Konzepte objektorientierter Programmierung

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Software Component Technology

Exercises 13: Mobile Code

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Remote Code Execution

- A client program should be able to send code to a remote server
- The server takes the code, executes it locally and returns the result to the client
- Hand-coded example where you see how the mechanism works

Package and Directory Layout

- Packages:
  - `common`: for client and server
  - `server`: server implementation
  - `client`: client implementation
- Directories:
  - The server only has access to the directories common and server
  - The client only has access to the directories common and client

Executable Interface

```
package common;

public interface Executable {
    Object run( Object param );
}
```

- Standardized interface for code that can be executed; takes one `Object` parameter and returns an `Object` as result
- This interface is not a remote interface!

ExeServer Interface

```
public interface ExeServer extends Remote {
  Object execute( String name, byte[] code,
      Object param ) throws RemoteException;
}
```

- The Remote interface for the server
- We transmit the class name and bytecode for the mobile code
- The method takes the parameter for the method
- The return value is the result of the code’s execution

ExeServer Implementation

```
package server;

public class ExeServerImpl
  extends UnicastRemoteObject
  implements ExeServer {

  public static void main( String[] args ) {
    try {
      Naming.rebind( "ExeServer",
                     new ExeServerImpl( ) );
    } catch( Exception ex ) {
      System.err.println("Binding failed!");
      ex.printStackTrace();
    }
  }
```

ExeServer Implementation – ClassLoader

```
private ServerClassLoader cl;

public ExeServerImpl()
   throws java.rmi.RemoteException {
  cl = new ServerClassLoader();
}
```

- We use our own ClassLoader to instantiate a class from the given bytecode

ExeServer Implementation – Execute

```
public Object execute( String name,
        byte[] code, Object param )
        throws RemoteException {
  cl.setBytecode( name, code );
  Executable exe = null;
  try {
    exe = (Executable)
          cl.loadClass(name).newInstance();
  } catch( Exception e ) {
    throw new RemoteException( “xxx!", e );
  }

  return exe.run( param );
}
```

ServerClassLoader Implementation

```
class ServerClassLoader extends ClassLoader {
  private Hashtable cache;

  public ServerClassLoader() {
    cache = new Hashtable();  }

  protected Class findClass(String name) {
    byte[] b = (byte[]) cache.get( name );
    return defineClass(name, b, 0, b.length);
  }

  public void setBytecode( String name,
    byte[] code ) { cache.put( name, code ); }
}
```

ExeClient Implementation

```
public static void main( String[] args ) {

  String url = "rmi://localhost/ExeServer";
  ExeServer es =
     (ExeServer) Naming.lookup(url);

  String cs_name = args[0];
  byte[] bytecode = getBytecode( cs_name );

  Object res = es.execute( cs_name, bytecode,
                           args[1] );

  System.out.println("Result: " + res );
}
```

ExeClient Implementation – getBytecode

```
public static byte[] getBytecode(String name){
  String cs_path = cs_name.replace('.', '/') +
                   ".class";

  FileInputStream fis = new FileInputStream(
                                     cs_path );
  byte[] buf = new byte[10000];
  int len = fis.read( buf );

  byte[] bytecode = new byte[ len ];
  System.arraycopy(buf, 0, bytecode, 0, len );

  return bytecode;
}
```

Example for Mobile Code

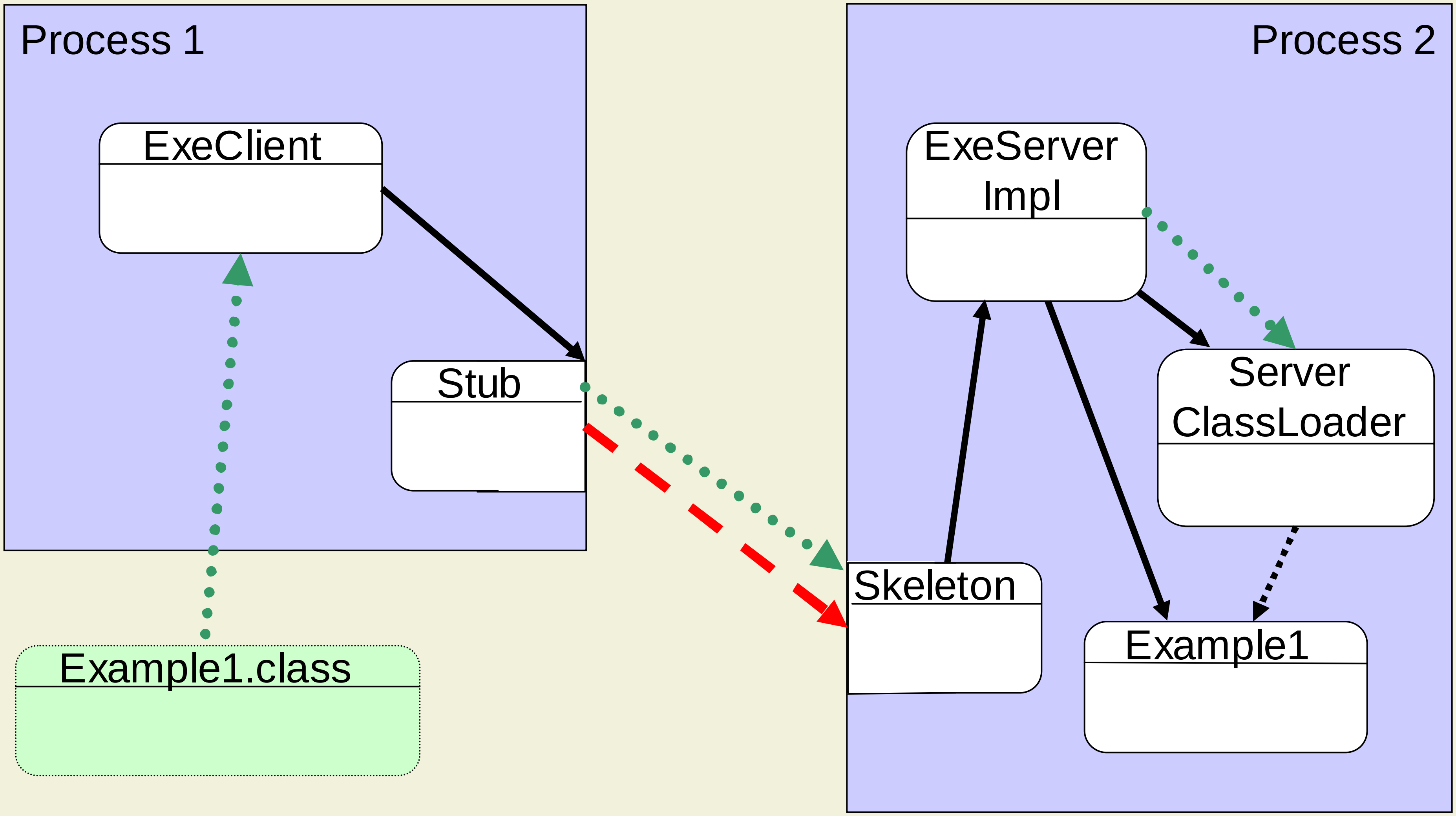
```
public class Example1 implements Executable {

  public Object run( Object param ) {
    int num=Integer.parseInt((String) param);

    return Integer.toHexString( num );
  }
}
```

- Not really an exciting example…

System Overview



Problems of this solution

- No sandbox for the mobile code, the code can do everything the server is allowed to do → security problem
- No object structures – just one class code is transferred. Usually the mobile code will be implemented by more than one object and we need to transfer the whole structure

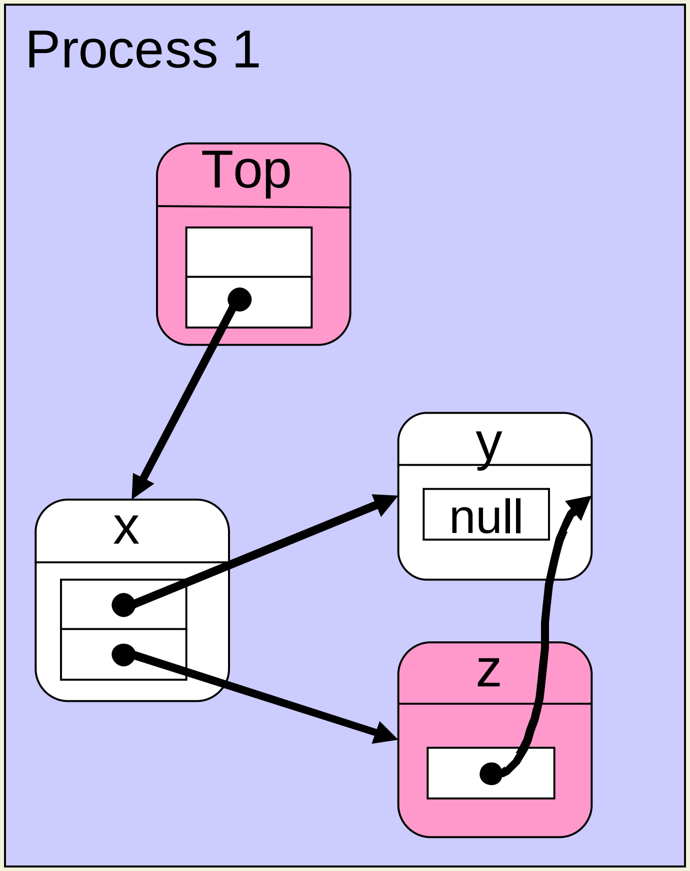
Better Java Solution

- Take a look at the Java Tutorial: `http://java.sun.com/docs/books/`… …`tutorial/rmi/example.html`
- Use an `RMISecurityManager` for safety
- Make the client code available remotely, e.g. via HTTP
- Use a policy file to allow the client and server to exchange bytecode and to restrict the actions of the mobile code
- System loads bytecode on demand whenever it needs the implementation of a class

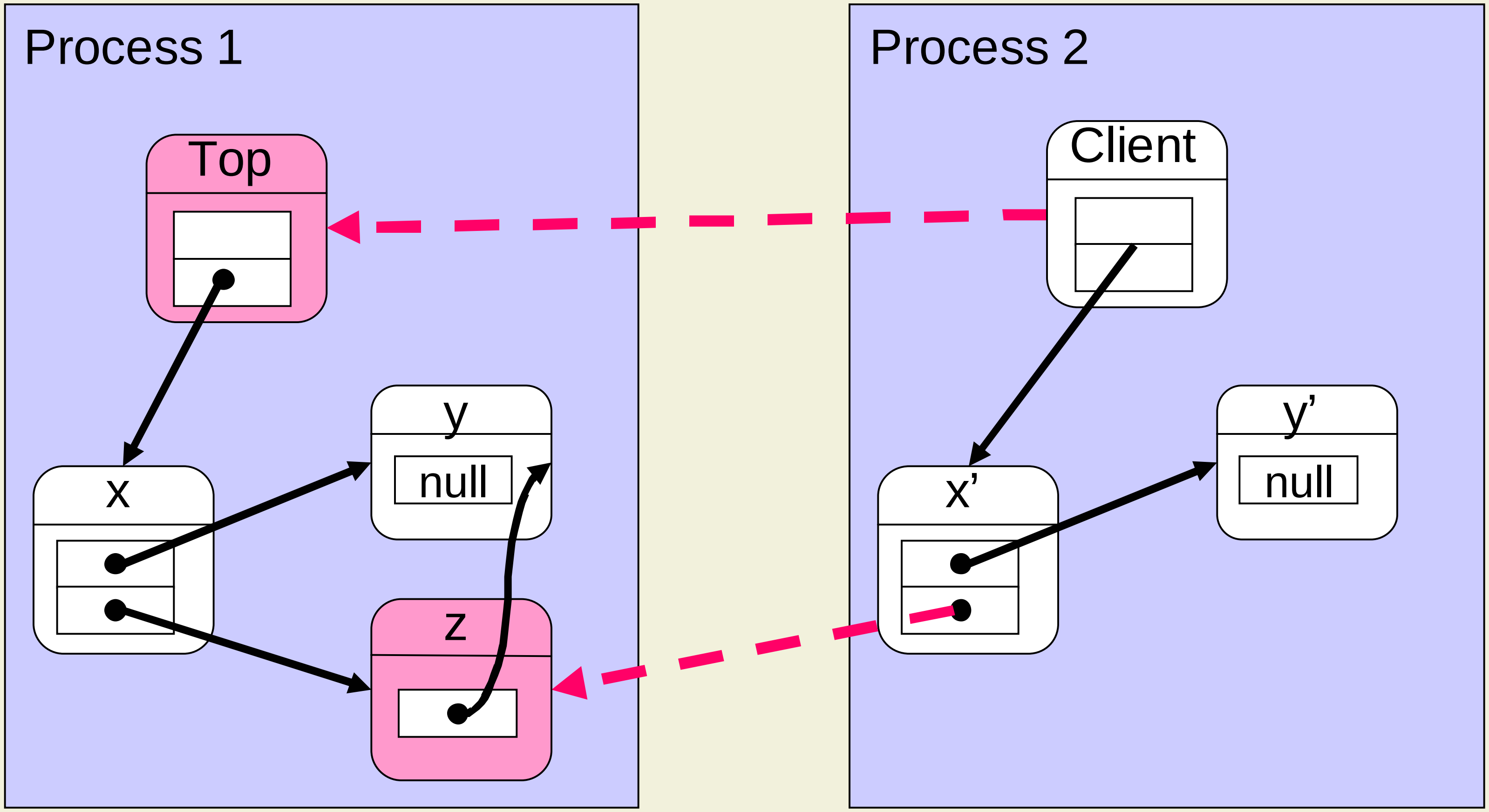
Consistency of Object Structures

- Client and Server that share an object structure
- The client modifies an object through one path
- And then reads the modified value through a different path
- The two values don’t match…
- Why?

Object Layout on the Server



Interaction with the Client



Top Interface and Server Main Method

```
public interface Top extends Remote {

   X getX() throws RemoteException;

}

public class Server {

   public static void main( String[] args ) {
      Top mytop = new TopImpl();
      Naming.rebind( "Top", mytop );
   }

}
```

Class X

```
public class X
  implements java.io.Serializable {
    private Y myy;
    private Z myz;

    public X( Y y, Z z ) { myy = y; myz = z; }

    public String getValue() {
       return myy.value; }

    public void setValue( String s ) {
       myy.value = s; }

    public Z getZ() { return myz; }
}
```

Class Y and Interface Z

```
public class Y
  implements java.io.Serializable {
    public String value;

    public Y( String v ) {
        value = v;
    }
}

public interface Z extends Remote {
   String getValue() throws RemoteException;
}
```

Implementation of Top

```
public class TopImpl extends
       UnicastRemoteObject implements Top {
  private X x;

  public TopImpl() throws RemoteException {
     Y y = new Y( "Y server initial" );
     Z z = new ZImpl( y );
     x = new X( y, z );
  }

  public X getX() throws RemoteException {
     return x;
  }
}
```

Z Implementation

```
public class ZImpl extends
       UnicastRemoteObject implements Z {
  private Y myy;

  public ZImpl( Y y )
         throws java.rmi.RemoteException {
     myy = y;
  }

  public String getValue()
         throws java.rmi.RemoteException {
     return myy.value;
  }
}
```

Client Setup

```
public class Client {
  public static void main( String[] args ) {
     String url = "rmi://gem/Top";

     Top t = null;
     X thex = null;

     try {
        t = (Top) Naming.lookup( url );
        thex = t.getX();
     } catch( Exception e ) {
        e.printStackTrace();
     }

...
```

Client Main Program

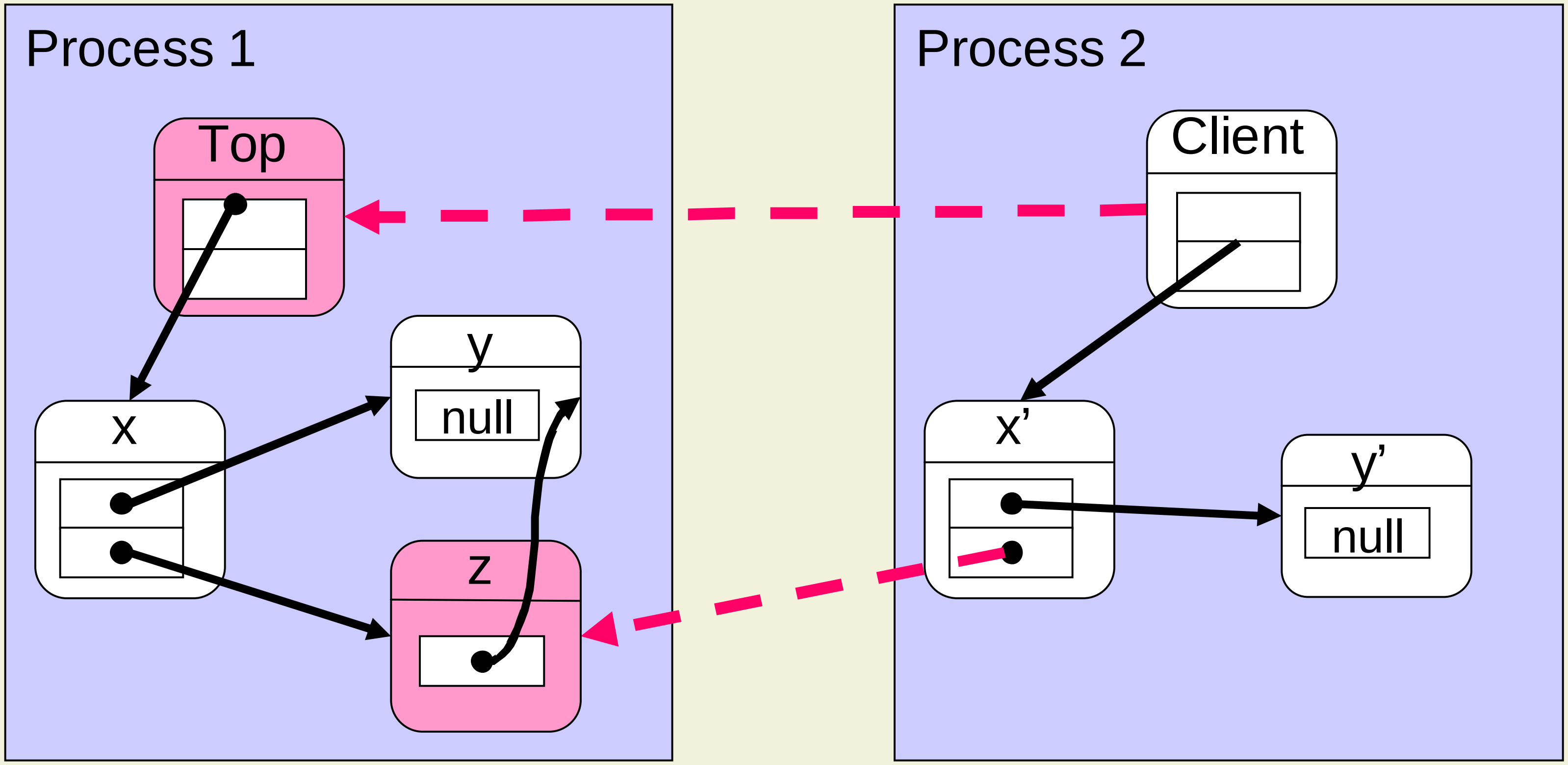
```
println("x.getY(): " + thex.getValue());
println("x.getZ().getY(): " +
  thex.getZ().getValue());

println("Calling x.setValue(...)... ");
thex.setValue("New Client Value!");

println("x.getY(): " + thex.getValue());
println("x.getZ().getY(): " +
  thex.getZ().getValue());
```

Interaction with the Client

`x.getY(): Y server initial`	**`x.getY(): New Client Value!`**
`x.getZ().getY(): Y server initial`	**`x.getZ().getY(): Y server initial`**

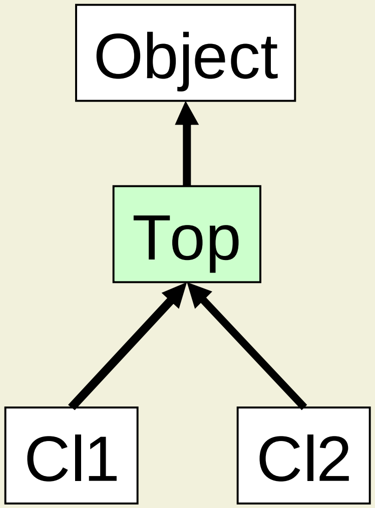


Bytecode Verification – Classes

```
abstract class Top {
  abstract void m();
}

class Cl1 extends Top {
  public void m() {
     System.out.println("Cl1.m"); }
}

class Cl2 extends Top {
  public void m() {
     System.out.println("Cl2.m"); }
}
```



Example Program

```
public class Test3 {
  public static void main( String[] args ) {
     xxx(true);
     xxx(false);
  }

  public static void xxx( boolean param ) {
     Top t = null;

     if( param ) {  t = new Cl1();  }
     else {         t = new Cl2();  }

     t.m();
  }
}
```

The Generated Bytecode

```
@signature "(Z)V"
public static void
xxx(boolean) {
  @line   24
      @aconst_null
      @astore     1
  @line   26  // if
      @iload      0
      @ifeq       _L9
  @line   27  //
      @new
      @dup
      @invokespecial
        void Cl1.<init>()
      @astore     1
      @goto       _L13
```

```
 @line   29  // else
 _L9: @new       Cl2
      @dup
      @invokespecial
        void Cl2.<init>()
      @astore    1

 @line   32  // call
_L13: @aload    1

      @invokevirtual
         void Top.m()

 @line   33
      @return
}
```

SCS determines Top as type

allowed

The Modified Bytecode

```
@signature "(Z)V"
public static void
xxx(boolean) {
  @line   24
      @aconst_null
      @astore     1
  @line   26  // if
      @iload      0
      @ifeq       _L9
  @line   27  // then
      @new        Cl1
      @dup
      @invokespecial
        void Cl1.<init>()
      @astore     1
      @goto       _L13
```

```
 @line   29  // else
_L9: @new java.lang.String
     @dup
     @invokespecial
 void
 java.lang.String.<init>()
     @astore    1

 @line   32  // call
_L13: @aload    1

     @invokevirtual
        void Top.m()

 @line   33
     @return
}
```

Explanation

- The SCS finds that register 1 in line _L13 has type Object
- Therefore the call to method m() is not allowed and already rejected by the bytecode verifier:

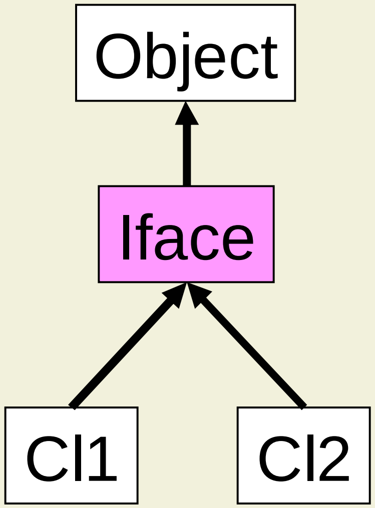
```
Exception in thread "main"
  java.lang.VerifyError: (class: Test3,
  method: xxx signature: (Z)V)
  Incompatible object argument for
  function call
```

Bytecode Verification – Interfaces

```
interface Iface {
  void m();
}

class Cl1 implements Iface {
  public void m() {
    System.out.println("Cl1.m"); }
}

class Cl2 implements Iface {
  public void m() {
    System.out.println("Cl2.m"); }
}
```



Example Program

```
public class Test1 {
  public static void main( String[] args ) {
     xxx(true);
     xxx(false);
  }

  public static void xxx( boolean param ) {
     Iface iface = null;

     if( param ) {   iface = new Cl1(); }
     else {          iface = new Cl2(); }

     iface.m();
  }
}
```

The Generated Bytecode

```
@signature "(Z)V"
public static void
xxx(boolean) {
  @line   24
      @aconst_null
      @astore     1
  @line   26  // if
      @iload      0
      @ifeq       _L9
  @line   27  // then
      @new        Cl1
      @dup
      @invokespecial
        void Cl1.<init>()
      @astore     1
      @goto       _L13
```

```
 @line   29  // else
 _L9: @new       Cl2
      @dup
      @invokespecial
        void Cl2.<init>()
      @astore    1

 @line   32  // call
_L13: @aload    1

      @invokeinterface
         void Iface.m() 1

 @line   33
      @return
}
```

Explanation

- The SCS for register 1 after the end of the `if`-statement (`_L13`) is Object
- At execution the system checks whether the actual object has the correct method
- The compiler makes sure that that is the case
- What happens if we manually modify the bytecode?

The Modified Bytecode

```
@signature "(Z)V"
public static void
xxx(boolean) {
  @line   24
      @aconst_null
      @astore     1
  @line   26  // if
      @iload      0
      @ifeq       _L9
  @line   27  // then
      @new        Cl1
      @dup
      @invokespecial
        void Cl1.<init>()
      @astore     1
      @goto       _L13
```

```
@line   29  // else
_L9: @new java.lang.String
     @dup
     @invokespecial
  void
  java.lang.String.<init>()
      @astore    1

 @line   32  // call
_L13: @aload    1

      @invokeinterface
         void Iface.m() 1

 @line   33
      @return
}
```

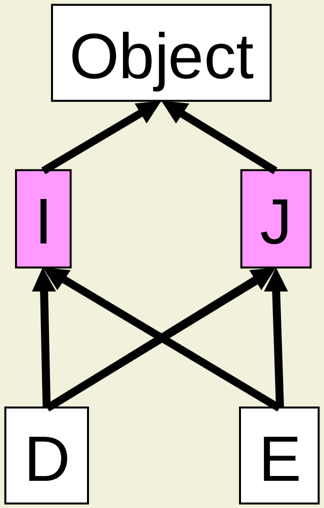
Program Output and Explanation

```
Cl1.m
Exception in thread "main"
  java.lang.IncompatibleClassChangeError
  at Test2.xxx(Test2.java:32)
  at Test2.main(Test2.java:20)
```

- The Bytecode-Verifier did not find the problem
- Only when the actual method call was executed did the virtual machine notice the problem
- Type safety limited

Handling Multiple Subtyping

- With multiple subtyping, **several smallest common supertypes** may exist
- JDK solution
  - Ignore interfaces
  - Treat all interface types as Object
  - Works because of single inheritance of classes
- Problem
  - **invokeinterface** I.m cannot check whether target object implements I
  - Runtime check is necessary



Exercise 3

```
class Example2 {
  void m(Object arg) {
    Object local;
    local = “Hello”;
    local.concat(“ World!”);
    arg.concat(“Ohh!”);
    …
  }
}
```

```
void m(java.lang.String);
   0:   ldc  #2; // String Hello
   2:   astore_2
   3:   aload_2
   4:   ldc  #3; // String  World!
   6:   invokevirtual  #4;
   // Method String.concat:(LString;)LString;
   9:   pop
   10:  aload_1
   11:  ldc  #5; // String Ohh!
   13:  invokevirtual  #4;
   // Method String.concat:(LString;)LString;
   16:  pop
   17:  return
}
```

How did you do this?

- The `javap` class file disassembler produces human-readable output, but it can not be assembled again
- For the examples I used the tools `dis` and `ksm` from the kopi compiler suite, available from:

  `http://www.kopiright.com/kopi_projekt.php`

- Great learning experience to look at the bytecode and play around with it

Questions?