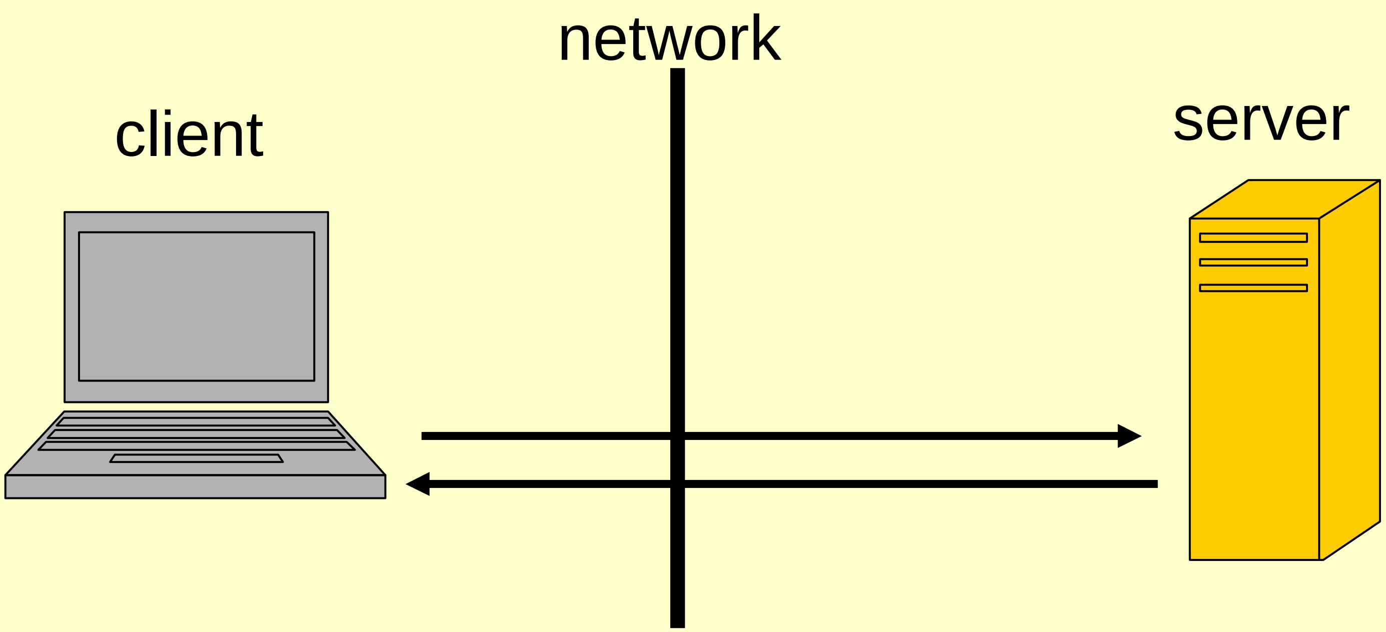
"Appletizing"

Java Applets



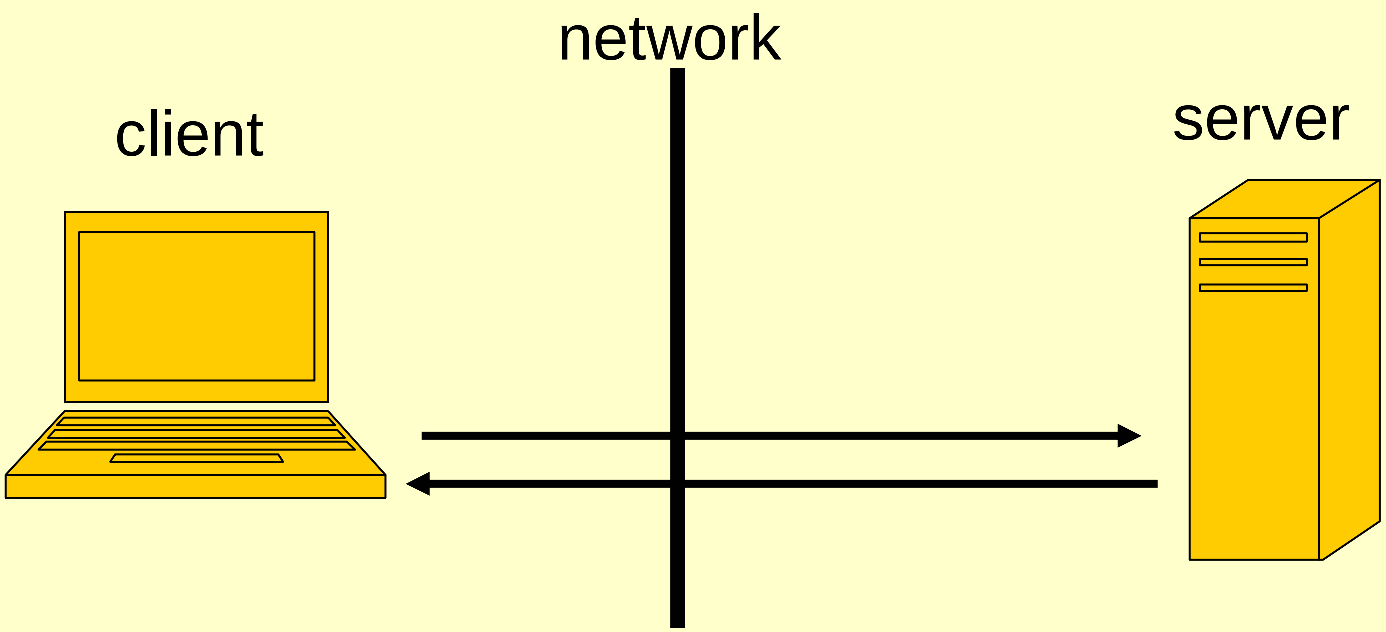
- Execute on the client.
- Transfer all code to client.
- Provide “sandbox” secure execution environment.

Java Servlets



- Execute on the server.
- Thin GUI through Web Forms.

Appletizing



- A hybrid between Applets and Servlets.
- Rich GUI client; full access to server resources.
- Safe and secure execution model.
- Ease of development and deployment.

Sanitizing GUI Code

- Some code inside GUI classes is rejected by the Applet Security Manager.
- E.g., *System.exit*, read/write graphical files from the local hard drive, closing a frame.
- Two approaches to replacing unsafe code:
  1. With different code.
  2. With semantically similar (identical) code.

Sanitizing: Reading Image From File

```
//Creates an ImageIcon from
//the specified file
//will cause a security exception when
//a file on disk is accessed
```

```
javax.swing.ImageIcon icon =
  new javax.swing.ImageIcon (“AnIconFile.gif”);
```

Sanitizing: Reading Image From File

```
//Sanitize by replacing with the
//following safe code
```

```
javax.swing.ImageIcon icon =
  new jorch.rt.ImageIcon("AnIconFile.gif");
```

```
//will safely read the image from
//the applets's jar file
```

Sanitizing: **`JFrame.setDefaultCloseOperation`**

- Method *`setDefaultCloseOperation`* in system class *`javax.swing.JFrame.`*
- Applet Security Manager prevents it from taking `EXIT_ON_CLOSE` parameter.

```
invokevirtual
  JFrame.setDefaultCloseOperation
```

Sanitizing: `JFrame.setDefaultCloseOperation`

```
pop //pop value on top of the stack

push 0 //param 0 is DO_NOTHING_ON_CLOSE

invokevirtual
  JFrame.setDefaultCloseOperation
```

Wrap up

J-Orchestra Impact

- Although the J-Orchestra work is well-cited, its greatest impact was unconventional
  - in late 2002, we gave a demo to Marc Fleury, head of the JBoss Group
    - JBoss: probably the world's most popular J2EE Application Server—millions of downloads (open-source)
    - Application Server: OS for server-side computing
      - handles persistence, communication, authentication, ...
      - imagine a web store, bank, auction site, etc.
  - great excitement about using bytecode engineering to generate and transform code, to turn Java classes into EJBs
    - J2EE middleware has strict conventions (e.g., "each session bean needs to implement local and remote interfaces, such that...")

Program Transformation and Generation in JBoss

- JBoss engineers had little expertise
  - my M.Sc. student Austin Chau did the first implementation
  - we fixed the bytecode generation platform (Javassist)
  - JBoss contributors then took over
- Radical innovation in version 4: can use plain Java objects as Enterprise Java Beans
  - a general mechanism: "Aspect-Oriented Programming in JBoss"
  - JBoss can now produce automatically much of the tedious J2EE code
    - given plain Java code (together with user annotations)
  - annotation mechanism in Java 5 largely motivated by program generation tasks for J2EE code

Publications

- Main paper: ECOOP'02
- Synchronization: Middleware '04
- Appletizing: ICSM'05
- Dealing with native code: ECOOP'02 + GPCE'06