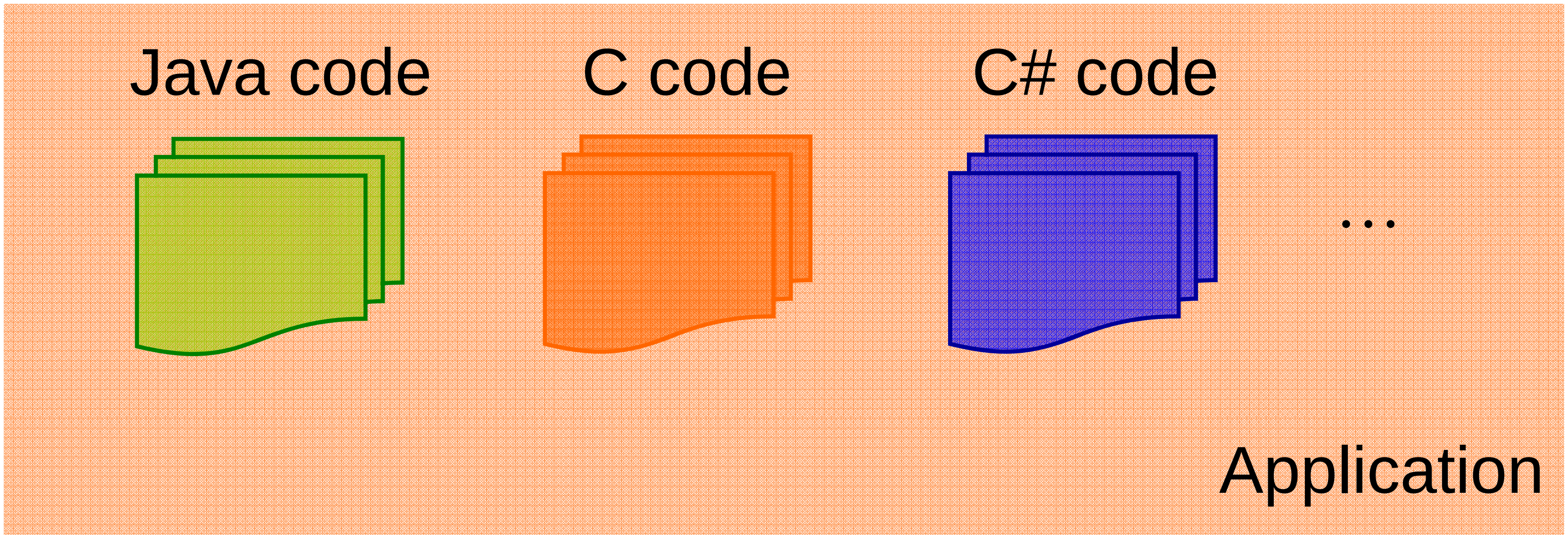
Safe Java Native Interface

Gang Tan*, Andrew W. Appel#, Srimat Chakradhar◇,
Anand Raghunathan◇, Srivaths Ravi◇, and Daniel Wang#

*Boston College
#Princeton University
◇NEC Labs America

Heterogeneous Programming Paradigm

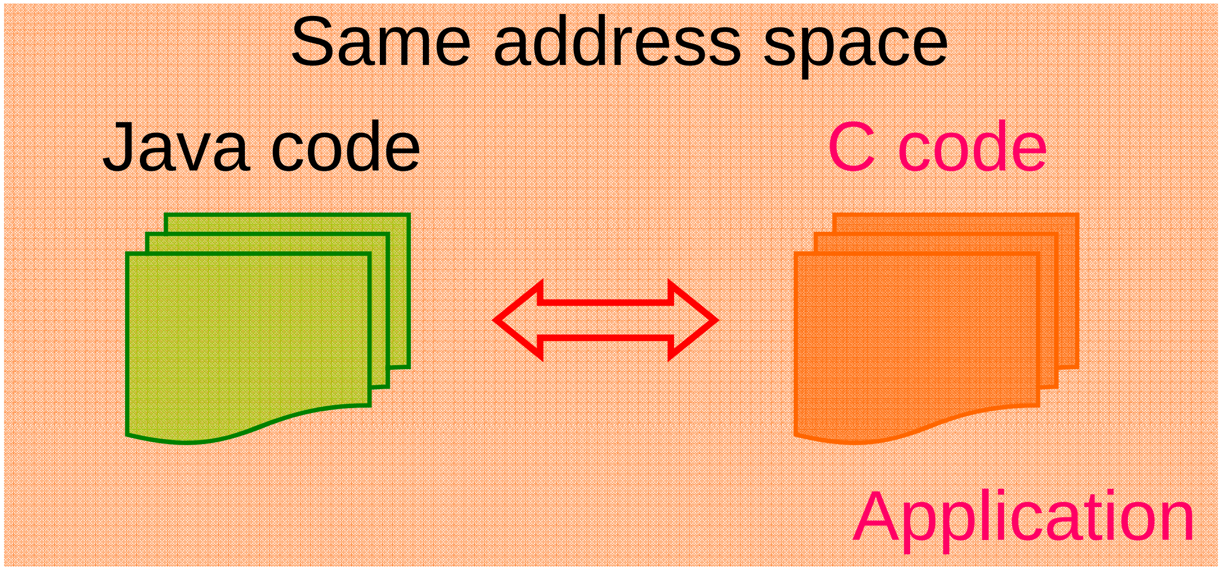


- Reuse legacy code
- Mix-and-match benefits of different languages
  - E.g., C is faster and more flexible than Java
  - E.g., Java based GUIs are easier to develop

Foreign Function Interfaces (FFIs)

- Most modern languages have FFIs
  - Java, ML, OCaml, Haskell, …
- FFIs address issues such as
  - Representation of data
  - Calling conventions
  - Memory management
  - …

What about Safety and Security?



Strongly typed | Weakly typed

Memory safe | Memory unsafe

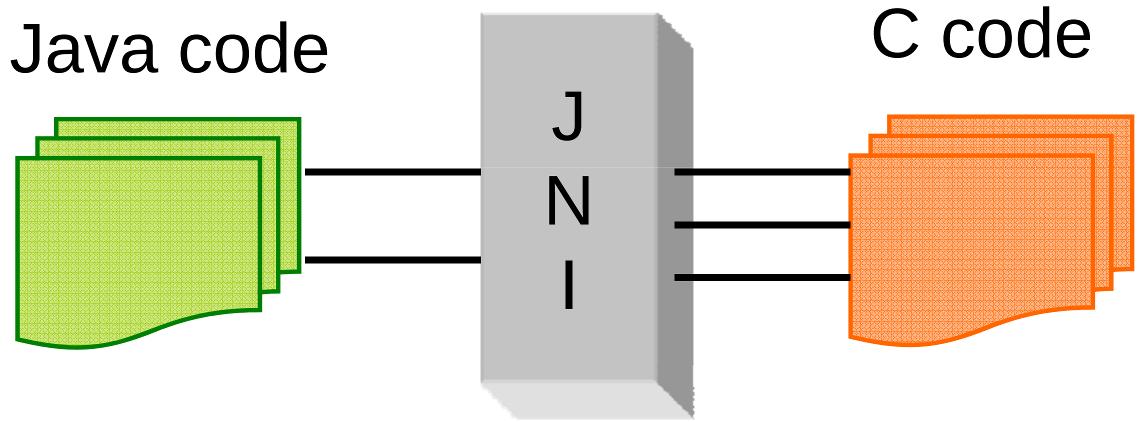
The whole application becomes memory unsafe!

Approaches for Safe Interoperation:

- Component models: COM, DCOM, SOAP, CORBA
  - Different address spaces
  - Communication via RPCs
  - But, high performance overhead and inflexible
- Rewrite every component in a safe language
  - Substantial programming effort
  - Hard/impossible sometimes

We focus on FFI-based approaches.

Our Focus: Java Native Interface (JNI)



- Java can call C-implemented methods
- C code can
  - Access, update and create Java objects
  - Call a Java method
  - Catch and raise exceptions
  - …

Our Goal

- Make calling native C code in Java as **safe** as calling Java code in Java
- Benefits:
  - Reuse legacy C code in Java safely and conveniently
  - Improve the security of Java platform
    - JDK 1.4.2 contains over 600,000 lines of C code under the cover of JNI
  - More lightweight and flexible comparing to RPC-based approaches

Two Subproblems

- Provide internal safety for C Code.
  - CCured [Necula, Condit, et al.]
    - Ensure memory-safety by source-to-source transformation
    - Insert runtime checks
    - Heavily optimized
  - Cyclone [Jim, Morrisett, et al.]
- Safe interoperation between C and Java
  - Ensure that C uses JNI in a principled way

Outline

- Motivation
- JNI and its loopholes
- SafeJNI system
- Preliminary experiments
- Future work

An Example Of Using JNI

```
class IntArray {
…
native int sumArray(int arr[]);
…
}
```

Java code

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  jint *body =
    (*env)->GetIntArrayElements(env, arr, 0);
  int i, sum = 0;
  for (i=0; i<len; i++) sum+=body[i];
  (*env)->ReleaseIntArrayElements(env, arr, body, 0);
  return sum;
}
```

C code

Using JNI in C Code

Get a pointer into the Java heap

Pass in a pointer to the int array

C code

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  jint *body =
    (*env)->GetIntArrayElements(env, arr, 0);
  int i, sum = 0;
  for (i=0; i<len; i++) sum+=body[i];
  (*env)->ReleaseIntArrayElements(env, arr, body, 0);
  return sum;
}
```

Pointer arith.

Get the length of the array

- Well-behaved C code manipulates Java objects through JNI APIs

Loophole: Out-of-Bounds Accesses

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  jint *body =
    (*env)->GetIntArrayElements(env, arr, 0);
  ...
  body[100]=9831;
  ...
}
```

Out-of-bound write;
destroys JVM's state

Loophole: Arguments of Wrong Classes

- JNI completely ignores the Java class hierarchy
  - All Java classes are mapped to jobject * in C

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  ...
}
```

C can pass objects of wrong classes to Java

Loophole: Calling Wrong Methods

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  jint *body =
    (*env)->GetIntArrayElements(env, arr, 0);
  ...
}
```

Nothing prevents C from calling GetFloatArrayElements

Loophole: Manual Memory Management

```
jint Java_IntArray_sumArray
(JNIEnv *env, jobject *obj, jobject *arr)
{
  jsize len = (*env)->GetArrayLength(env, arr);
  jint *body =
    (*env)->GetIntArrayElements(env, arr, 0);
  ...
  (*env)->ReleaseIntArrayElements(env, arr, body, 0);
  ...
}
```

Dangling pointers; memory leak; release twice

Safety/Security Vulnerabilities in JNI

- Bypassing JNI: direct read/write through Java pointers
- Out-of-bounds array access
- Passing objects of wrong classes to Java
- No access control
- Manual memory management
- Calling wrong methods
- Exception handling
- Out of the Java sandbox security model

At best: causes a JVM crash

At worst: security violation

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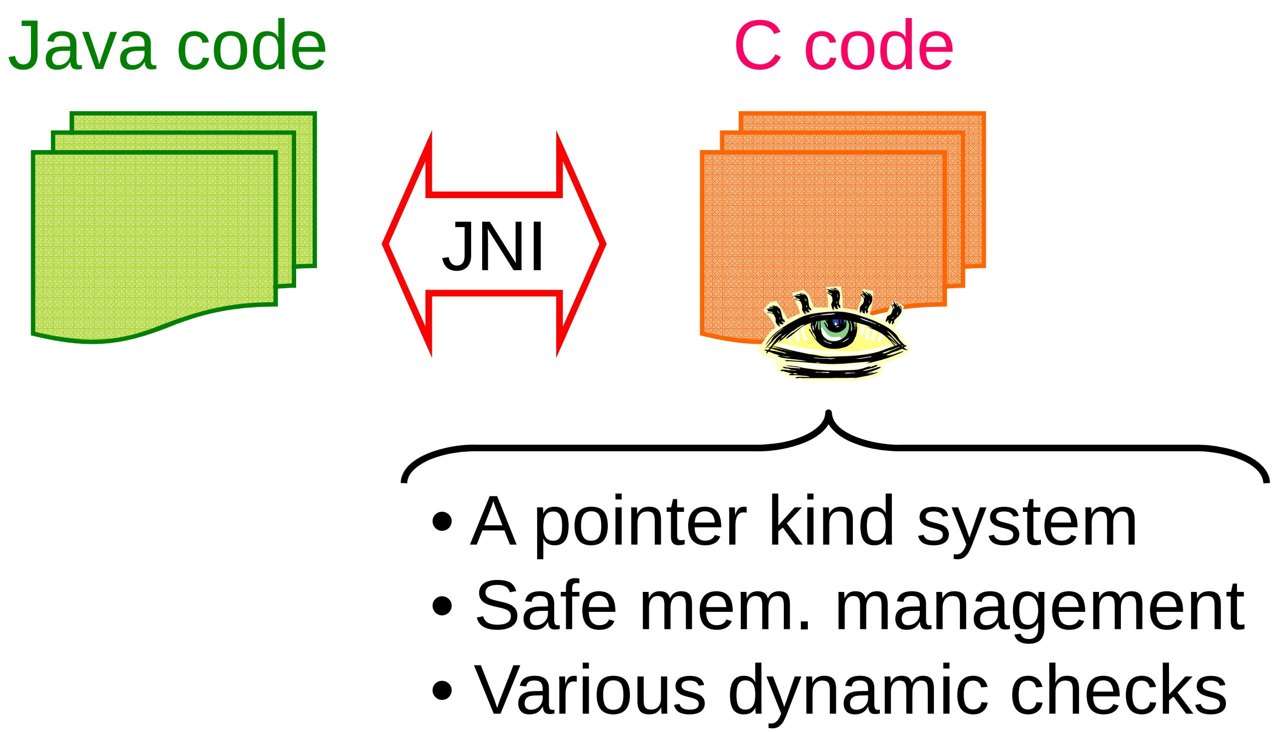
Safe Java Native Interface (SafeJNI)

- Goal:
  - Make calling native C code in Java as **safe** as calling Java code in Java



Restricting Capabilities of Pointers

- Opaqueness of Java object pointers
  - Can pass them as arguments to JNI APIs
  - No pointer arith./cast/read/write
- Java primitive array pointers
  - Allow pointer arith., but must be within bounds
  - Carry bounds information at runtime

A Pointer Kind System

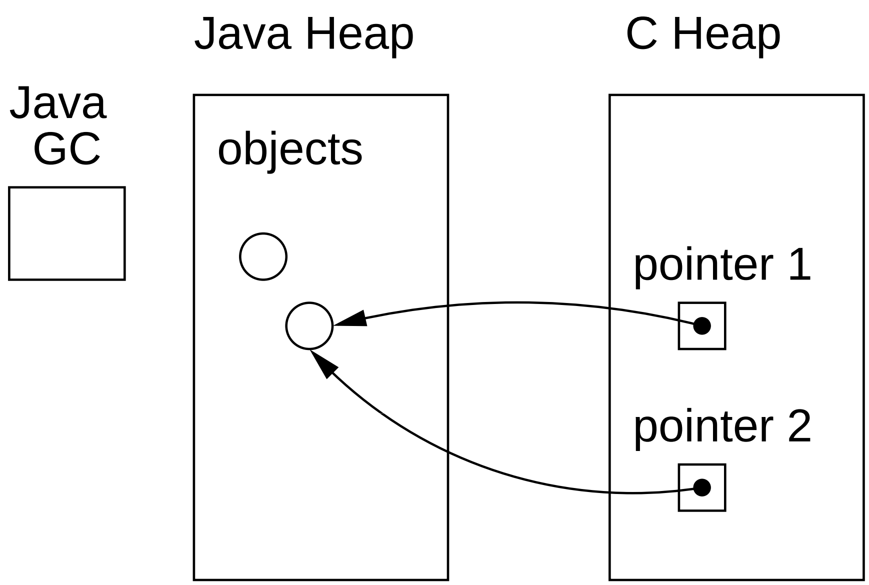
- Classify pointers with different capabilities
- An extension of CCured’s pointer kinds

Pointer Kind	Description	Capabilities
t *HNDL	Java handle Pointers	Pass to JNI APIs; equality testing
t *RO	Read-only pointers	read
t *SAFE	Safe pointer	read/write
t *SEQ	Sequence pointers	Above + pointer arithmetic
t *WILD	Wild pointers	Above + casts

Model JNI interface pointers

Model Java primitive array pointers

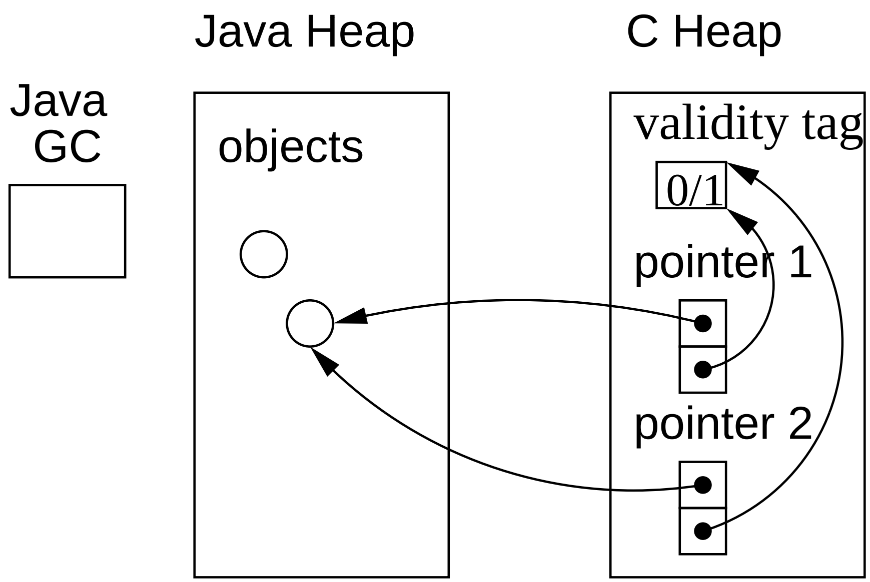
Memory Management in JNI



After step 4, "Pointer 1" is dangling if GC recycles the buffer

1. C calls GetIntArrayElements and gets "pointer 1"
2. In GetIntArrayElements, JVM pins the buffer so that GC will not move it
3. When it's done, C calls ReleaseIntArrayElements
4. JVM unpins the buffer

Our Solution for Mem. Management



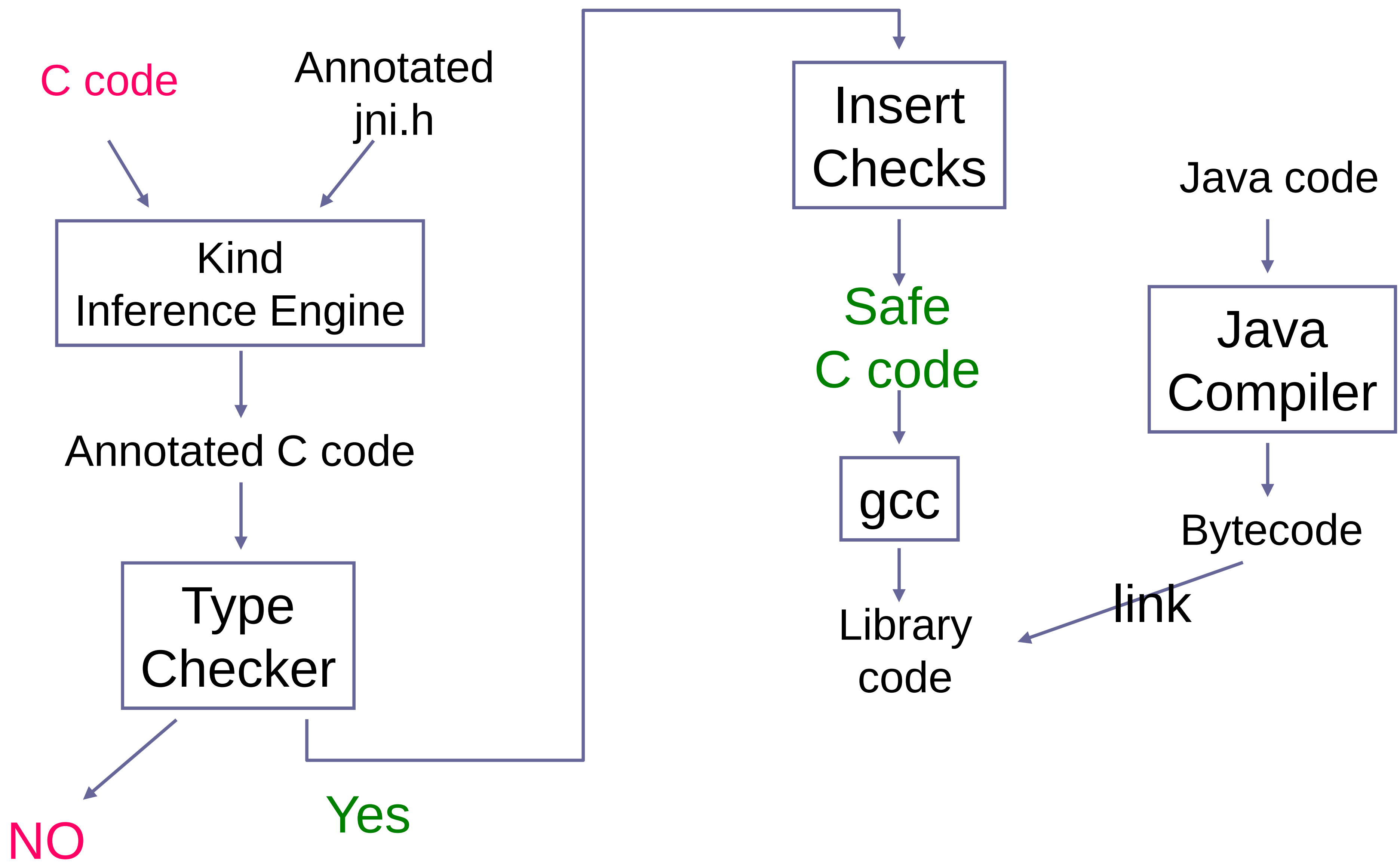
- Create a validity tag
- Change the representation of a pointer to a struct
- In GetIntArrayElements, init the tag to 1
- In ReleaseIntArrayElements, change the tag to 0
- Before dereferencing, check that the tag is 1

Various Dynamic Checks

- Runtime type checking
  - E.g., when GetIntArrayElements is called, check the second arg. is an int-array object
  - When a Java method is called, check the number and classes of arguments
- Access control
  - Check during "get field ID"
- Exception checking
- Non-null checking

Java maintains all information at runtime

SafeJNI System: On Top of CCured



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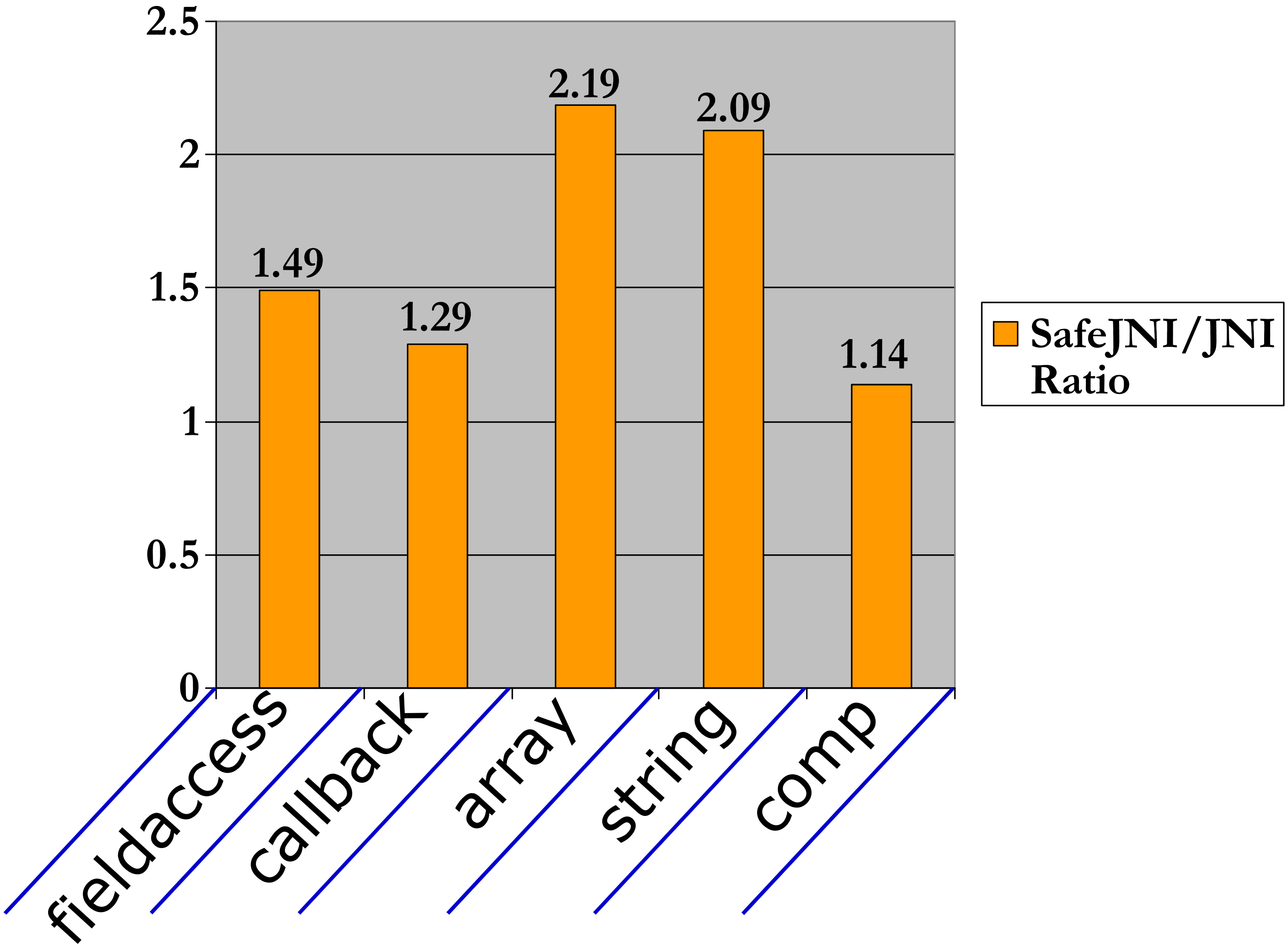
Microbenchmarks



Zlib Experiment

- Zlib compression library
  - 9,000 lines of C code + 262 lines of glue code
  - The basis for java.util.zip

	SafeJni Ratio	CCured Ratio	JZlib* Ratio
Zlib	**1.63**	1.46	1.74

* JZlib is a 100% pure Java reimplemention of Zlib

A Safety Loophole in java.util.zip

- Zlib maintains a z_stream struct
  - For keeping state info
- The Deflater object needs to store a pointer to this C struct
  - However, it's difficult to define a pointer to a C struct in Java!

```
class Deflater {
    private long strm;
    …
}
```

- Then C casts it back to a pointer

A Safety Loophole in java.util.zip

- With reflection support, we can change the private long.

```
import java.lang.reflect.*;
import java.util.zip.Deflater;
public class Bug {
  public static void main(String args[]) {
    Deflater deflate = new Deflater();
      byte[] buf = new byte[0];
      Class deflate_class = deflate.getClass();
      try {
        Field strm = deflate_class.getDeclaredField("strm");
        strm.setAccessible(true);
        strm.setLong(deflate,1L);
      } catch (Throwable e) {
        e.printStackTrace();
      }
      deflate.deflate(buf);
   }
}
/* Policy file needed in a secure environment */
grant {
  permission java.lang.RuntimePermission "accessDeclaredMembers";
  permission java.lang.reflect.ReflectPermission "suppressAccessChecks";
};
```

Crashed Sun’s JVM and IBM’s VM

Related Work

- OCaml’s FFI [Furr and Foster]
  - Track OCaml types in C to prevent misuse
- NestedVM [Alliet and Megacz]
  - Put native code into a separate VM
  - Slowdown ratio: 200% to 900%
- Janet [Bubak et al.]
  - A cleaner interface
- “-Xcheck:jni”
  - Incomplete and undocumented

Future Work

- Reduce the amount of dynamic checks
  - Keep track of Java types in C code
  - Use static analysis/theorem proving
- .Net: interaction between managed and unmanaged code

SafeJNI: Conclusions

- Reuse legacy C code **safely** and conveniently
- More lightweight and flexible comparing to RPC-based approaches

The End