Homework 3 Challenge Writeup

Reverse Engineering Part 3

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Table of Contents

Challenge Details

Hand Rolled Cryptex

Overview

Hand Rolled Cyptex		
1o0 Points	Flag Value	flag{str1PP3d_B1N4R135_r_S0o0_much_FUN_408012}
	Location	nc offsec-chalbroker.osiris.cyber.nyu.edu 7332
	Lore	Dan Brown Multiverse

Details

The hand_rolled_cryptex program asks for two input values at the beginning. Entering an incorrect value will cause the program to stop.

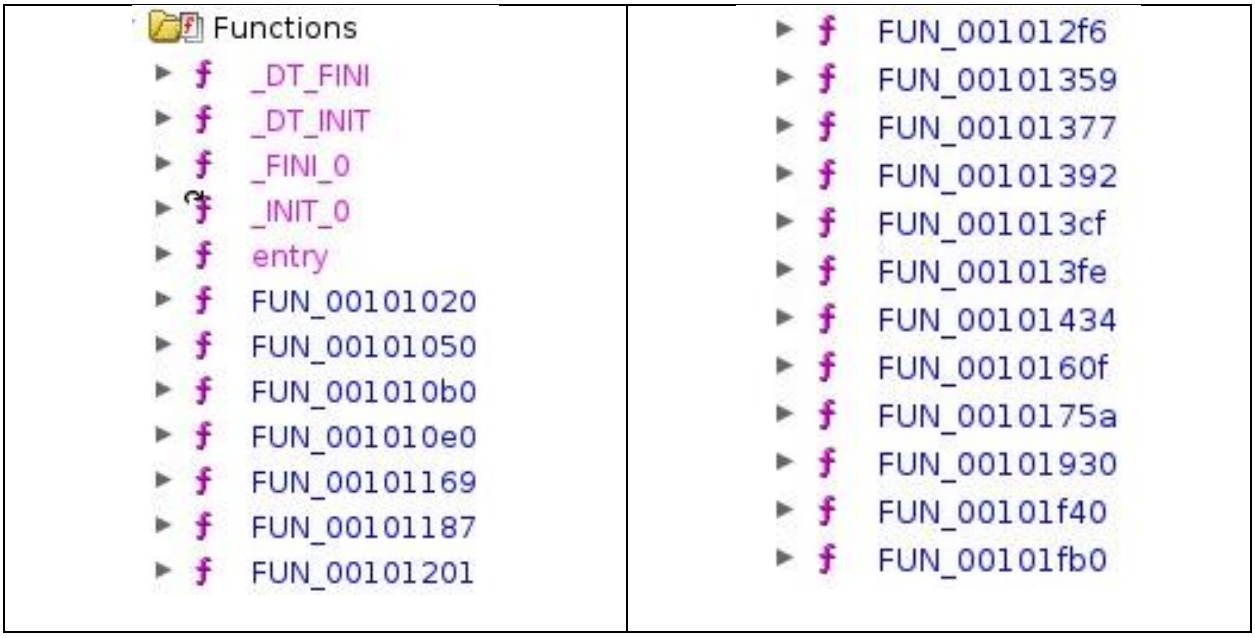
```
./hand_rolled_cryptex
I found this weird cryptex...
...it seems to take some weird series of operations...
...but all the symbols are obscured...
...could you crack it for me??

The first round requires two inputs...
 > 13
 > 22

Oh no! That input broke the vial of vinegar, ruining
the papyrus scroll with the flag!
```

First Run

Looking at the program in Ghidra reveals that the binary has been stripped. There are no function names.



Function Names in Ghidra

However, BinaryNinja was able to infer where the main method began.

```
setvbuf
_start
deregister_tm_clones
sub_10e0
__do_global_dtors_aux
frame_dummy
sub_1169
sub_1187
sub_1201
sub_12f6
sub_1359
sub_1377
sub_1392
sub_13cf
sub_13fe
sub_1434
sub_160f
sub_175a
main
```

Function Names in Binary Ninja

The main method, disassembled using BinaryNinja, is shown below.

```
__builtin_strncpy(&var_1b8, "I found this weird cryptex...\n", 0x1f)
sub_1169(1, &var_1b8, sub_13fe(&var_1b8))
int64_t var_108
__builtin_strcpy(&var_108, "...it seems to take some weird series of operations...\n")
sub_1169(1, &var_108, sub_13fe(&var_108))
int64_t var_138
__builtin_strcpy(&var_138, "...but all the symbols are obscured...\n")
sub_1169(1, &var_138, sub_13fe(&var_138))
int64_t var_198
__builtin_strncpy(&var_198, "...could you crack it for me??\n\n", 0x21)
sub_1169(1, &var_198, sub_13fe(&var_198))
int32_t var_1bc = 0
int32_t rax_6 = sub_1434()
int32_t var_1c4
int64_t var_c8
if (rax_6 s>= 0)
    var_1c4 = sub_160f()
    if (var_1c4 s>= 0)
        int32_t rax_10 = sub_175a()
        if (var_1c4 s>= 0)
            __builtin_strcpy(&var_c8, "\nThe final chamber opened, but a flaw in the design\npopped a vinegar
            sub_1169(1, &var_c8, sub_13fe(&var_c8))
            sub_1169(rax_10, &data_4140, sub_13fe(&data_4140))
if ((rax_6 s>= 0 && var_1c4 s>= 0 && var_1c4 s< 0) || rax_6 s< 0 || (rax_6 s>= 0 && var_1c4 s< 0))
    __builtin_strncpy(&var_c8, "\nOh no! That input broke the vial of vinegar, ruining\n", 0x37)
    int64_t var_168
    __builtin_strncpy(&var_168, "the papyrus scroll with the flag!\n", 0x23)
    sub_1169(1, &var_c8, sub_13fe(&var_c8))
    sub_1169(1, &var_168, sub_13fe(&var_168))
if (rax == *(fsbase + 0x28))
    return 0
```

Main Method

Each if statement highlighted in red corresponds with a different question function. If any of the functions return a value less than 0, the program will not output the flag.

Debugging

Even though there are no symbols in the binary, we can see that it calls __libc_start_main by using strings.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ strings hand_rolled_cryptex
/lib64/ld-linux-x86-64.so.2
sKkTGT2"/
mgUa
libc.so.6
__stack_chk_fail
stdin
stdout
__cxa_finalize
setvbuf
__libc_start_main
GLIBC_2.4
GLIBC_2.2.5
_ITM_deregisterTMCloneTable
__gmon_start__
```

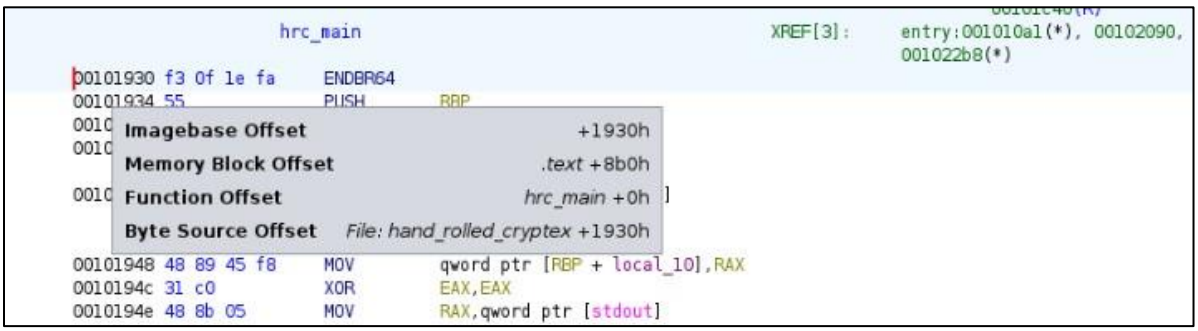
__libc_start_main

The call to __libc_start_main passes the location of the main method as the first parameter in the call. The call is visible in entry and includes the location of the main method.

```
void processEntry entry(undefined8 param_1,undefined8 param_2)
{
  undefined auStack_8 [8];
__libc_start_main(FUN_00101930,param_2,&stack0x00000008,FUN_00101f40,FUN_00101fb0,p
aram_1, auStack_8);
  do {
    /* WARNING: Do nothing block with infinite loop */
  } while( true );
}
```

Entry

This information makes it easy to find the main method in Ghidra and is also valuable for finding memory locations for dynamic analysis.



Main Method Offset

After running the program, find the memory address of the entry point.

```
gdb ./hand_rolled_cryptex
...omitted for brevity...
Oh no! That input broke the vial of vinegar, ruining
the papyrus scroll with the flag!
[Inferior 1 (process 3736152) exited normally]
(gdb) info file
Symbols from "/home/kali/Desktop/3-Week/hand_rolled_cryptex".
Local exec file:
        `/home/kali/Desktop/3-Week/hand_rolled_cryptex', file type elf64-x86-64.
        Entry point: 0x555555555080
```

Entry Address

Then, set a breakpoint at the entry address and look at the process map to find the start address.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ gdb ./hand_rolled_cryptex
(gdb) break *0x555555555080
...omitted for brevity...
Breakpoint 1, 0x0000555555555080 in ?? ()
(gdb) info proc map
process 100090
Mapped address spaces:

          Start Addr           End Addr       Size     Offset  Perms  objfile
      0x555555554000     0x555555555000     0x1000        0x0  r--p
```

Start Address

The location of the main method is equal to the Start Address increased by the Byte Source Offset.

```
[Start Address] + [Main Method Offst]
555555554000 + 1930 = 5555555559300x0  r--p
```

Main Method Math

Question 1

The first question takes in two pieces of user-entered data and then opens a file specified in the first user-entered string.

```
undefined4 Question1(void)

{
  undefined4 uVar1;
  int iVar2;
  long local_10;

  // Print question 1 message and store answer
  uVar1 = get_Length(&local_48);
  hrc_write(1,&local_48,uVar1);
  iVar2 = hrc_read(0,&readData,0x100);
  if (iVar2 == 0) {
    uVar1 = 0xffffffff;
  }
  else {
    if ((&readData)[iVar2 - 1] == '\n') {
      (&readData)[iVar2 - 1] = 0;
    }
    hrc_copy(&storedData,&readData,0x20);
    hrc_overwrite(&readDat,0,0x100);
    local_4d = 0x203e200a;
    local_49 = 0;
    // Print ">" for next answer
    uVar1 = get_Length(&local_4d);
    hrc_write(1,&local_4d,uVar1);
    iVar2 = hrc_read(0,&DAT_00104040,0x100);
    if (iVar2 == 0) {
      uVar1 = 0xffffffff;
    }
    else {
      iVar2 = FUN_001013cf((int)DAT_00104040);
      if (iVar2 == -1) {
        uVar1 = 0xffffffff;
      }
      else {
          // Print question 1 message and store answer
        DAT_00104010 = hrc_open(&DAT_00104240,iVar2);
        hrc_overwrite(&DAT_00104240,0,0x20);
        hrc_overwrite(&DAT_00104040,0,0x100);
        uVar1 = DAT_00104010;
      }
    }
  }
```

Question 1

While the first parameter must point to a valid filename, at this point in the reverse engineering process, it seems that the second parameter is just a number.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ echo "testtesttest" > test.txt
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ gdb ./hand_rolled_cryptex
(gdb) r
Starting program: /home/kali/Desktop/3-Week/hand_rolled_cryptex
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
I found this weird cryptex...
...it seems to take some weird series of operations...
...but all the symbols are obscured...
...could you crack it for me??

The first round requires two inputs...
 > ./test.txt

 > 13
*The first chamber opened! Ok, the second phase requires a single input...
```

Question 1 Success

Question 2

Question two takes in one number before performing operations.

```
uint64_t sub_160f()

void* fsbase
int64_t rax = *(fsbase + 0x28)
int64_t var_68
__builtin_strncpy(&var_68, "*The first chamber opened! Ok, the second phase requires a single input...\n > ", 0x4f)
sub_1169(1, &var_68, sub_13fe(&var_68))
uint64_t rax_3
if (sub_1359(0, &data_4040, 0x100) != 0)
    int32_t rax_8 = sub_1359(not.b(data_4040) ^ 0xc9, &data_4140, 0x100)
    sub_1392(&data_4040, 0, 0x100)
    rax_3 = rax_8
else
    rax_3 = 0xffffffff
if (rax == *(fsbase + 0x28))
    return rax_3
__stack_chk_fail()
noreturn
```

Question 2

The function reads in a number and then performs bitwise arithmetic before using the final value as the file descriptor in a read call.

```
iVar2 = hrc_read(0,&DAT_00104040,0x100);
// ...omitted for brevity...
else {
      uVar1 = hrc_read(~DAT_00104040 ^ 0xc9,&DAT_00104140,0x100);
      hrc_overwrite(&DAT_00104040,0,0x100);
}
```

Main Functionality

In previous read operations, the file descriptor value was 0. The below solver found the correct input for a result of 0:

```
def question2():
      s = Solver()
      a = BitVec('a',4)
      s.add(~(a) ^ 0xc9 == 0)
      print(s.check())
      print(s.model())

>> sat
>> [a = 6]
```

Solver

However, the answer was not correct. After further testing, I set a breakpoint after the call to Question1 to see what value was returned.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ gdb ./hand_rolled_cryptex
(gdb) break *0x555555555C08
...omitted for brevity...
The first round requires two inputs...
 > ./test.txt
 > 13
Breakpoint 2, 0x0000555555555c08 in ?? ()
(gdb) info registers rax
rax            0x3                 3
```

Registers

After rerunning the solver with a target value of 3, I discovered that an input value of 5 was correct, but only if the second input from Question1 was 0.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ gdb ./hand_rolled_cryptex
(gdb) r
I found this weird cryptex...
...it seems to take some weird series of operations...
...but all the symbols are obscured...
...could you crack it for me??

The first round requires two inputs...
 > ./flag.txt
 > 0
*The first chamber opened! Ok, the second phase requires a single input...
 > 5
Nice, the second chamber opened! Ok, the final level requires another single
input...3
```

Question 2 Success

Question 3

On the first attempt, it looked like I had the third question almost correct.

```
Nice, the second chamber opened! Ok, the final level requires another single
input...
 > 13

The final chamber opened, but a flaw in the design
popped a vinegar vial which started to eat away at the papyrus
scroll inside. You hold it up, trying to decipher the text... [Inferior 1 (process
107790) exited normally]
```

Attempt

In the program main method, it appears that the function tries to print the flag value after the message.

```
int32_t rax_6 = sub_1434()
int32_t var_1c4
int64_t var_c8
if (rax_6 s>= 0)
    var_1c4 = sub_160f()
    if (var_1c4 s>= 0)
        int32_t rax_10 = sub_175a()
        if (var_1c4 s>= 0)
            __builtin_strcpy(&var_c8, "\nThe final chamber opened, but
            sub_1169(1, &var_c8, sub_13fe(&var_c8))
            sub_1169(rax_10, &data_4140, sub_13fe(&data_4140))
```

Main Method

The value highlighted in green is the address of the filename saved during the first question.

```
else
    int32_t rax_13 = sub_13cf(data_4040)
    if (rax_13 != 0xffffffff)
        data_4010 = sub_1377(&data_4240, rax_13)
        sub_1392(&data_4240, 0, 0x20)
        sub_1392(&data_4040, 0, 0x100)
        rax_3 = data_4010
    else
        rax_3 = 0xffffffff
```

Question 1

Question3 makes some checks based on the input. If the value is less than - or equal to 1, the return value is set to 01.

```
guess_Q3 = (int)DAT_00104040;
if (guess_Q3 == 1) {
  uVar1 = 0xffffffff;
}
else if (guess_Q3 < 0) {
  uVar1 = 0xffffffff;
}
```

Check 1

If the value is equal to 2, the program sets the return value to the ASCII value of the first character in the entered text.

```
if (guess_Q3 == 2) {
       local_90 = get_Length(&guess_Q3);
       uVar1 = local_90;
} else {
```

Check 2

It appeared that an entered value of 2 would be correct, but when looking at the registers during the comparison, it appears that the EAX register contains 32, the ASCII value of 2, instead of the integer itself.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ gdb ./hand_rolled_cryptex
(gdb) break *0x55555555586d
Breakpoint 1 at 0x55555555586d
...omitted for brevity...
Nice, the second chamber opened! Ok, the final level requires another single
input...
 > 2
Breakpoint 1, 0x000055555555586d in ?? ()
(gdb) info registers eax
eax            0x32               50
...omitted for brevity...
[Inferior 1 (process 354433) exited normally]

(gdb) r
...omitted for brevity...
Nice, the second chamber opened! Ok, the final level requires another single
input...
 > 1234
Breakpoint 1, 0x000055555555586d in ?? ()
(gdb) info registers eax
eax            0x31               49
```

Registers

The below script fuzzes the Question3 input to determine which encoding of 2 was correct. The runFuzz function sets up a breakpoint and then loops through a list of potential encodings. The complete code for HRC_Local_Debug.py is available in Appendix C.

```
def runFuzz(p):
	fuzz =
['2','32','02','032','002','0032','%2','%32','%02','%032','x2','x32','x02','#x32','
&#x32','\2','\32','\02','\\x2','\x32','\x02','0x2','0x32','0x02','\0x2','\0x32','\0
x02']
	log = open("HRC_Q3_dbg.txt", "a")
	log.write("Hand Rolled Cryptex Q3 Debug Log:" + "\n")
	p.sendline('break *0x55555555586d')
	flag = -1
	i = 0
	for guess in fuzz:
		p.sendline('r')
		question1(p)
		question2(p)
		q3 = FuzzQ3(p, guess)
		p.sendline('c')
		reg = re.split("\s+", q3)
		if(reg[3] == '2'):
			print("Correct Answer Found")
			log.write("Valid Answer!\n")
			log.write("Guess at index " + str(i) + "= "+ guess + "\n" + q3)
			p.recvuntil(b'flag')
			flag = cleanLine(p.recvline())
		else:
			p.recvuntil("(gdb)")
		i += 1
	return flag

def main():
	# Start gdb session
	p =  process('/bin/bash')
	p.sendline('gdb ./hand_rolled_cryptex -q')
	print(runFuzz(p))49
```

runFuzz

With each new guess, it runs hand_rolled_cryptex and sends the correct answers until Question3. For the third question, the script calls the FuzzQ3 function to send the guess.

```
def FuzzQ3(p, ans):
	p.recvuntil(b'>')
	p.sendline(ans.encode())
	p.recvuntil("Breakpoint")
	p.recvline()
	p.sendline("info registers eax")
	return(cleanLine(p.recvline()))
```

FuzzQ3

The runFuzz function checks the EAX value. If it is equal to 2, the guess is correct. In that case, the runFuzz function logs the answer and saves the flag value. Otherwise, the function waits for the program to end before running again.

When run against a local instance of hand_rolled_cryptex, the debugging script produces three correct answers and prints the value stored in flag.txt.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ python3 HRC_Local_Debug.py
[+] Starting local process '/bin/bash': pid 313099
Correct Answer Found
Correct Answer Found
Correct Answer Found
{This is not a real flag}
[*] Stopped process '/bin/bash' (pid 313099)

┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ cat HRC_Q3_dbg.txt
Hand Rolled Cryptex Q3 Debug Log:
Valid Answer!
Hand Rolled Cryptex Q3 Debug Log:
Valid Answer!
Guess at index 15=
(gdb) eax            0x2                 2
Valid Answer!
Guess at index 17=
(gdb) eax            0x2                 2
Valid Answer!
Guess at index 20=
(gdb) eax            0x2                 2
```

Output

The correct values are shown below:

```
'\2', '\02', '\x02'
```

Values

Solution

I created a new solver script for the remote challenge. Each question function sends its respective answer, and question3 waits for the flag data. The complete code for HRC_Remote.py is available in Appendix D.

```
def question1(p):
      p.recvuntil(b'>')
      ans = "./flag.txt"
      p.sendline(ans.encode())
      p.recvuntil(b'>')
      ans = "0"
      p.sendline(ans.encode())
      return(cleanLine(p.recvline()))

def question2(p):
      p.recvuntil(b'>')
      ans = "5"
      p.sendline(ans.encode())
      return(cleanLine(p.recvline()))

def question3(p):
      p.recvuntil(b'>')
      ans = "\x02"
      p.sendline(ans.encode())
      p.recvuntil(b'flag')
      return(cleanLine(p.recvline()))
```

Script

When run, the script successfully retrieves the hand_rolled_cryptex flag from the remote server.

```
┌──(kali㉿kali)-[~/Desktop/3-Week]
└─$ python3 HRC_Remote.py
[+] Opening connection to offsec-chalbroker.osiris.cyber.nyu.edu on port 7332: Done
b'I found this weird cryptex...\n'
 *The first chamber opened! Ok, the second phase requires a single input...
 Nice, the second chamber opened! Ok, the final level requires another single
input...
{str1PP3d_B1N4R135_r_S0o0_much_FUN_408012}
[*] Closed connection to offsec-chalbroker.osiris.cyber.nyu.edu port 7332
```

Success

Appendix A: Student Information

Lindsay Von Tish	
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Appendix B: Tools

Name	URL
EDB	https://www.kali.org/tools/edb-debugger/
GDB	https://www.gnu.org/software/gdb/gdb.html
Ghidra	https://ghidra-sre.org/
Netcat	https://netcat.sourceforge.net/
PwnTools	https://github.com/Gallopsled/pwntools

Appendix C: HRC_Local_Debug.py

```
from pwn import *
import re

#################################################################
#      HRC_Local_Debug.py
       #
#      Lindsay Von Tish (lmv9443@nyu.edu)                                    #
#      Reverse Engineering 3: Hand Rolled Cryptex                        #
#      02/21/2024
              #
#################################################################

# A function to convert encoded input to a string and remove text format characters
#      Input: Encoded string
#      Output: Unencoded string
def cleanLine(ln):
       ansi_escape = re.compile(r'\x1B(?:[@-Z\\-_]|\[[0-?]*[ -/]*[@-~])')
       l = ansi_escape.sub('', str(ln, encoding='utf-8'))
       return l

# A function to send the answer to question 1
#      Input: Connection
#      Output: Response
def question1(p):
       p.recvuntil(b'>')
       ans = "./flag.txt"
       p.sendline(ans.encode())
       p.recvuntil(b'>')
       ans = "0"
       p.sendline(ans.encode())
       return(cleanLine(p.recvline()))

# A function to send a the answer to question 2
#      Input: Connection
#      Output: Response
def question2(p):
       p.recvuntil(b'>')
       ans = "5"
       p.sendline(ans.encode())
       return(cleanLine(p.recvline()))

# A function to send a string to question 3 and get register information
#      Input: Connection, potential answer string
#      Output: String containing register data
def FuzzQ3(p, ans):
       p.recvuntil(b'>')
       p.sendline(ans.encode())
       p.recvuntil("Breakpoint")
       p.recvline()
       p.sendline("info registers eax")
       return(cleanLine(p.recvline()))

# A function to solve question 3
```

```
#     Input: Connection
#     Output: N/A
def runFuzz(p):
      fuzz =
['2','32','02','032','002','0032','%2','%32','%02','%032','x2','x32','x02','#x32','
&#x32','\2','\32','\02','\\x2','\x32','\x02','0x2','0x32','0x02','\0x2','\0x32','\0
x02']
      log = open("HRC_Q3_dbg.txt", "a")
      log.write("Hand Rolled Cryptex Q3 Debug Log:" + "\n")
      p.sendline('break *0x55555555586d')
      flag = -1
      i = 0
      for guess in fuzz:
            p.sendline('r')
            question1(p)
            question2(p)
            q3 = FuzzQ3(p, guess)
            p.sendline('c')
            reg = re.split("\s+", q3)
            if(reg[3] == '2'):
                  print("Correct Answer Found")
                  log.write("Valid Answer!\n")
                  log.write("Guess at index " + str(i) + "= "+ guess + "\n" + q3)
                  p.recvuntil(b'flag')
                  flag = cleanLine(p.recvline())
            else:
                  p.recvuntil("(gdb)")
            i += 1
      return flag

# A function to send a the answer to question 3
#     Input: Connection
#     Output: Response
def question3(p):
      p.recvuntil(b'>')
      ans = "\x02"
      p.sendline(ans.encode())
      p.recvuntil(b'flag')
      return(cleanLine(p.recvline()))

# A function to solve question 3
#     Input: Connection
#     Output: N/A
def runSolve(p):
      p.sendline('r')
      #print(p.recvline())
      print(question1(p))
      print(question2(p))
      print(question3(p))
      # Close remote session
      p.close()
      return 0

def main():
```

```
        # Start gdb session
        p =  process('/bin/bash')
        p.sendline('gdb ./hand_rolled_cryptex -q')

        # Uncomment for if solving or debugging
        #runSolve(p)
        print(runFuzz(p))


if __name__=="__main__":
        main()
```

Appendix D: HRC_Remote.py

```
from pwn import *
import re

#################################################################
#      HRC_Remote.py
       #
#      Lindsay Von Tish (lmv9443@nyu.edu)                                    #
#      Reverse Engineering 3: Hand Rolled Cryptex                          #
#      02/21/2024
              #
#################################################################

# Host and port for the remote challenge
HOST = 'offsec-chalbroker.osiris.cyber.nyu.edu'
PORT = 7332

# A function to convert encoded input to a string and remove text format characters
#      Input: Encoded string
#      Output: Unencoded string
def cleanLine(ln):
       ansi_escape = re.compile(r'\x1B(?:[@-Z\\-_]|\[[0-?]*[ -/]*[@-~])')
       l = ansi_escape.sub('', str(ln, encoding='utf-8'))
       return l

# A function to send the answer to question 1
#      Input: Connection
#      Output: Response
def question1(p):
       p.recvuntil(b'>')
       ans = "./flag.txt"
       p.sendline(ans.encode())
       p.recvuntil(b'>')
       ans = "0"
       p.sendline(ans.encode())
       return(cleanLine(p.recvline()))

# A function to send a the answer to question 2
#      Input: Connection
#      Output: Response
def question2(p):
       p.recvuntil(b'>')
       ans = "5"
       p.sendline(ans.encode())
       return(cleanLine(p.recvline()))

# A function to send a the answer to question 3
#      Input: Connection
#      Output: Response
def question3(p):
       p.recvuntil(b'>')
       ans = "\x02"
       p.sendline(ans.encode())
       p.recvuntil(b'flag')
```

```
	return(cleanLine(p.recvline()))


def main():
	# Start remote session
	p = remote(HOST, PORT)
	print(p.recvline())
	print(question1(p))
	print(question2(p))
	print(question3(p))
	# Close remote session
	p.close()

if __name__=="__main__":
	main()
```