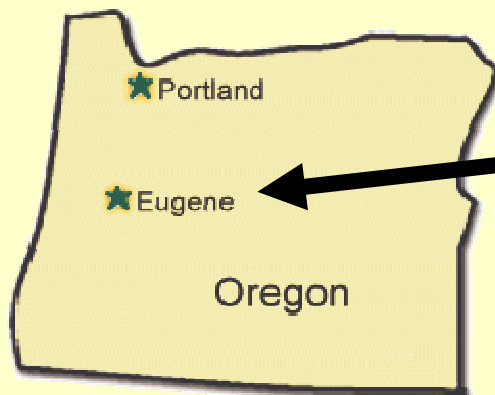


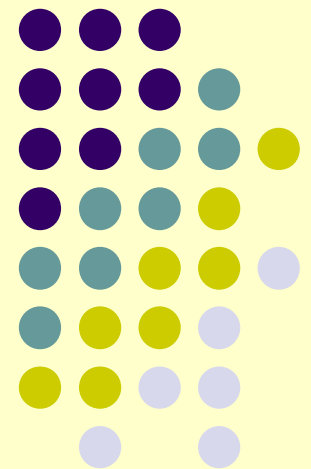
J-Orchestra: Automatic Java Application Partitioning



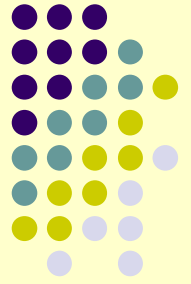
Yannis Smaragdakis
University of Oregon

with Eli Tilevich—Virginia Tech
(more credits at end)

research supported by NSF grants
CCR-0220248 and CCR-0238289



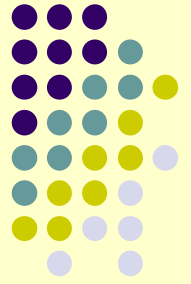
My Research



- ***The systems and languages end of SE***
 - **language tools for distributed computing**
 - NRMI, J-Orchestra, GOTECH
 - **automatic testing**
 - JCrasher, Check-n-Crash (CnC), DSD-Crasher
 - **program generators and domain-specific languages**
 - cJ, Meta-AspectJ (MAJ), SafeGen, JTS, DiSTiL
 - **multiparadigm programming**
 - FC++, LC++
 - **software components**
 - mixin layers, layered libraries
 - **memory management**
 - EELRU, compressed VM, trace reduction, adaptive replacement



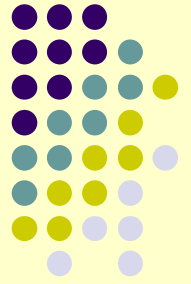
Quick Review of Java Projects: NRMI



- NRMI: drop-in replacement of RMI, more natural programming model
 - *invariant: all changes from the server are visible to client when RPC returns*
 - no matter what data are used and how they are linked
 - solves a long standing, well-known open problem!
 - call-by-copy-restore semantics for complex data structures
 - simple distributed programming: most calls behave like local calls, no need to worry about aliases
 - could do by hand, but NRMI eliminates complexity and code (~50 LOC per remote call/argument type)
 - optimized implementation: taps into existing serialization, uses Java 1.4+ “unsafe” facility for direct memory access



Quick Review of Java Projects: cJ



- Safe type conditionals as a Java extension
- Solves conciseness/safety issues of the Java Collections Framework

- (no UnsupportedOperationExceptions)

- **interface Collection<E, M> {**

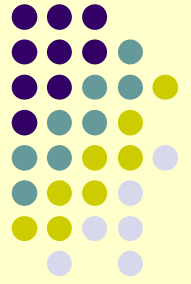
```
    ...  
    <M extends VariableSize>?  
    boolean add(E e);  
}
```

```
interface List<E, M> extends Collection<E, M> {
```

```
    ...  
    <M extends Modifiable>?  
    E set(int index, E element);  
}
```



Quick Review of Java Projects: JCrasher, CnC, DSD-Crasher

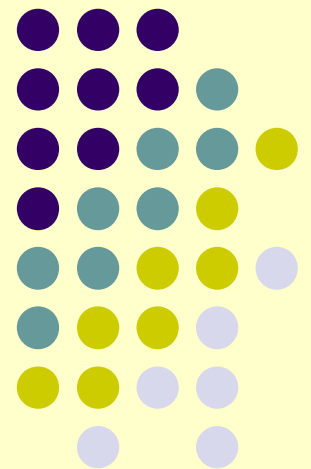


- Automatic testing tools
 - **JCrasher**: random testing, reports runtime exceptions that pass some heuristics
 - **CnC (Check'n'Crash)**: analyzes program, finds conditions for throwing exceptions, solves constraints to create values, outputs test case and tries it with JCrasher
 - **DSD-Crasher**: tries to extract program invariants from existing test suite, then uses CnC

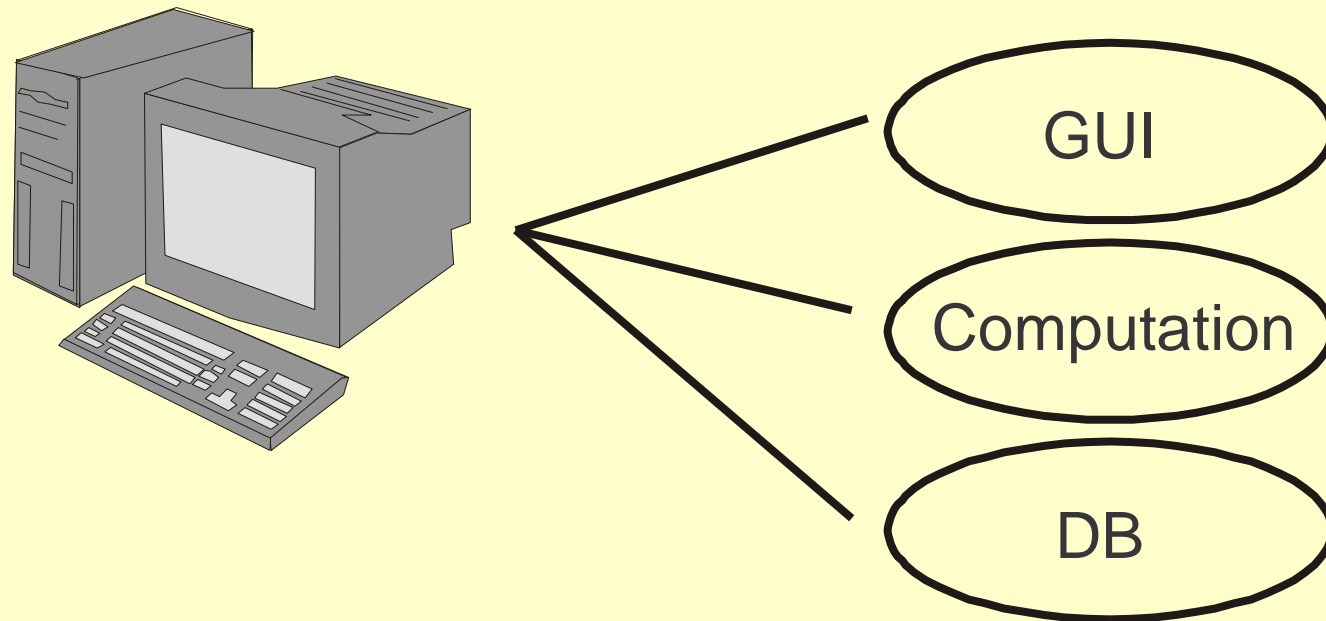
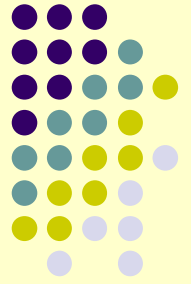


And for the main course...

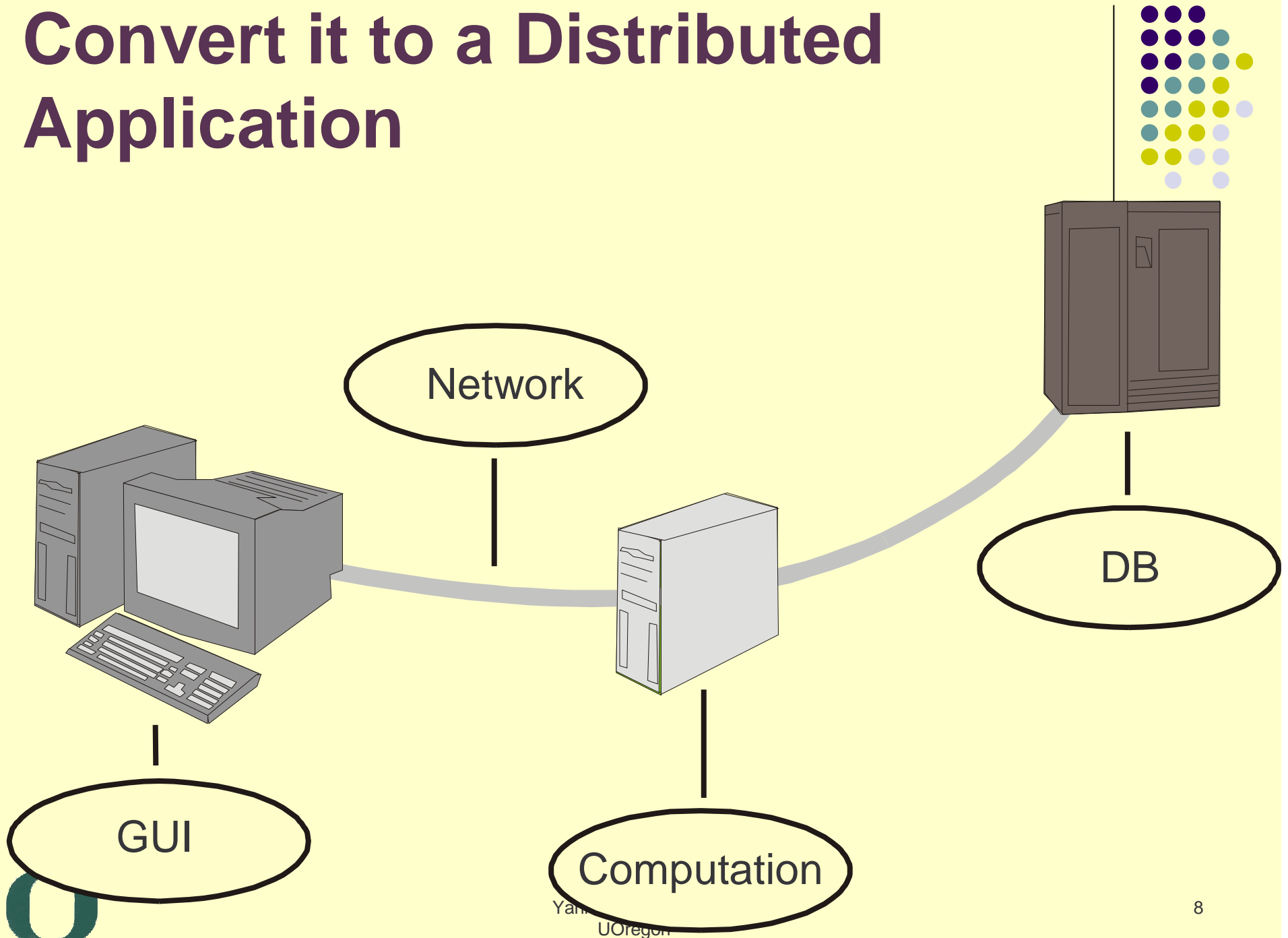
J-Orchestra: Automatic Java
Application Partitioning



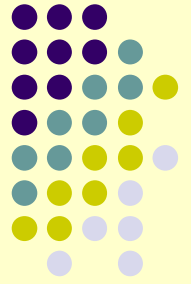
Partitioning: Start with a Centralized Application



Convert it to a Distributed Application

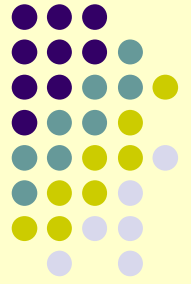


Automatic Program Partitioning



- 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

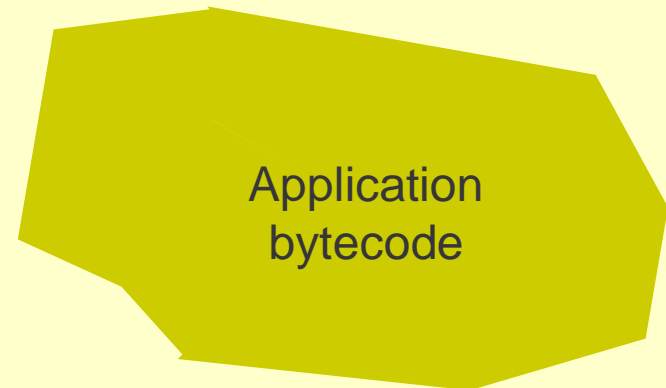




J-Orchestra

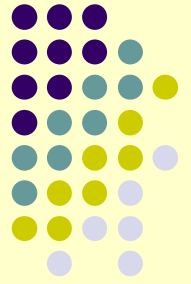
- For the past 5 years, J-Orchestra has been one of my major research projects
 - an automatic partitioning system for Java
 - works as a bytecode compiler
 - think of result as “applets on steroids”
 - “code near resource”

Network



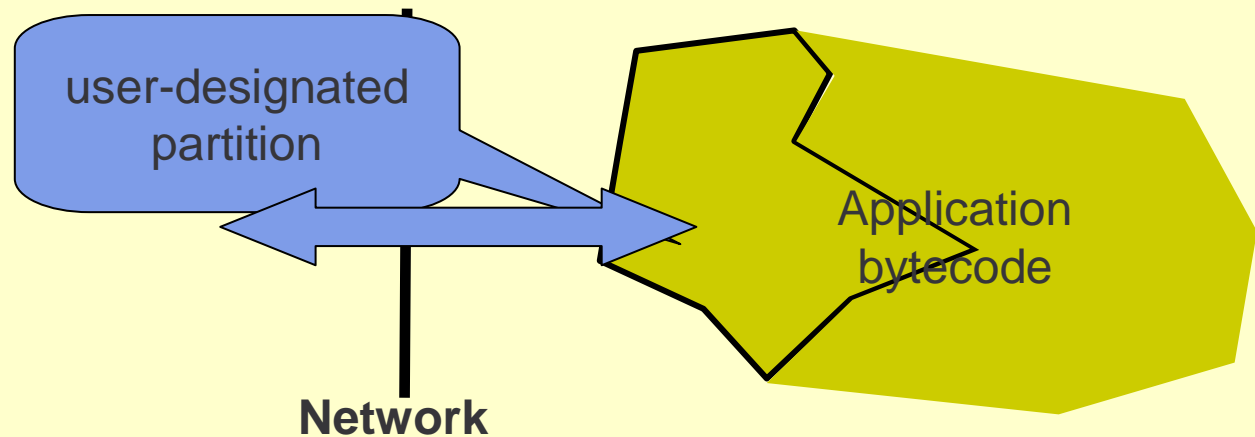
Application
bytecode



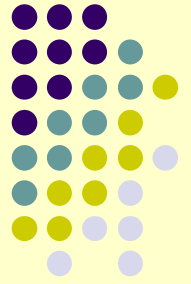


J-Orchestra

- For the past 5 years, J-Orchestra has been one of my major research projects
 - an automatic partitioning system for Java
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 - “code near resource”



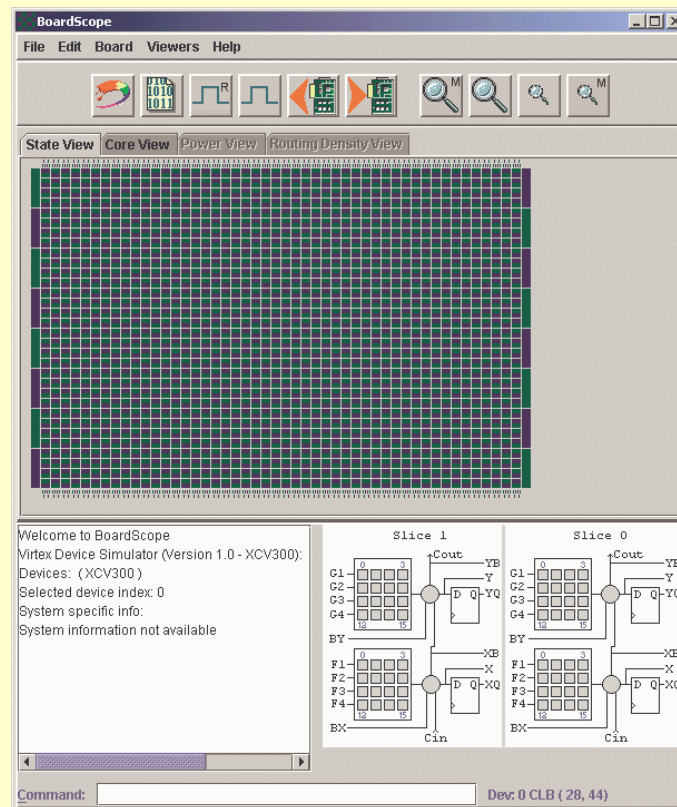
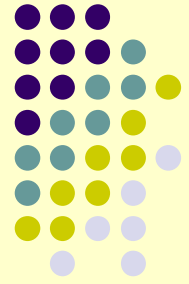
J-Orchestra Executive Summary

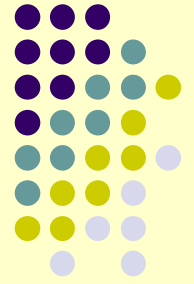


- Partitioned program is *equivalent* to the original centralized program for a very large subset of Java.
 - we handle synchronization, all OO language features, object construction, ...
 - nice analysis and compilation technique for dealing with native code
 - result: *most scalable automatic partitioning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

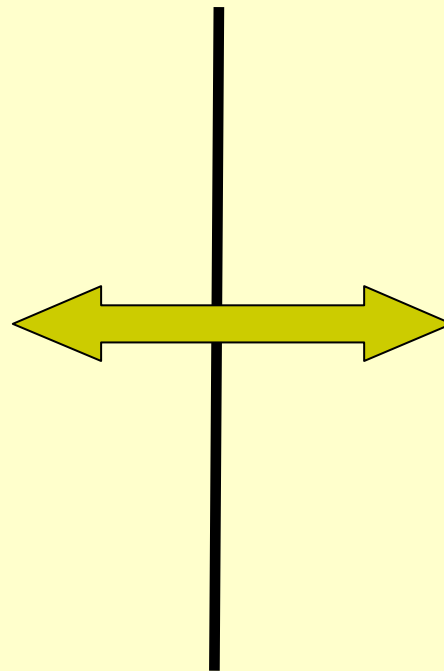
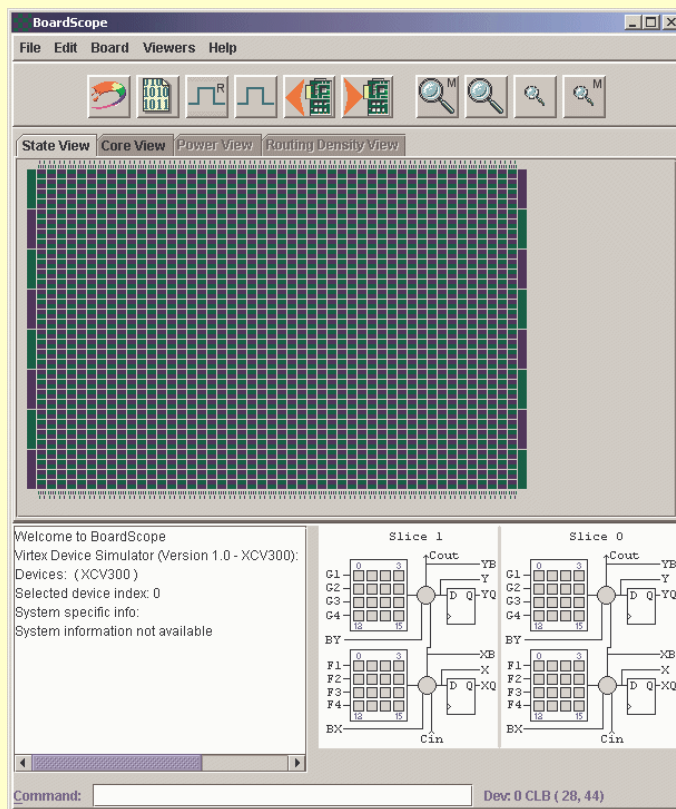


Example Partitioning



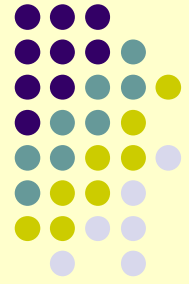


Example Partitioning



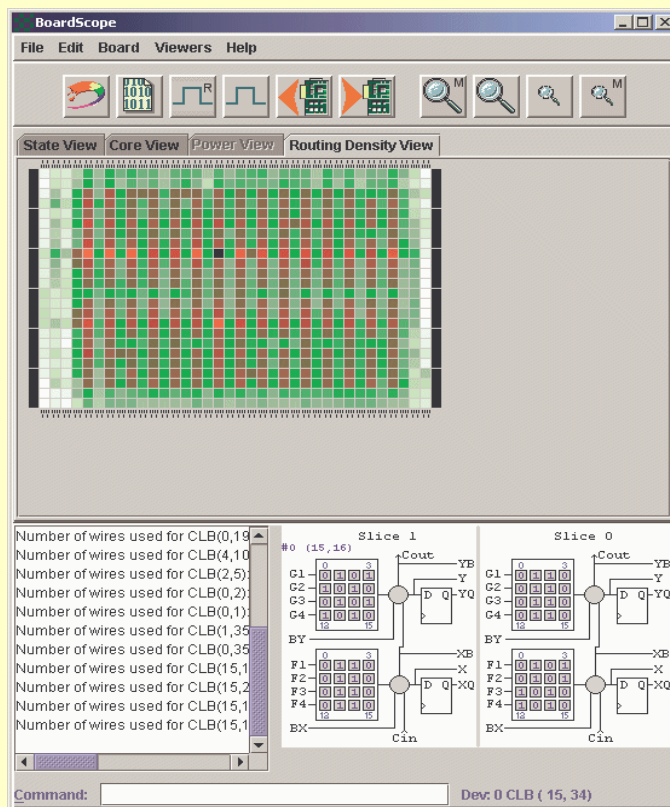
Network





Example Partitioning

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

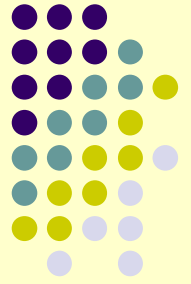


Network

**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

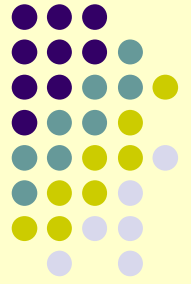


J-Orchestra Program Transformation Techniques



Neo: Programs hacking
programs. Why?

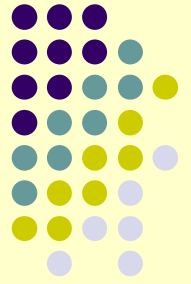
[Matrix Reloaded]



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.



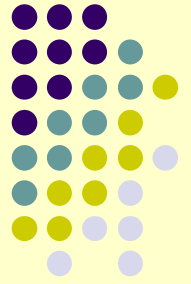


The Approach: User Level Indirection

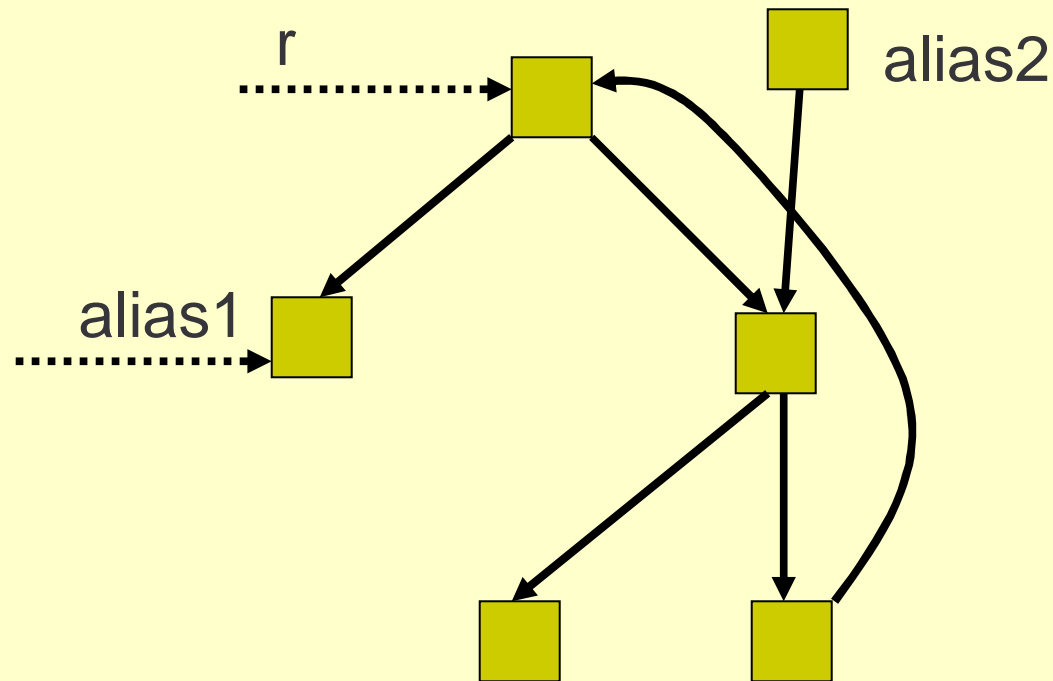
- We cannot change the VM to change the notion of “pointer”/“reference”
- Can we do it by careful rewriting of the entire program?
 - any reference, method call, etc. is through a proxy
 - where an original program reference would be to an object of type A, the same reference will now be to a proxy for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

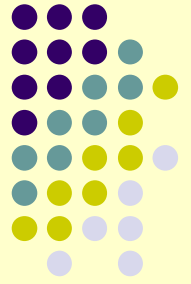


User Indirection (Proxy) Approach



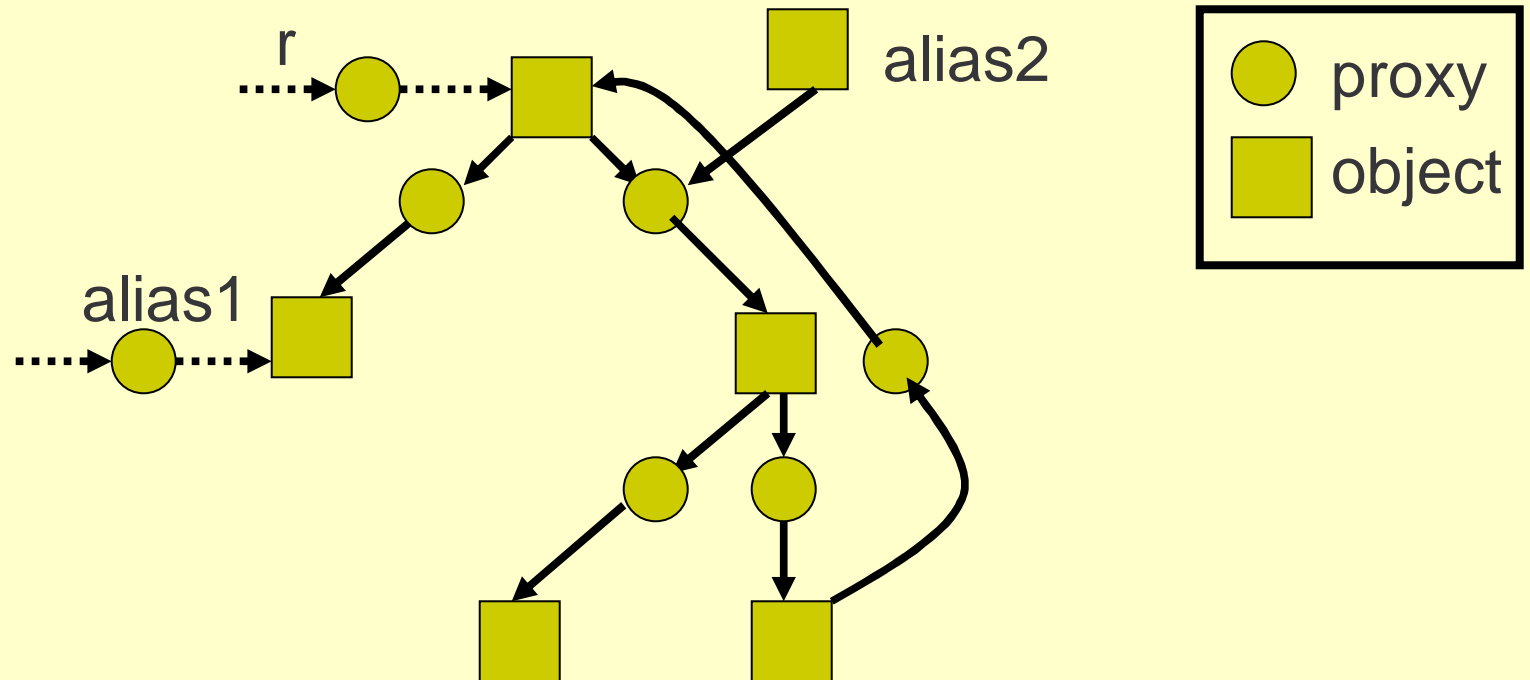
- All clients (aliases) should view the same object regardless of location
- Change all references from direct to indirect

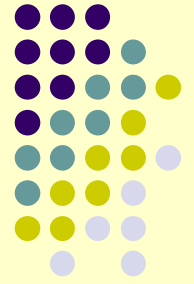




The Proxy Approach

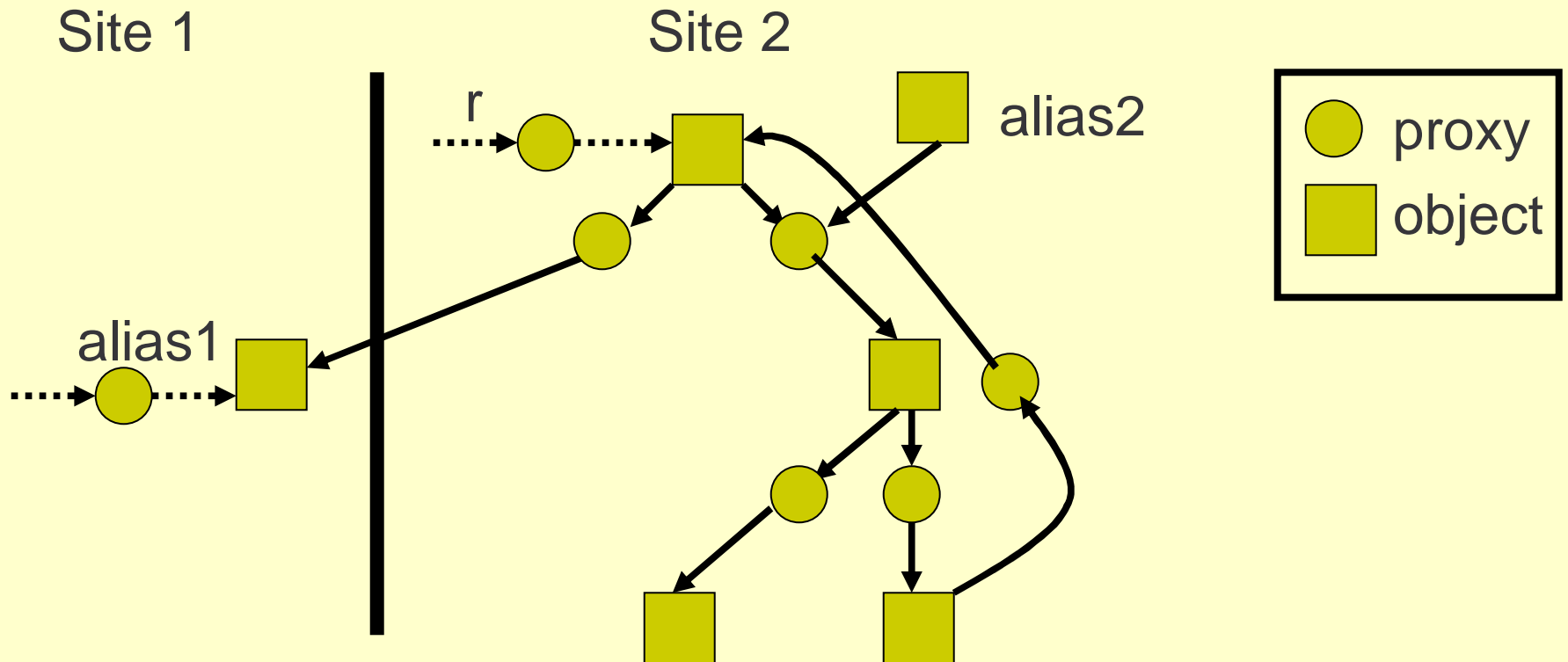
- Changing all references from direct to indirect ensures correct behavior in the presence of aliases
- A remote object can have several proxies on different network sites



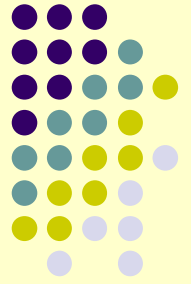


The Proxy Approach

- 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**

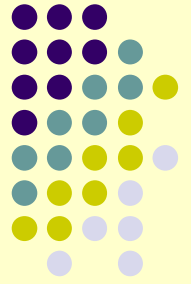
Local class **A__local**

Interface **A__iface**

class **A__static_delegator**

Interface **A__static_iface**





Generated Code

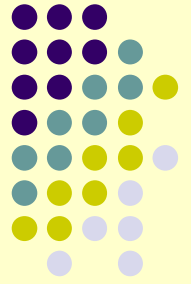
For each original class A:

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





Generated Code

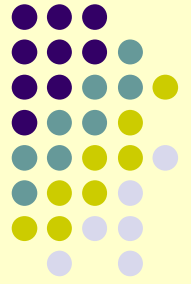
For each original class A:

```
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();  
    }  
}
```

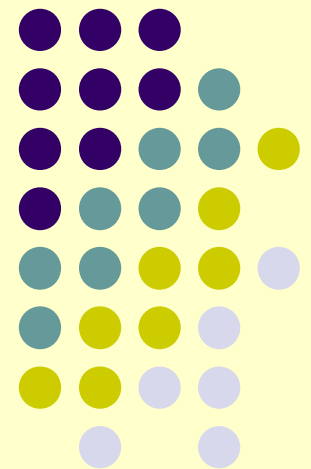
class A is binary-modified:

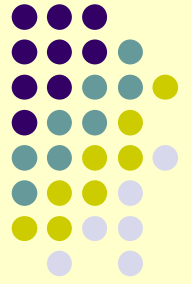
```
class A__remote  
extends UnicastRemoteObject  
implements A__iface  
{  
    proxy.java.io.File _file;  
  
    public void foo(A p) {  
        _file.read();  
        p.get_file().read();  
    }  
    public proxy.java.io.File  
    get_file() { return _file; }  
}
```



Complexities

Overheads, Grouping Objects,
System Code





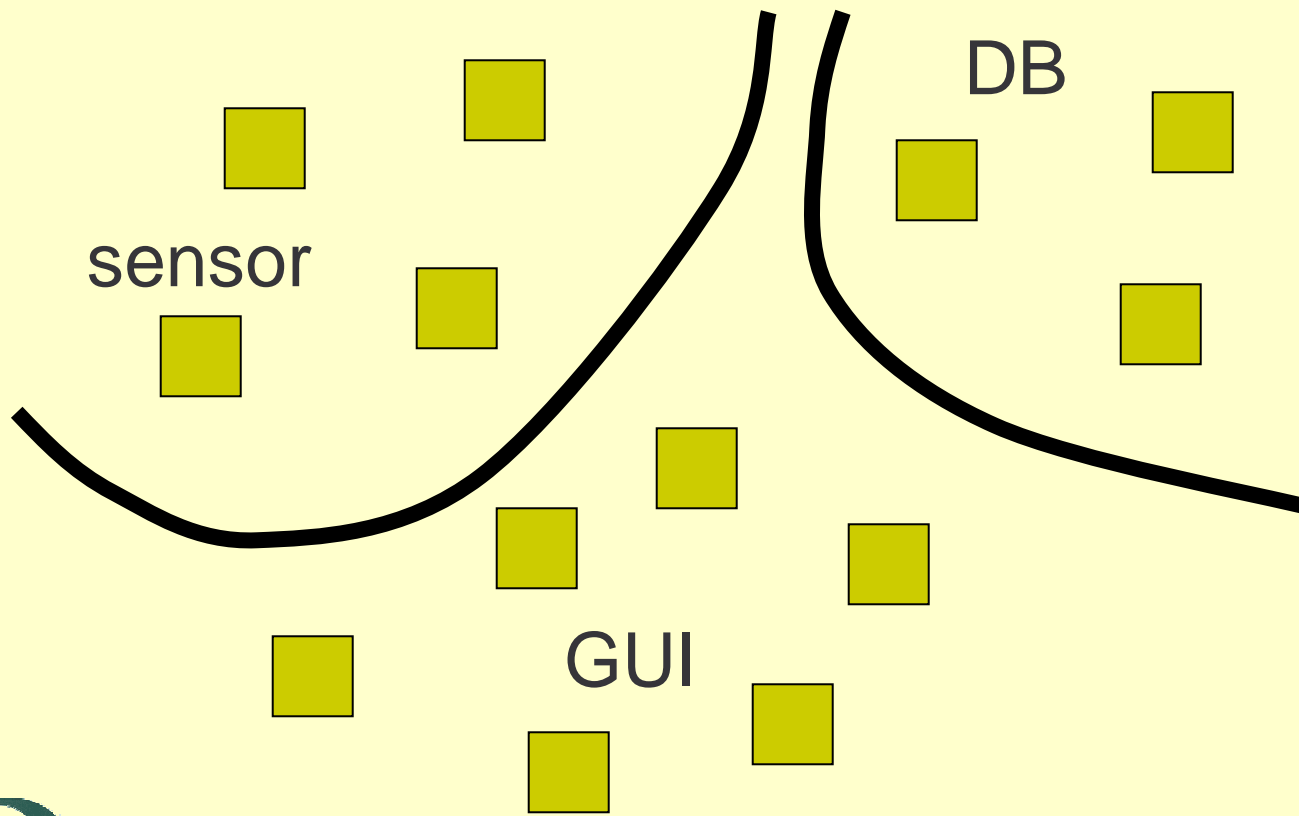
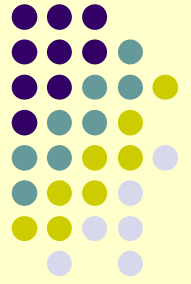
Proxy Indirection Overhead

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%

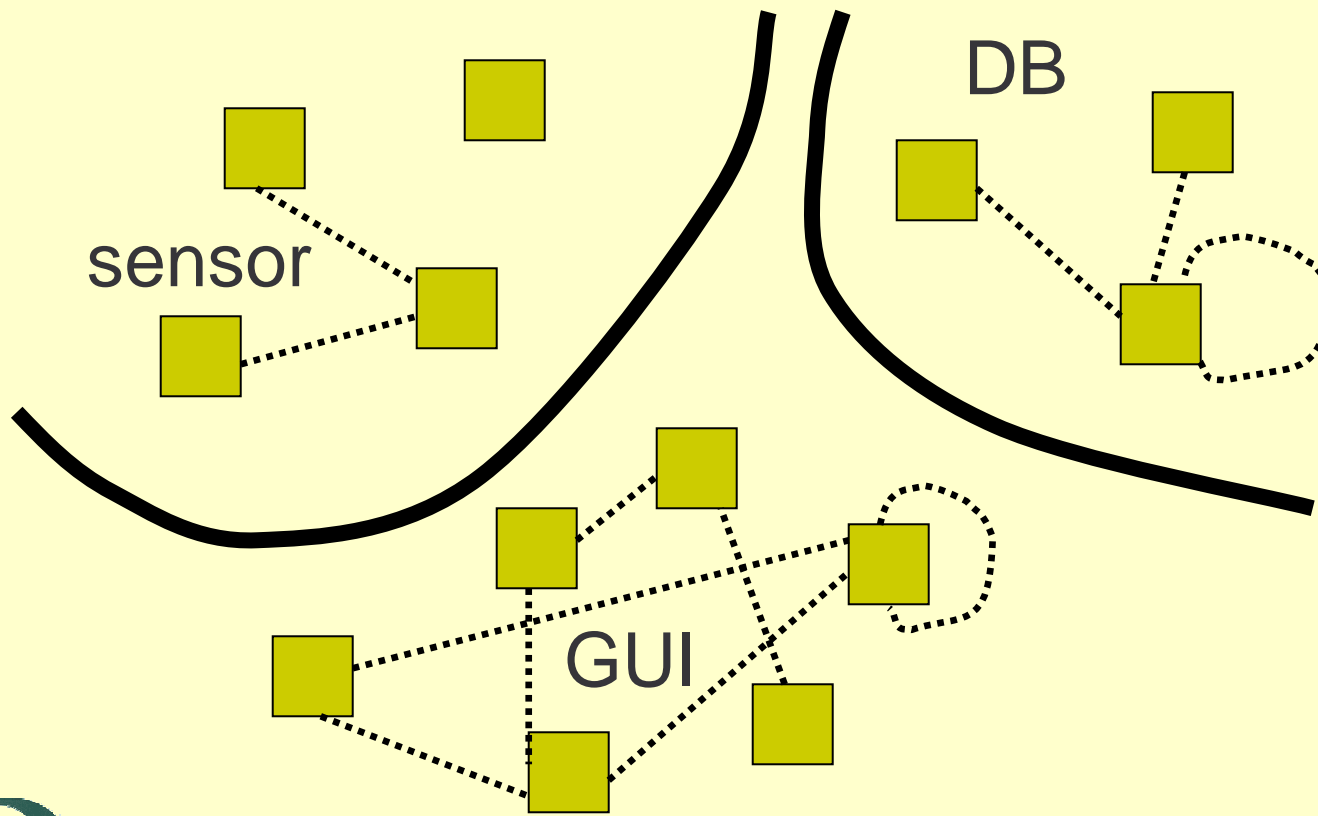
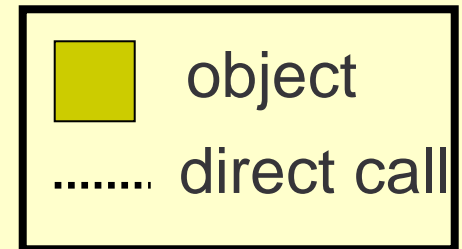
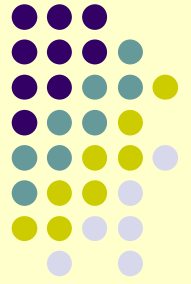
- Micro benchmark
- A function of average work per method call
- 1 billion calls total



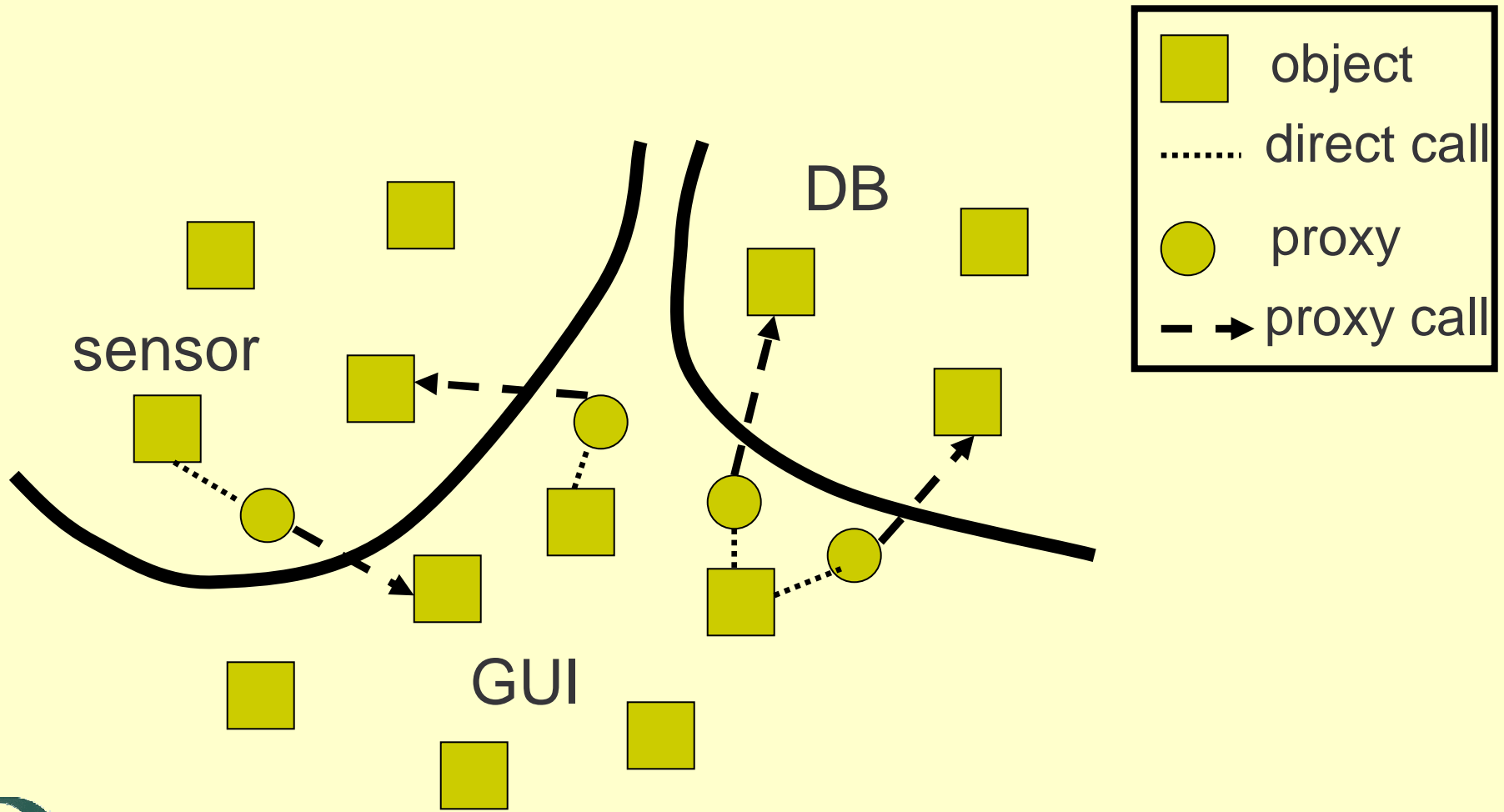
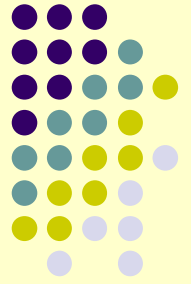
Optimizing Proxy Indirection



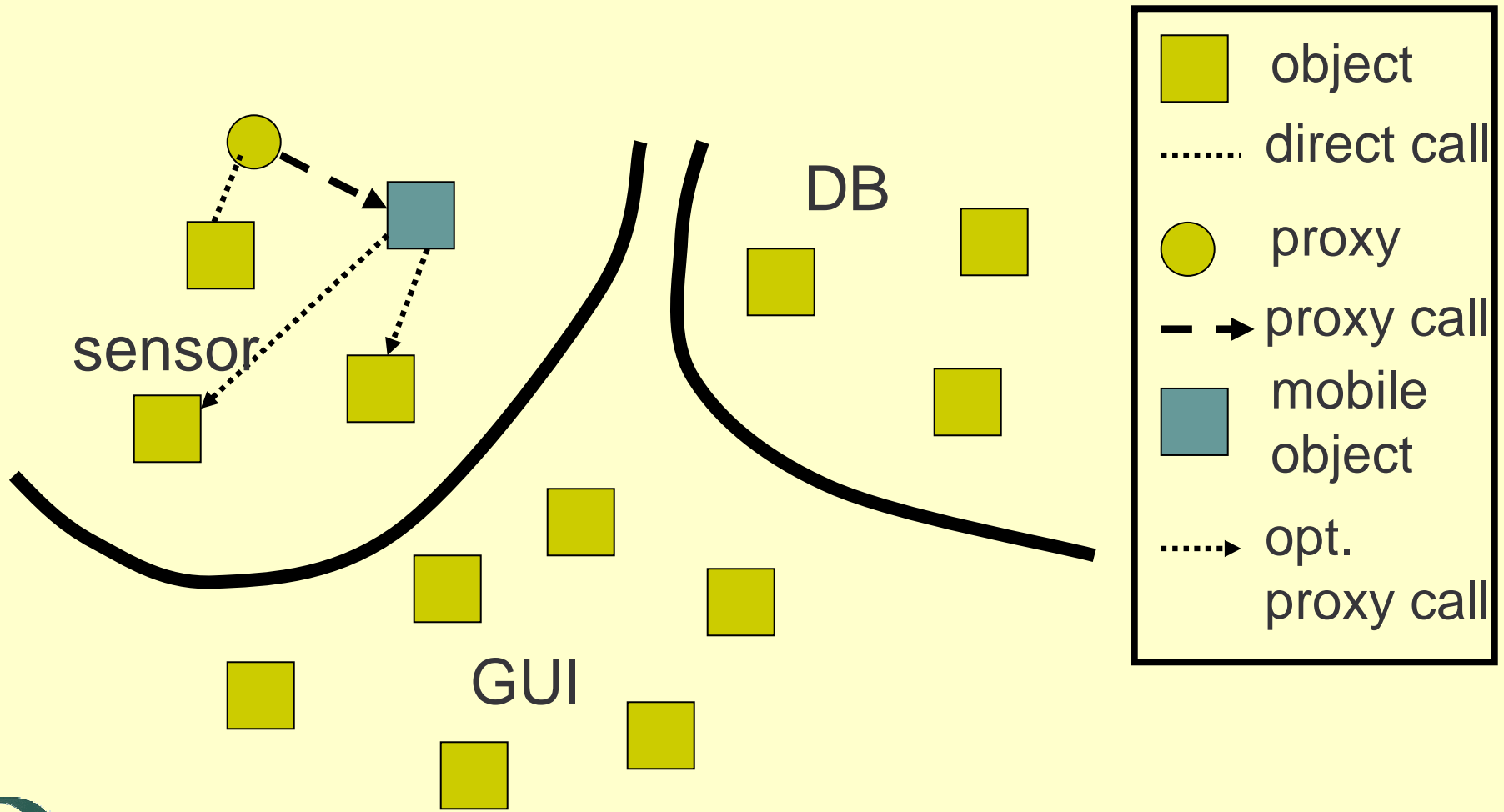
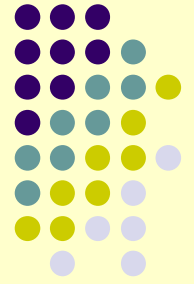
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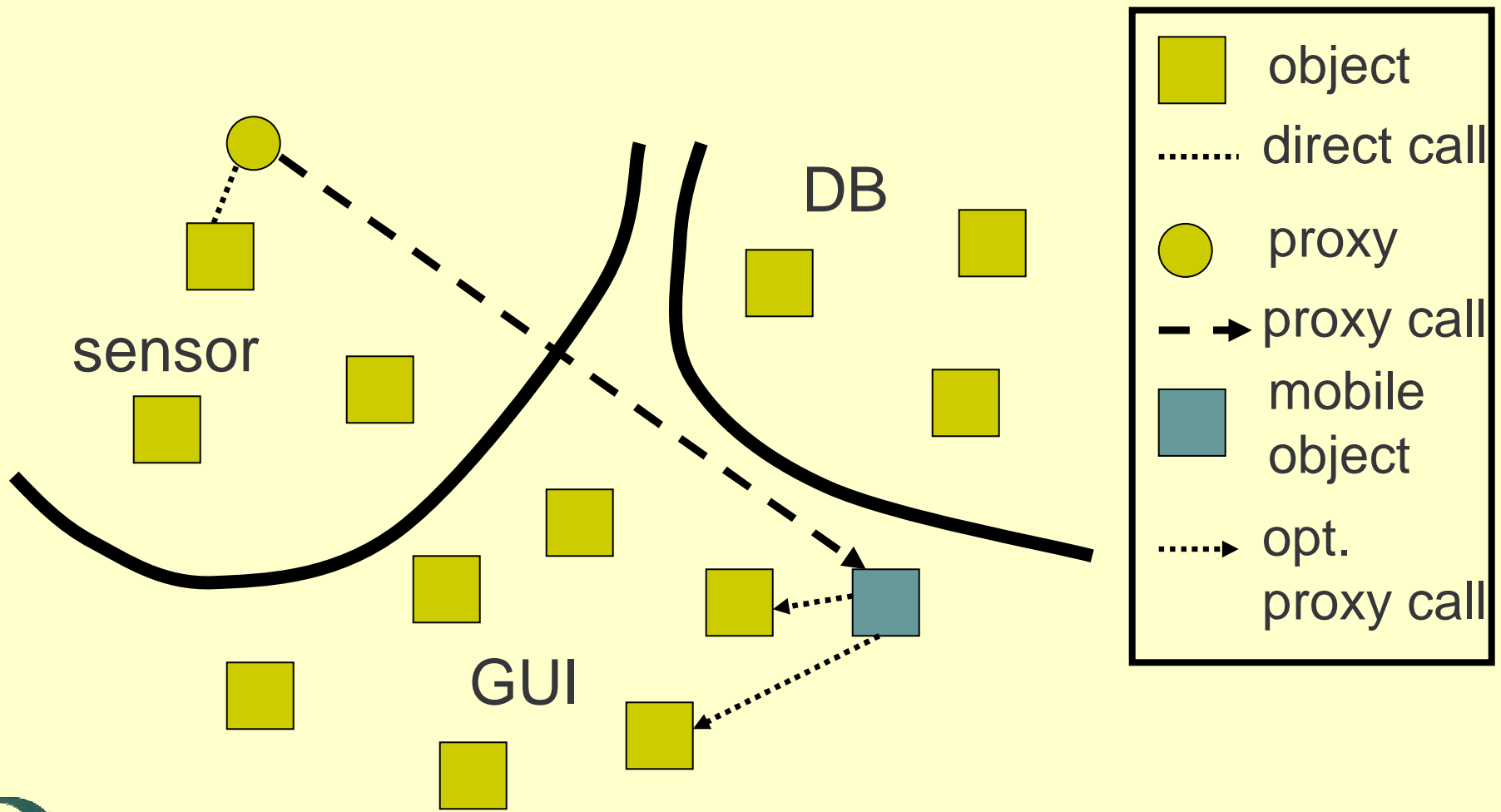
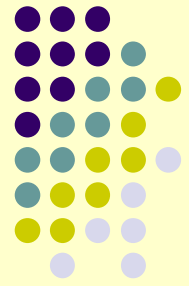
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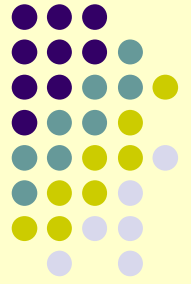


Optimizing Proxy Indirection



Optimizing Proxy Indirection

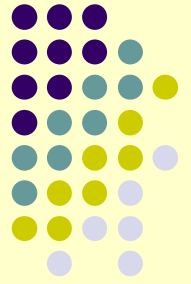




How is This Implemented?

- 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

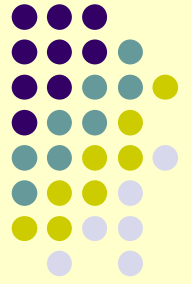




System Code

- 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



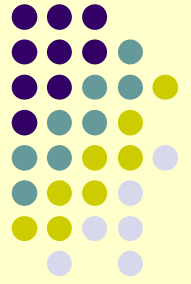


Wrapping / Unwrapping

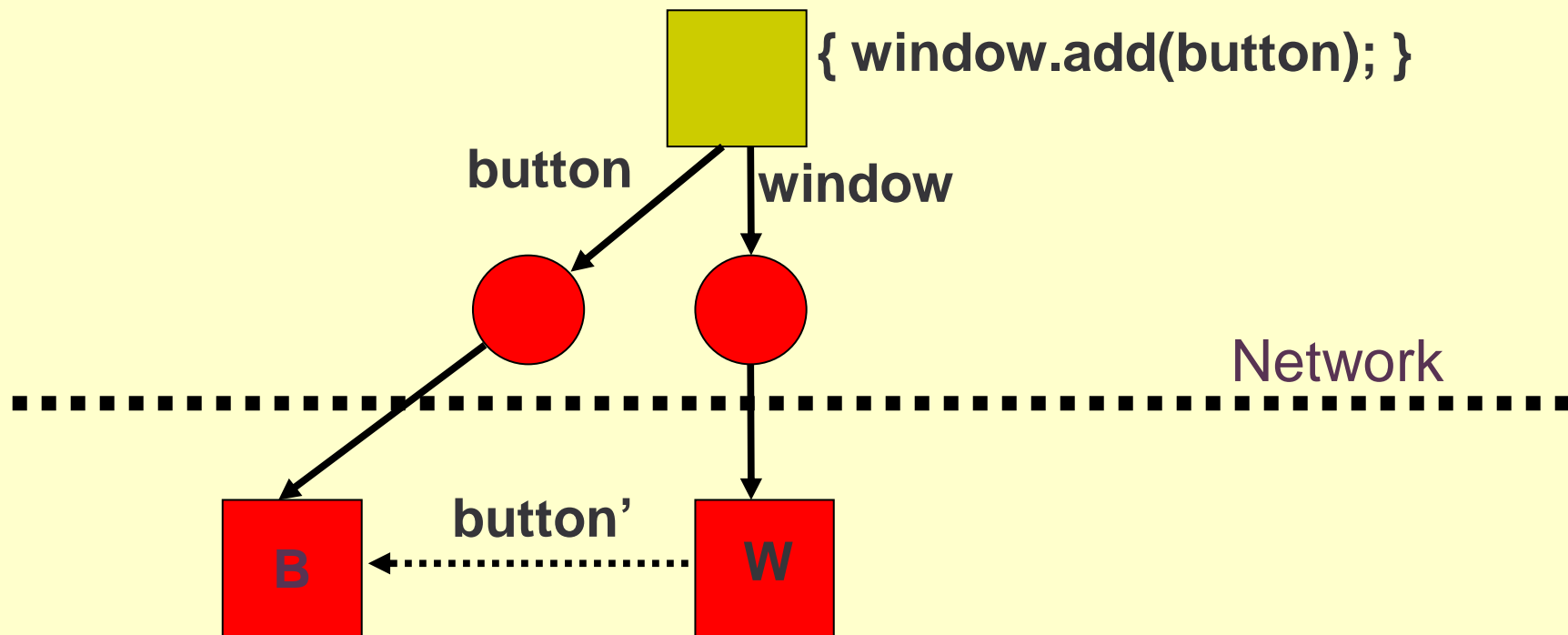
- For this approach to work, we need to inject code in many places to convert direct references to indirect and vice-versa
 - dynamic “*wrapping/unwrapping*”
 - code injected at compile time, wrapping/unwrapping takes place at run time

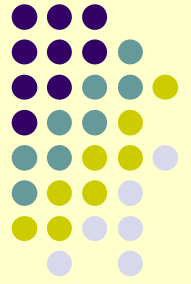


Example: Pass a Reference to System Code



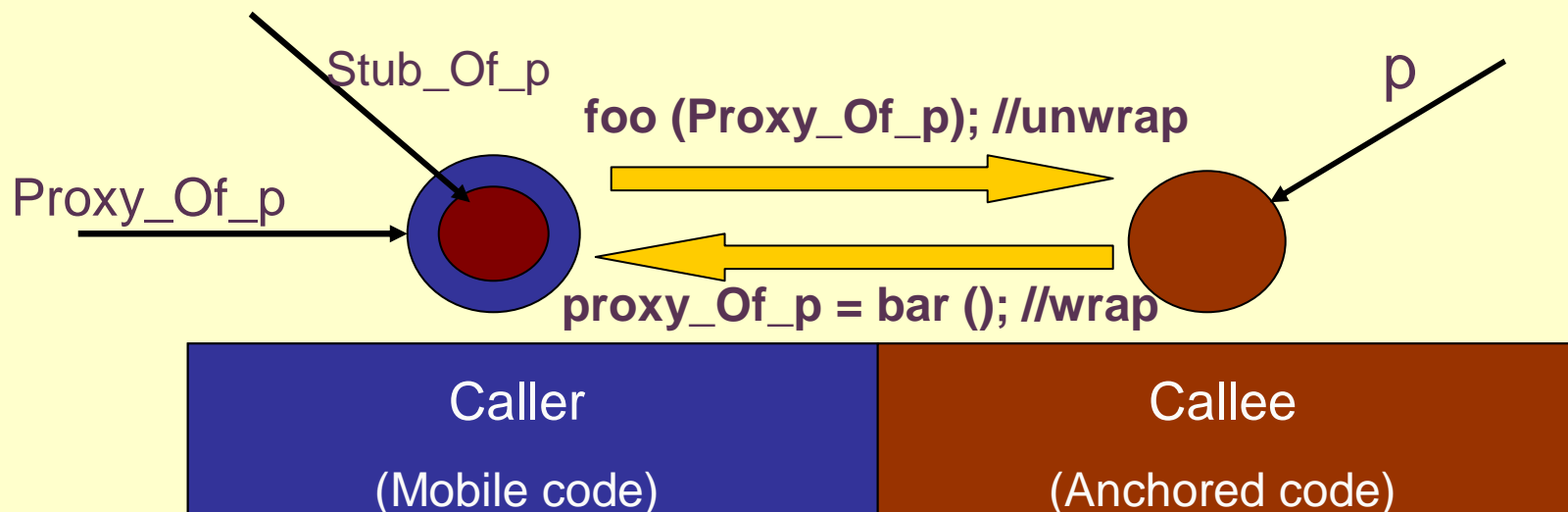
- What if a system object is passed from user code to system code?



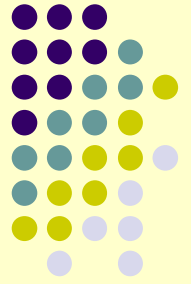


Wrapping/Unwrapping at the Proxy

- 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
```

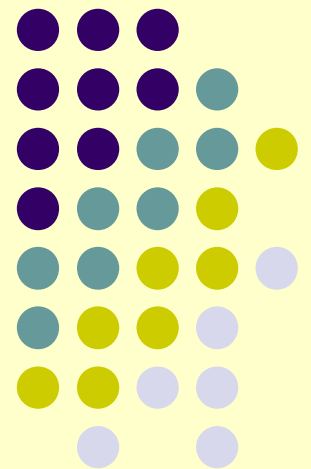
```
aload_1                //load b
```

```
aload_2                //load proxy (of type A)
```

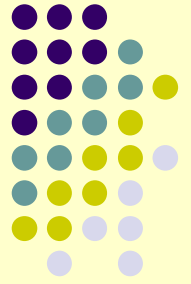
```
invokevirtual B.baz
```


“How Do You Handle...?”

Native code,
Synchronization

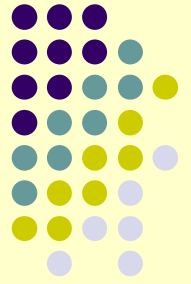


Handling Java Language Features



- 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



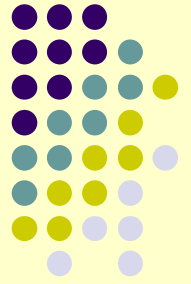


Native Code

- 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

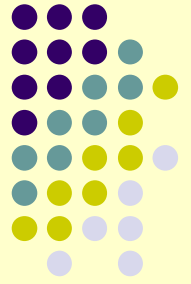


Heuristic Type-Based Analysis: Group Based on Types



- 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

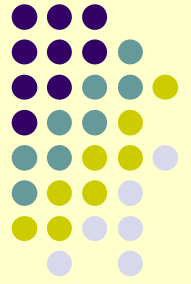




How Safe?

- 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**, **InstanceOf**
- Overall, fairly safe—few violations
 - PlainSocketImpl.socketGetOption casts Object to InetAddress
 - GlyphVector assumed to be StandardGlyphVector, Composite assumed to be AlphaComposite
 - native code respects types more than library code!
 - JNI **InstanceOf** : 69 occurrences
 - Java **instanceof** : 5900 occurrences
- In practice, J-Orchestra works without (much) intervention



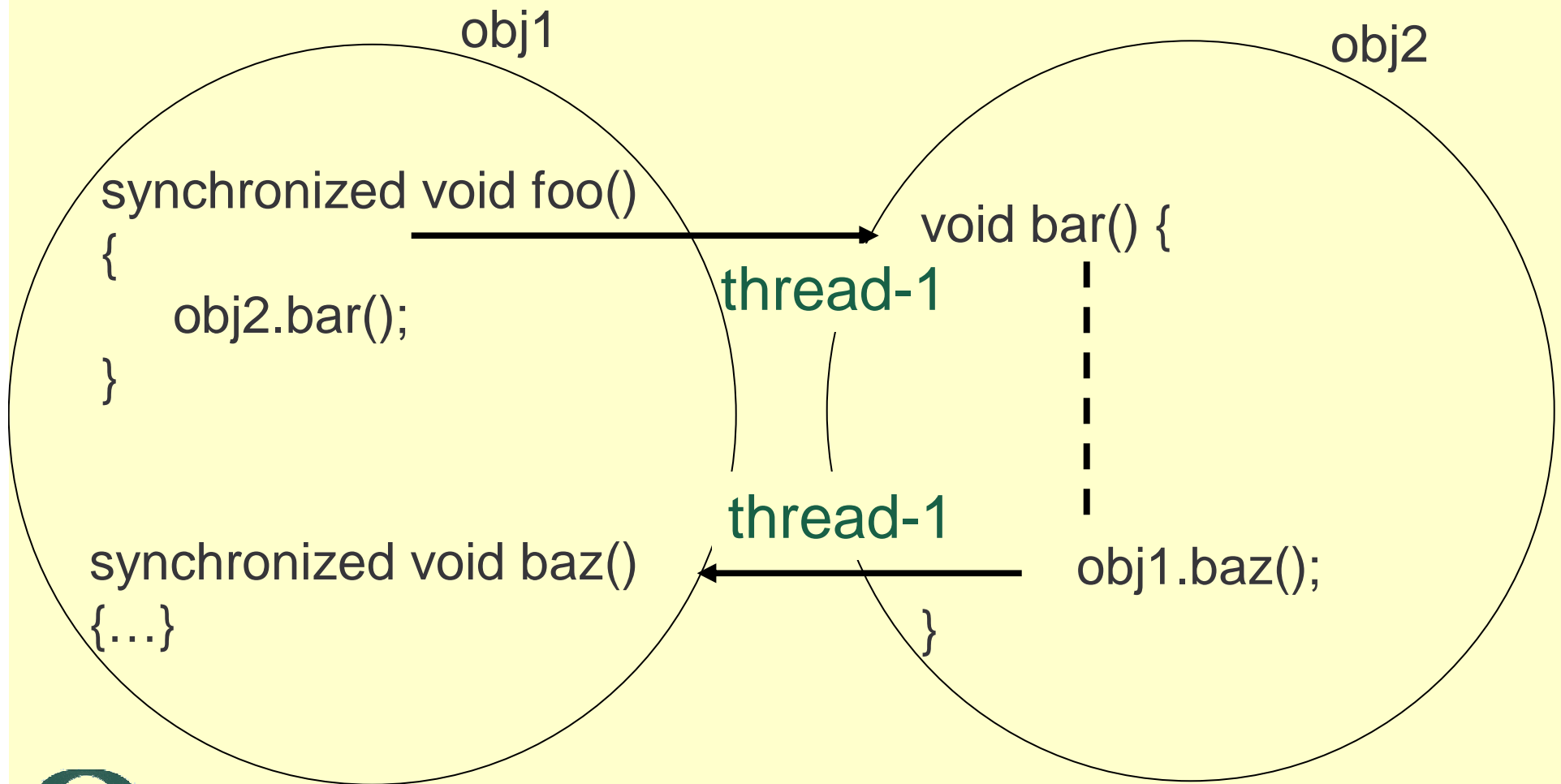
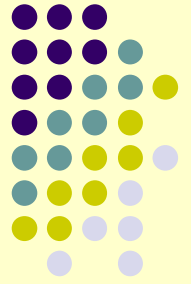


Synchronization

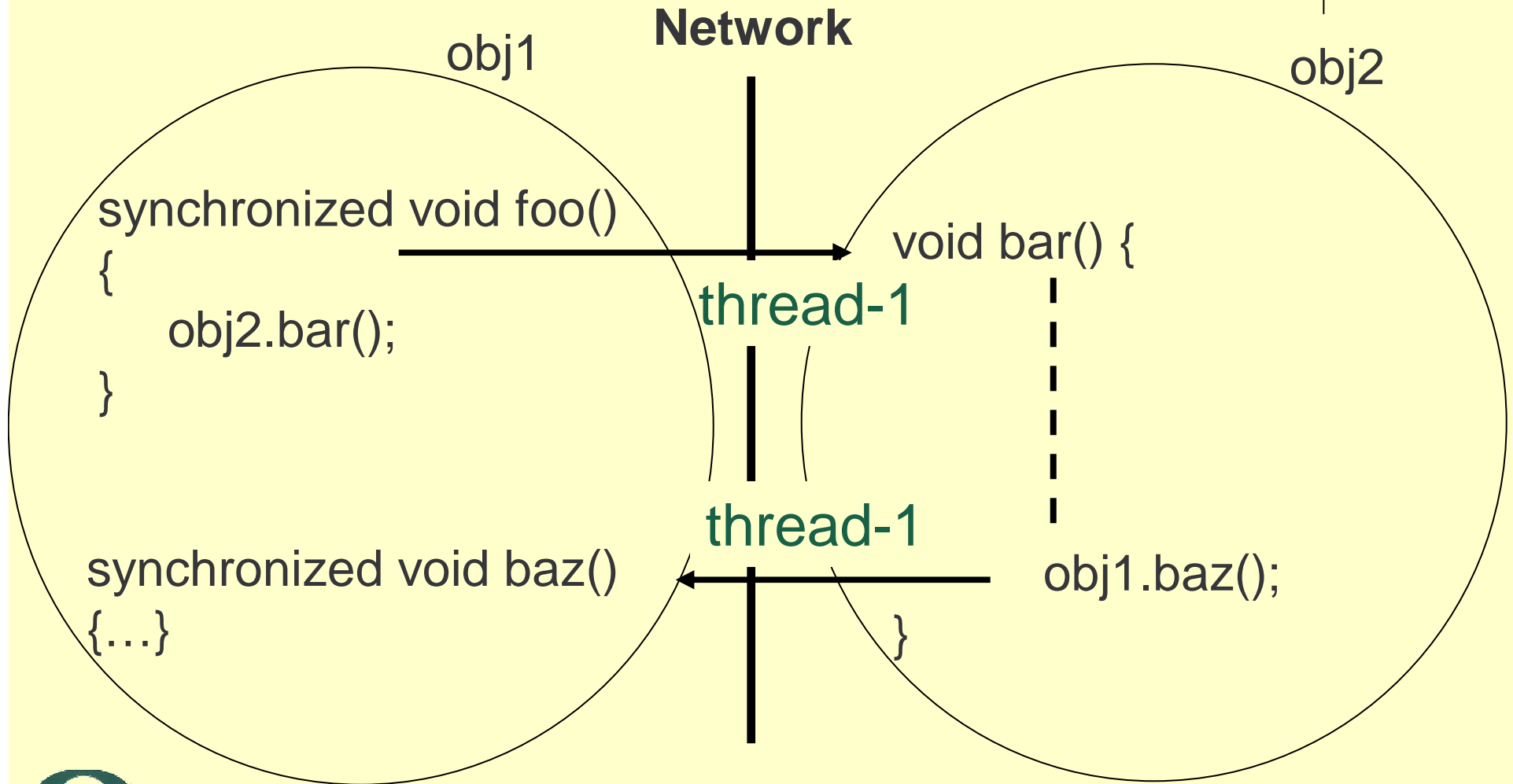
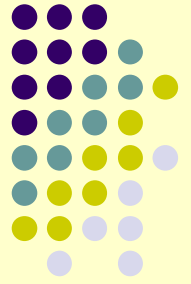
- We only handle monitor-style synchronization: synchronized blocks and methods, wait/notify/notifyAll
 - not volatile variables, concurrent data structures, atomic operations, etc.
- Two problems:
 - thread identity is not maintained over the network
 - synchronization operations (synchronized, wait,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



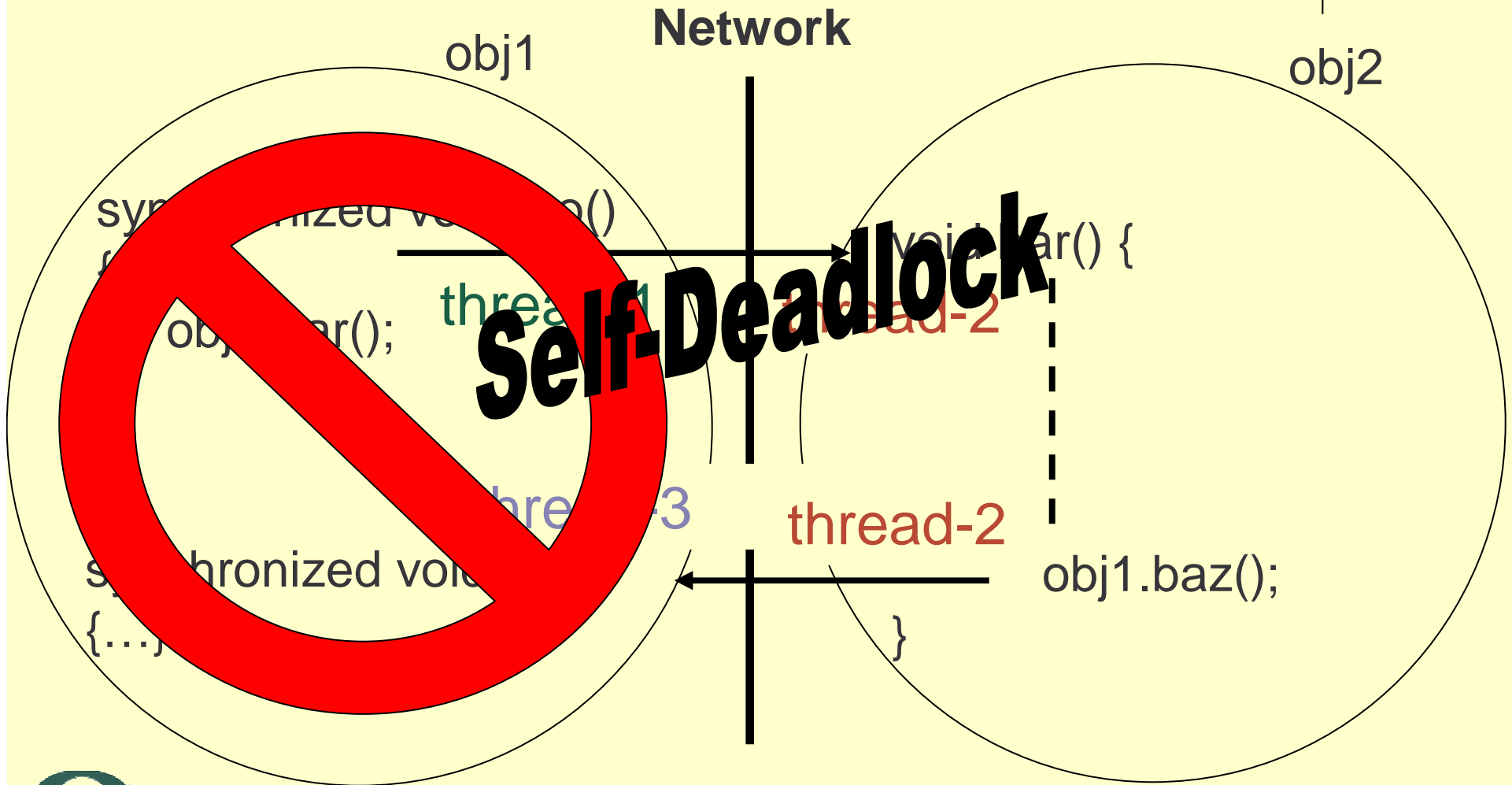
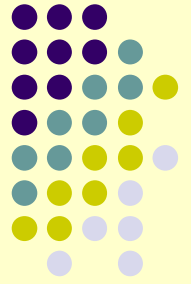
Thread Identity Is Not Maintained (The Zigzag Deadlock Problem)



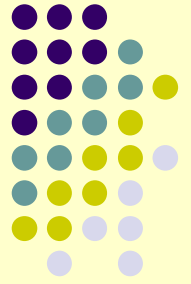
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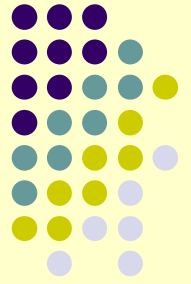


Synchronization Operations Don't Get Propagated Over the Network

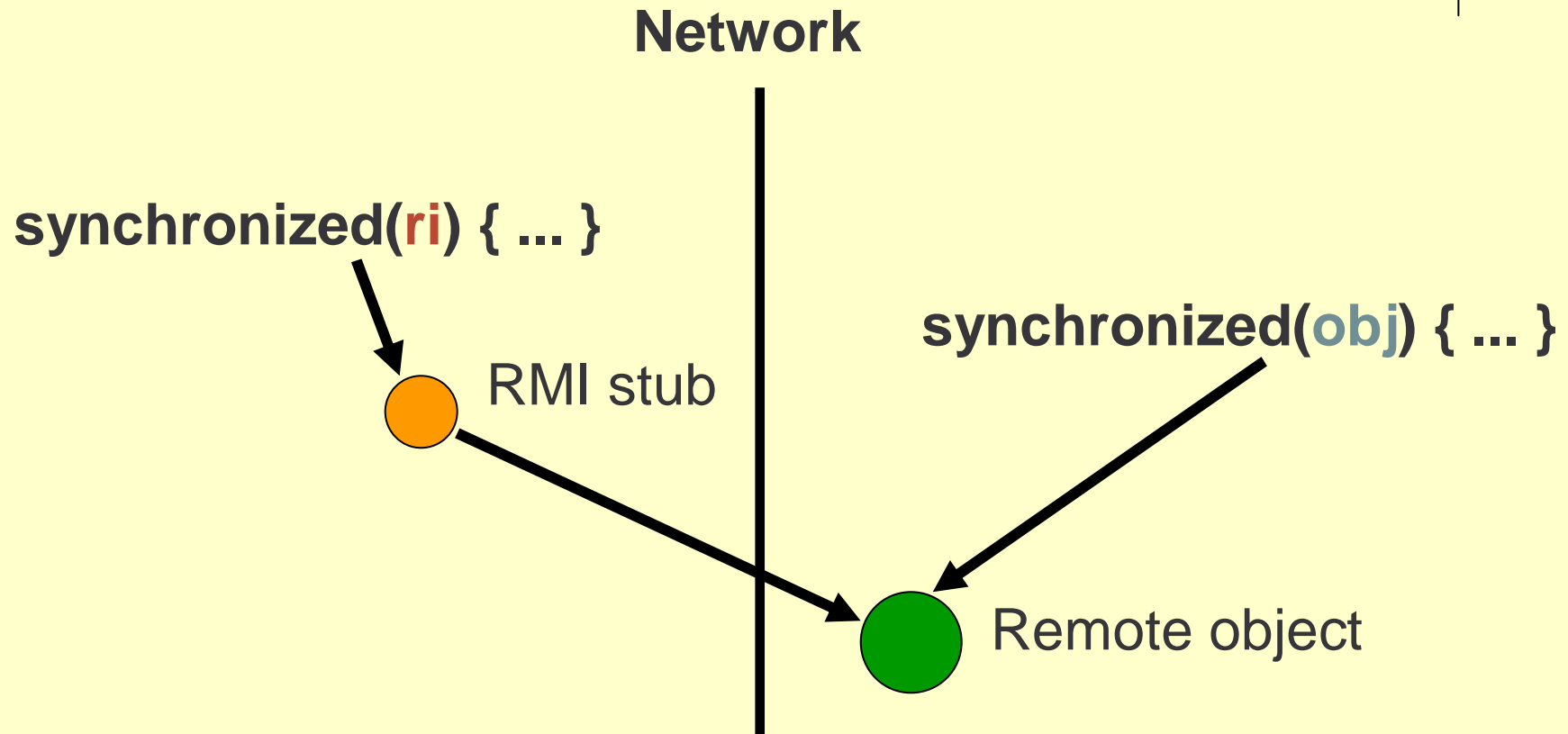


- *obj* – a remote object, implementing interface *RI* and remotely accessible through it
- *RI ri* – points to a local RMI “stub” object
- *ri.foo()*; //will be invoked on *obj* on a remote machine
- The stub serves as an intermediary, propagating method calls to the *obj* object
- Only *synchronized*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



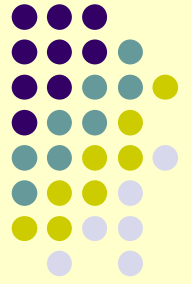


Synchronized Blocks



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

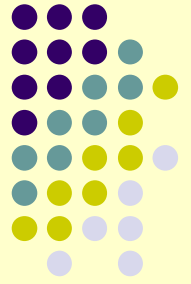




Synchronization Operations Don't Get Propagated Over the Network

- 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



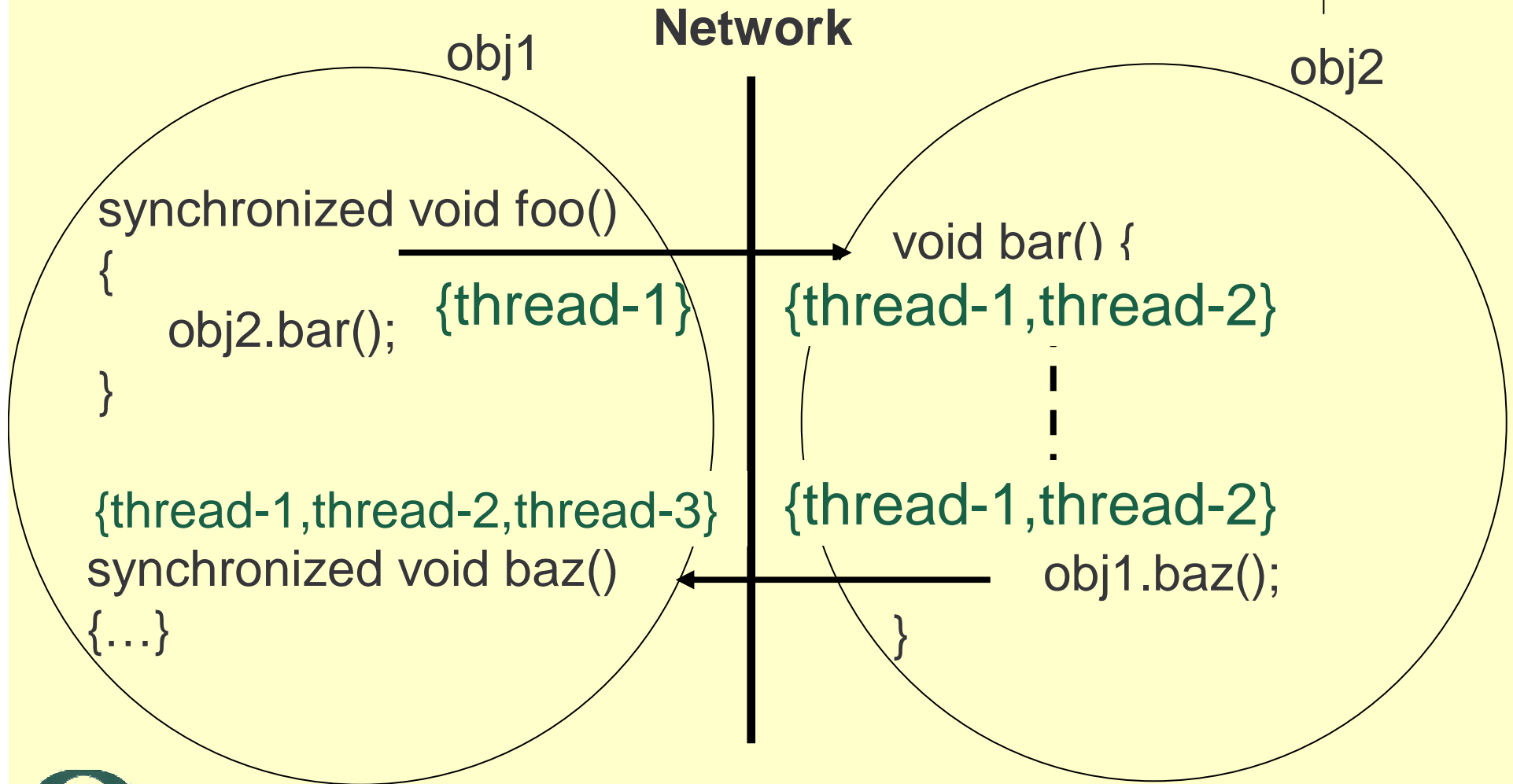
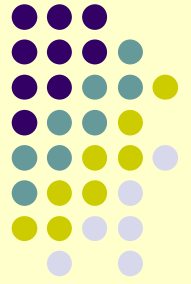


J-Orchestra Synchronization

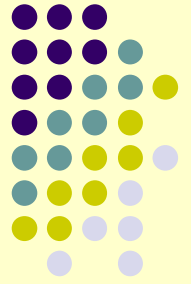
- Maintain per-site “thread id equivalence classes”
- Replace all the standard synchronization constructs (**monitorenter**, **Object.wait**, **Object.notify**) with the corresponding calls to a per-site synchronization library



Thread Identity Is Not Maintained (The Zigzag Deadlock Problem)



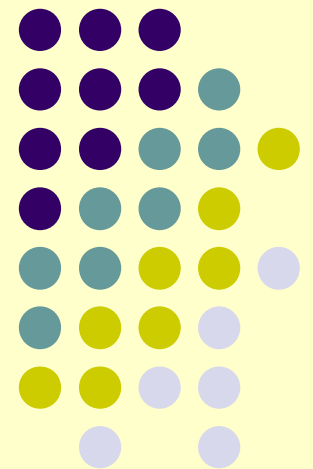
Maintaining Thread Id Equivalence Classes *Efficiently*

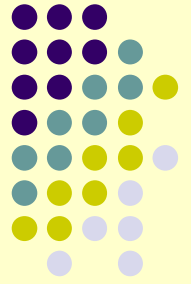


- Updating thread equivalence classes *only* when the execution of a program crosses the network boundary
- This happens only after it enters a method in an RMI stub
- Use bytecode instrumentation on standard RMI stubs
- Equivalence classes' representation is very compact (encoded into a *long int*).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



Wrap up



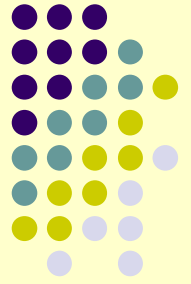


J-Orchestra Impact

- 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...”)

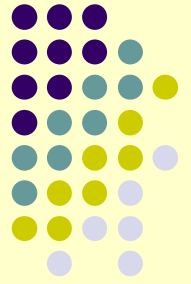


Program Transformation and Generation in JBoss



- 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



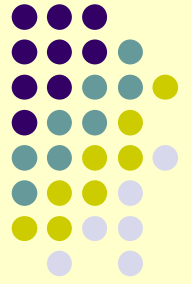


Broader Impact

- *“The research of Yannis's group at Georgia Tech has influenced key features in JBoss.”*
- *“Our interaction has been an example of a highly successful collaboration of academia and industry.”*
- *“The bytecode engineering techniques of J-Orchestra have been the inspiration for the Aspect-Oriented Programming features of JBoss 4.”*

Marc Fleury, JBoss Group



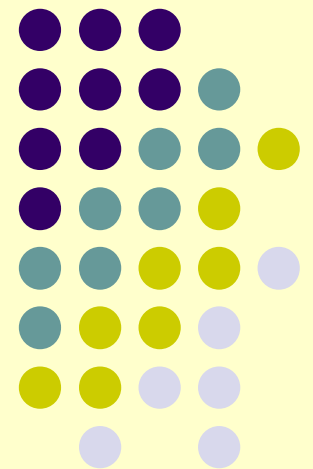


Publications

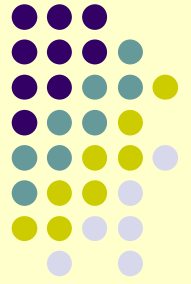
- Main paper: ECOOP'02
- Synchronization: Middleware '04
- Appletizing: ICSM'05
- Dealing with native code: ECOOP'02 + GPCE'06



That's all folks...



My Research



- ***The systems and languages end of SE***
 - **language tools for distributed computing**
 - NRMI, J-Orchestra, GOTECH
 - **automatic testing**
 - JCrasher, Check-n-Crash (CnC), DSD-Crasher
 - **program generators and domain-specific languages**
 - cJ, Meta-AspectJ (MAJ), SafeGen, JTS, DiSTiL
 - **multiparadigm programming**
 - FC++, LC++
 - **software components**
 - mixin layers, layered libraries
 - **memory management**
 - EELRU, compressed VM, trace reduction, adaptive replacement

