A Secure Implementation of Java Inner Classes

By

Anasua Bhowmik and William Pugh

Department of Computer Science

University of Maryland

More info at:

http://www.cs.umd.edu/~pugh/java

Motivation and Overview

- Present implementation of Java inner classes provides a security hole in order to allow inner classes access the private fields of the outer class and vice versa
- We designed a secure technique for allowing access to private fields and methods
- No need to change the JVM
- Very little overhead
- Developed a byte code transforming tool which modify the class files and make the inner classes safe

Java Inner Classes

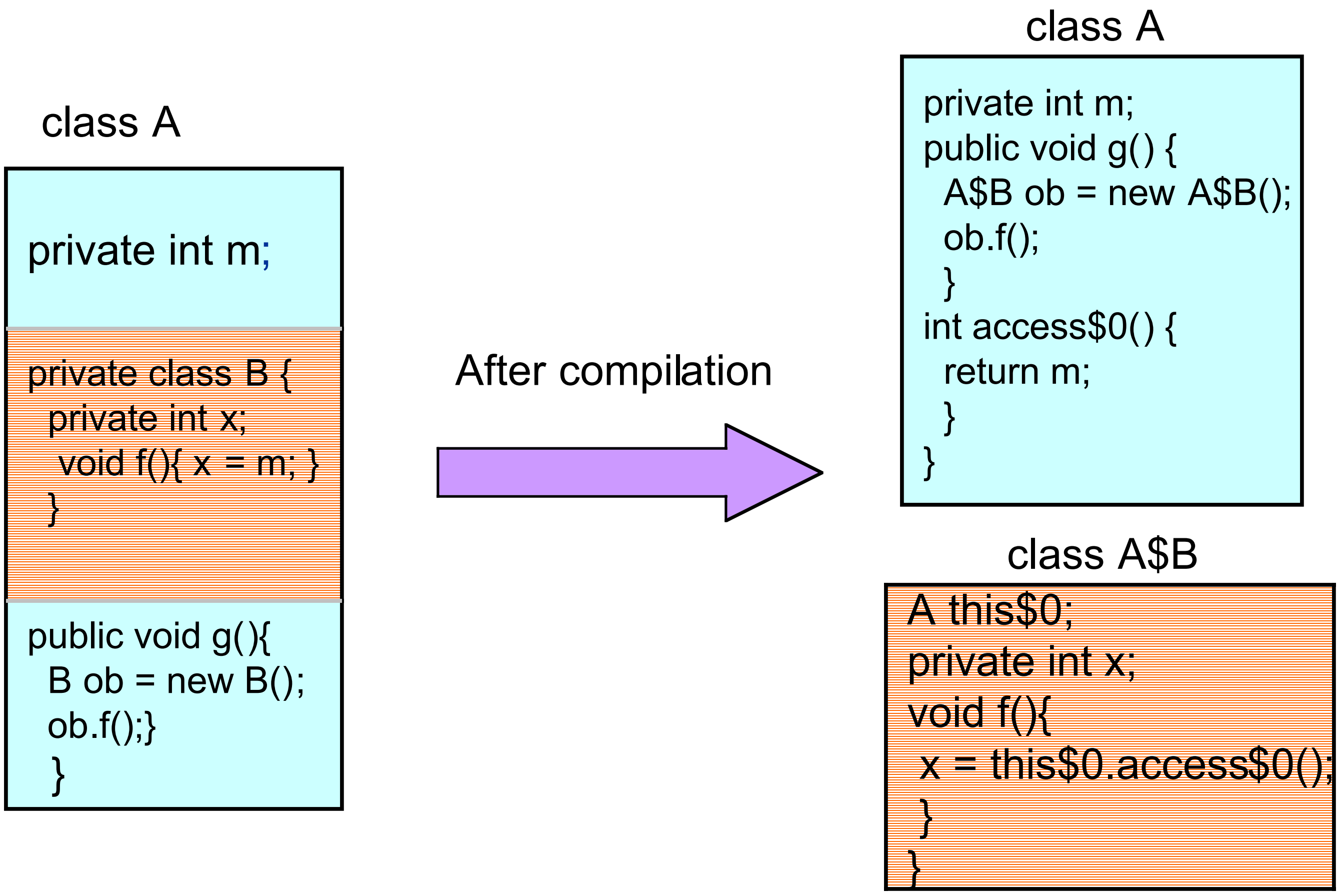
- *Inner class* is a new feature added in Java 1.1
- *Inner classes* are classes defined as member of other class
- *Inner classes* are allowed to access the private members of the enclosing class and vice versa
- For each instance of an outer class there is a corresponding instance of the inner classes

```
class A {
   private a;
   class B {
     private b;
     void f() {
      b = a+a;  // accessing pvt. var of A
      }
    public g(){
    B myObj = new B();
    myObj.f();
    int x = myObj.b; // accessing pvt.  var
                                  of A
 }
}
```

Inner Classes Aren’t Understood By JVMs

- Inner classes are implemented as a compiler transformation
- JVM do not need to understand inner classes
  - code will run on 1.0 JVM’s
- JVM prohibits access to private members from outside the class
- Compiler transforms the class, containing inner classes, to a number of non-nested classes

Implementation of Inner Classes



class A

```
private int m;

private class B {
  private int x;
   void f(){ x = m; }
  }

public void g(){
  B ob = new B();
  ob.f();}
  }
```

After compilation

class A

```
private int m;
public void g() {
  A$B ob = new A$B();
  ob.f();
  }
int access$0() {
  return m;
  }
}
```

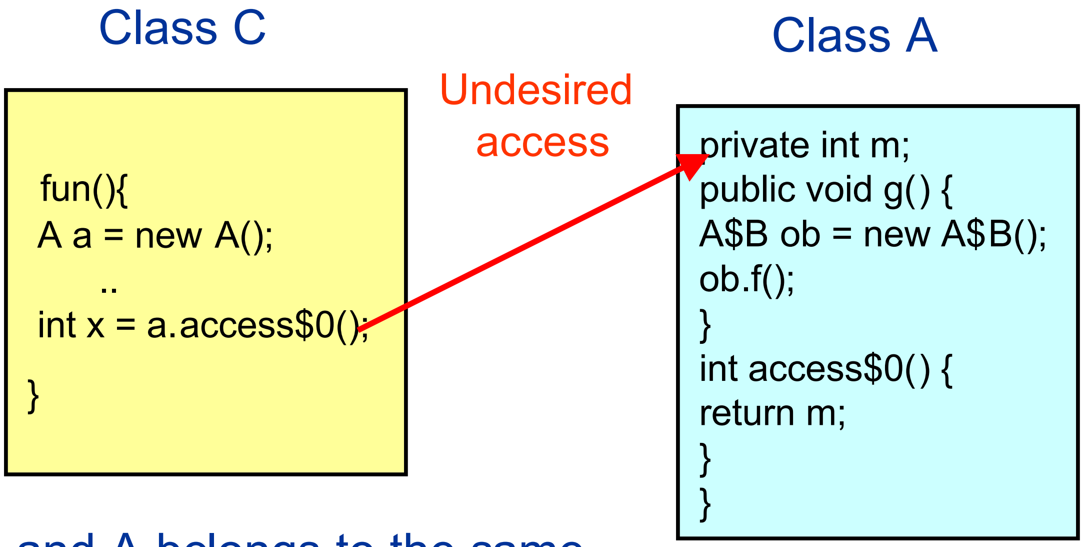
class A$B

```
A this$0;
private int x;
void f(){
 x = this$0.access$0();
 }
}
```

- Access$0() of class A has package level visibility.
- The class A$B also has package level visibility

Security Threats with Present Implementation

- The private data members of classes get exposed through access functions
- Other classes belonging to the same package can call the access functions and tamper the private data member



Class C

```
fun(){
A a = new A();
      ..
int x = a.access$0();

}
```

Undesired access

Class A

```
private int m;
public void g() {
A$B ob = new A$B();
ob.f();
}
int access$0() {
return m;
}
}
```

- Class C and A belongs to the same package

Is This A Problem?

- Lots of Java code uses inner classes
- Using new 1.2 security model, all privileged code is put in inner classes
- Still requires attacker get inside package
- One security barrier down
  - Prefer defense in depth
- Ed Felton recommends against using current version of inner classes

New Implementation of Inner Classes

- The access to the private members are restricted only to the intended classes
- The new implementation is built on top of the current implementation
  - class files are rewritten
- No need to change the JVM
- A *secret key* is shared between all the classes that need access to each others private data members
  - Class *B* wants to access a class *A*'s private member *m*
  - invokes *A*'s access function
  - *B* passes it's shared *secret key* to *A*'s access function
  - *A* verifies whether *B*'s *secret key* and *A*'s *secret key* are the same object
    - if yes, give access to its private variable m
    - otherwise, throw a security exception

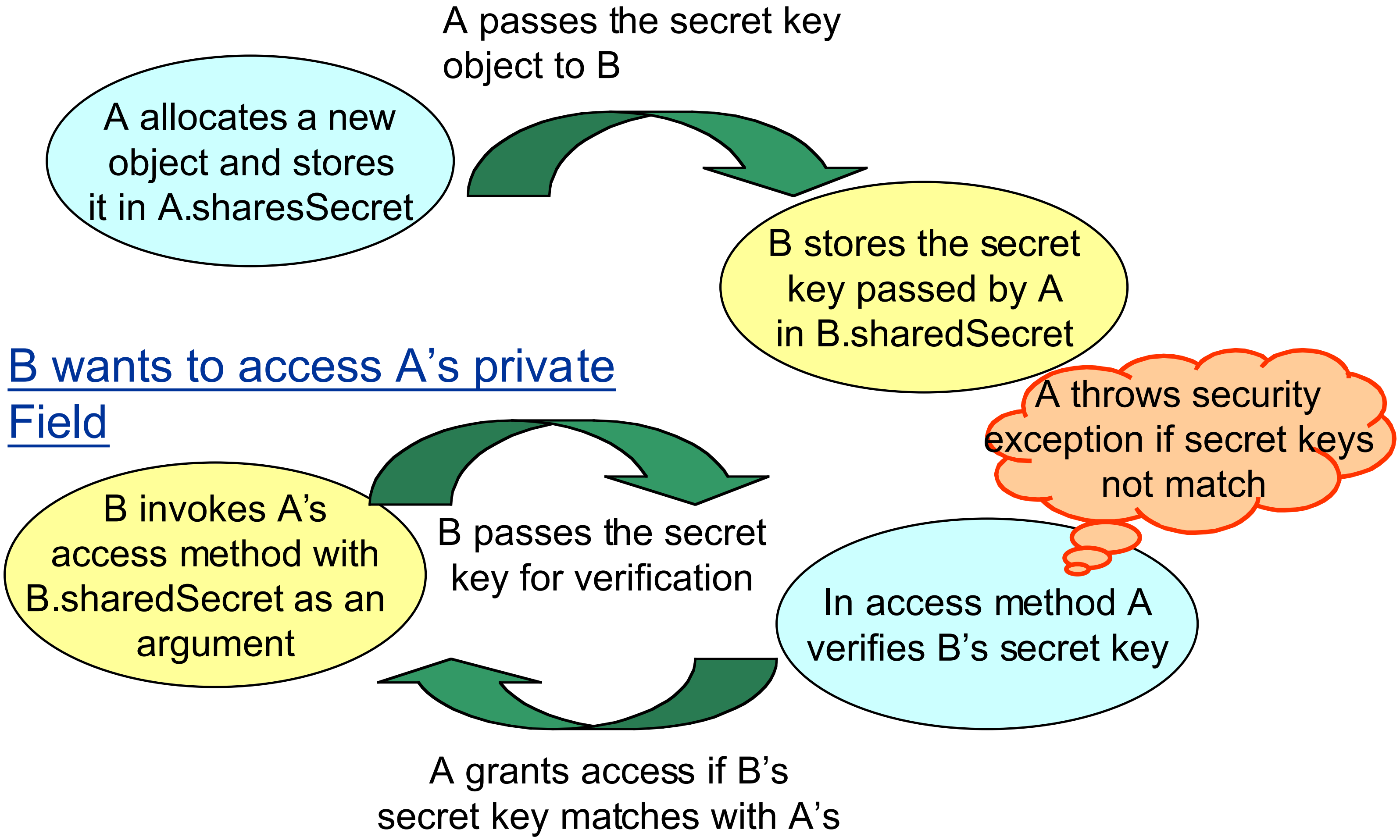
New Implementation of Inner Classes

- The *secret key* is an object allocated dynamically during run time.
- Class *A* allocates an object in its static initializer and stores it in its own private static field A.sharedSecret
- Class *A* passes down the secret key by invoking the receiveSecretKey(A.sharedSecret) of class B
- In receiveSecretKey(Object) *B* stores *A*'s secret key in it's own private static field, B.sharedSecret
- Whenever B tries to access A's private field it passes it's shared secret key for authentication

New Implementation of Inner Classes

Initialization Phase

B wants to access A’s private Field



A passes the secret key object to B

A allocates a new object and stores it in A.sharesSecret

B stores the secret key passed by A in B.sharedSecret

A throws security exception if secret keys not match

B invokes A’s access method with B.sharedSecret as an argument

B passes the secret key for verification

In access method A verifies B’s secret key

A grants access if B’s secret key matches with A’s

```
Class A {
    static private final Object sharedSecret = new Object();
    static {   A$B.receiveSecretForA(sharedSecret); }
    private int x;
    int access$1(Object secretForA) {
        if (secretForA !=sharedSecret) throw
                        new SecurityException();
        return x;
        }
    }
Class A$B {
    private A this$0;
    static private Object sharedSecret;
    static void receiveSecretForA(Object secretKey) {
        if (sharedSecret != null) throw new VerifyError();
         sharedSecret = secretKey;
        }
    … invoke this$0.access$1(sharedSecret)…
    }
```

Advantages of the New Implementation

- Access is permitted only to the desired classes
- No need to change the existing JVMs
- The secret key value is a pointer to memory, allocated dynamically
  - **Absolutely impossible to forge**
- The additional overhead for initialization and validation of the secret keys are small
- Very small increase in the size of the class files

Overhead Due to Modification

- For each class allowing/needing access
  - One static field
- For each set of objects needing mutual access
  - One object created
- All initializations are done in static initializer
- One additional argument in each *access$* method
- Few additional instructions are executed for each access call to
  - pass the extra argument
  - verify the secret key

A Rewriting Tool For Jar Files

- Developed a tool to transform the byte codes
- Takes a *jar* file, examines the class files and finds out the sets of classes which need mutual access
- modify all the class files which are either defining *access$* methods or invoking *access$* methods
- All the classes in the jar file are made safe in the presence of inner classes
- Used our tool to modify several *jar* files - rt.jar, swing.jar etc.

Experimental Result for swing.jar

Static Evaluation:

% increase in the code size - 2.9%

# of class files in swing.jar - 1498

# of inner classes - 898

# of inner classes needing access - 139

# of objects created - 53

# of new fields added - 195

# of access methods - 145

# of places access methods are invoked - 439

Experimental Result for swing.jar

Runtime Performance

For a trial run of SwingSet demo, which tests all the functionalities

Total number of calls to access$ functions - 46,638

Total user time - 59.44 sec

Total system time - 3.91 sec

Note: The user and system times are comparable when we run the demo with original *swing.jar* file. Although it is not possible to run the demo exactly the same way and compare precisely

Even Better Security

- Before A gives the secret to A$B
  - Check signatures on A$B imply the signatures on A
- Prevents situation where an attacker tries to combine a signed version of A with a modified (and unsigned) version of A$B

Conclusion

- Designed a new implementation for inner classes to fix the security hole of the current implementation
- Little additional overhead
  - regarding both code size and execution time
- Implemented a byte code rewriter to incorporate the changes by transforming the byte code
- Can be implemented in the compiler
- Can extend this idea to have friend classes like C++