Lab 6: Program Security Detect

Software Testing 2022

2022/04/14

Valgrind & Sanitizer

Valgrind

- 在 user space 層級對程式進行動態分析的框架
- 有多種工具能追蹤和分析程式效能
- EX: 偵測記憶體錯誤
  - 未初始化的記憶體
  - 不當的記憶體配置
  - 記憶體越界存取
- $ valgrind --tool=<toolname> <program>
- 注意：使用 Valgrind 會讓程式執行速度比平常更慢

動態分析 dynamic Binary Instrumentation

- Valgrind 透過 shadow values 技術來實作

- 對所有的 register 和使用到的 memory 做 shadow（自行維護的副本）
  - shadow State
  - shadow registers
  - shadow memory
  - read / write

Valgrind 實做方法

- 透過 動態重新編譯（dynamic binary re-compilation）的方法把測試程式的 machine code 轉成 IR（VEX intermediate representation）

- 如果發生有興趣的事件執行（例如：記憶體配置），就會使用對應的工具對 IR 加入一些分析程式碼，再轉成 machine code 存到 code cache 中

- 簡單的來說
  - Valgrind 執行的都是他們所加工過後的程式

Example

使用範例

- Valgrind 是動態追蹤且會追蹤到 glibc，使用前要安裝對應的 glibc debug 套件
  - $ sudo apt install libc6-dbg

- 以下舉個例子：

```
→ test vim test.c
→ test gcc test.c
→ test ./a.out
a
```

```c
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

int main(){
    char *str = malloc(4);
    str[4] = 'a';
    printf("%c\n", str[4]);
    free(str);

    return 0;
}
```

使用範例

```
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 valgrind ./a.out
==21373== Memcheck, a memory error detector
==21373== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
==21373== Using Valgrind-3.15.0 and LibVEX; rerun with -h for copyright info
==21373== Command: ./a.out
==21373==
==21373== Invalid write of size 1
==21373==    at 0x1091AB: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
==21373==  Address 0x4a67044 is 0 bytes after a block of size 4 alloc'd
==21373==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==21373==    by 0x10919E: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
==21373==
==21373== Invalid read of size 1
==21373==    at 0x1091B6: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
==21373==  Address 0x4a67044 is 0 bytes after a block of size 4 alloc'd
==21373==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==21373==    by 0x10919E: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
==21373==
a
==21373==
==21373== HEAP SUMMARY:
==21373==     in use at exit: 0 bytes in 0 blocks
==21373==   total heap usage: 2 allocs, 2 frees, 1,028 bytes allocated
==21373==
==21373== All heap blocks were freed -- no leaks are possible
==21373==
==21373== For lists of detected and suppressed errors, rerun with: -s
==21373== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 0 from 0)
```

```c
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

int main() {
    char *str = malloc(4);
    str[4] = 'a';
    printf("%c\n",str[4]);
    free(str);

    return 0;
}
```

```
Invalid write of size 1
   at 0x1091AB: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
 Address 0x4a67044 is 0 bytes after a block of size 4 alloc'd
   at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
   by 0x10919E: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
```

```
Invalid read of size 1
   at 0x1091B6: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
 Address 0x4a67044 is 0 bytes after a block of size 4 alloc'd
   at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
   by 0x10919E: main (in /home/a13579and2468/software_testing_2022/lab6/a.out)
```

Sanitizers

- 以下是常見的 Sanitizers
  - AddressSanitizer　　檢查記憶體存取
  - LeakSanitizer　　檢查 memory leak
  - ThreadSanitizer　　檢查 deadlocks, race condition
  - MemorySanitizer　　檢查未初始化的問題
  - UndefinedBehaviorSanitizer（UBsan）

- 以下用 AddressSanitizer (ASan) 當例子

原理

- 主要透過兩個方法
  - 程式碼插樁（Instrumentation)
  - 動態運行庫（Run-time library）
- 插樁
  - 在程式碼編譯時期對程式碼加料，來處理一些對記憶體的操作
- 動態運行庫：攔截一些特別的程式碼，並改由特定 library 處理
  - malloc
  - free
  - strcpy
  - ……
- 有用到 gcc 特有的東西會炸掉
- 使用： gcc -fsanitize=address

例子

- 可以看到多了很多 library

```
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 gcc -o  t1 test.c
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 ldd t1
        linux-vdso.so.1 (0x00007ffd7ef89000)
        libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f10a9b85000)
        /lib64/ld-linux-x86-64.so.2 (0x00007f10a9da6000)
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 gcc -fsanitize=address -o t2 test.c
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 ldd t2
        linux-vdso.so.1 (0x00007ffc6ebf5000)
        libasan.so.5 => /usr/lib/x86_64-linux-gnu/libasan.so.5 (0x00007fba065fe000)
        libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007fba0640c000)
        libdl.so.2 => /lib/x86_64-linux-gnu/libdl.so.2 (0x00007fba06406000)
        librt.so.1 => /lib/x86_64-linux-gnu/librt.so.1 (0x00007fba063fc000)
        libpthread.so.0 => /lib/x86_64-linux-gnu/libpthread.so.0 (0x00007fba063d9000)
        libm.so.6 => /lib/x86_64-linux-gnu/libm.so.6 (0x00007fba0628a000)
        libgcc_s.so.1 => /lib/x86_64-linux-gnu/libgcc_s.so.1 (0x00007fba0626d000)
        /lib64/ld-linux-x86-64.so.2 (0x00007fba0705f000)
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6
```

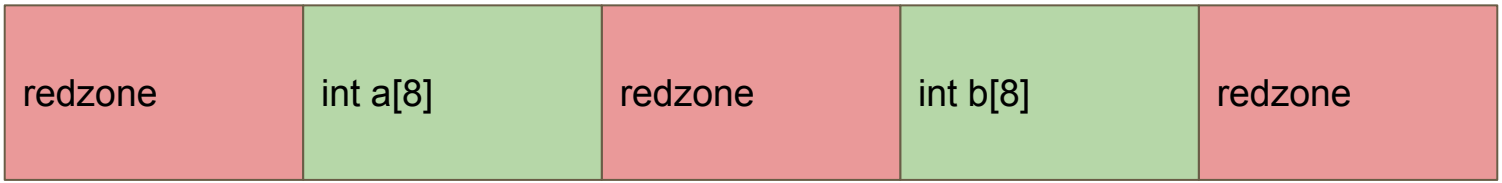
例子

```
undefined8 main(void)

{
  char cVar1;
  undefined8 *puVar2;
  ulong uVar3;
  long lVar4;
  undefined8 *puVar5;
  long in_FS_OFFSET;
  undefined auVar6 [16];
  undefined8 local_d8 [23];
  long local_20;

  puVar5 = local_d8;
  if (__asan_option_detect_stack_use_after_return != 0) {
    puVar2 = (undefined8 *)__asan_stack_malloc_2(0xa0);
    if (puVar2 != (undefined8 *)0x0) {
      puVar5 = puVar2;
    }
  }
  *puVar5 = 0x41b58ab3;
  puVar5[1] = "2 32 32 3 a:6 96 32 3 b:7";
  puVar5[2] = main;
  uVar3 = (ulong)puVar5 >> 3;
  auVar6 = CONCAT88(puVar5 + 0x18,uVar3);
  *(undefined4 *)(uVar3 + 0x7fff8000) = 0xf1f1f1f1;
  *(undefined4 *)(uVar3 + 0x7fff8008) = 0xf2f2f2f2;
  *(undefined4 *)(uVar3 + 0x7fff8010) = 0xf3f3f3f3;
  local_20 = *(long *)(in_FS_OFFSET + 0x28);
  cVar1 = *(char *)(((long)puVar5 + 0x3fU >> 3) + 0x7fff8000);
  if (cVar1 <= (char)((byte)((long)puVar5 + 0x3fU) & 7) && cVar1 != '\0' ||
      0x7f < *(byte *)(((ulong)(puVar5 + 4) >> 3) + 0x7fff8000)) {
    auVar6 = __asan_report_store_n(puVar5 + 4,0x20);
  }
  lVar4 = SUB168(auVar6 >> 0x40,0);
  *(undefined8 *)(lVar4 + -0xa0) = 0;
  *(undefined8 *)(lVar4 + -0x98) = 0;
  *(undefined8 *)(lVar4 + -0x90) = 0;
  *(undefined8 *)(lVar4 + -0x88) = 0;
  *(undefined8 *)(lVar4 + -0x60) = 0;
  *(undefined8 *)(lVar4 + -0x58) = 0;
  *(undefined8 *)(lVar4 + -0x50) = 0;
  *(undefined8 *)(lVar4 + -0x48) = 0;
```

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

int main()
{
    int a[8] = {0};
    int b[8] = {0};
    a[8] = 0xcafe;
    return 0;
}
```

redzone

- 在每個變數中間插一塊不可讀寫的區域，有做存取就噴錯



例子

```
a13579and2468@a13579and2468-X555LD ~/software_testing_2022/lab6 ./t4
=================================================================
==24698==ERROR: AddressSanitizer: stack-buffer-overflow on address 0x7fff5b745150 at pc 0x5620428da372 bp 0x7fff5b745100 sp 0x7fff5b7450f0
WRITE of size 4 at 0x7fff5b745150 thread T0
    #0 0x5620428da371 in main (/home/a13579and2468/software_testing_2022/lab6/t4+0x1371)
    #1 0x7f8c69ea10b2 in __libc_start_main (/lib/x86_64-linux-gnu/libc.so.6+0x240b2)
    #2 0x5620428da12d in _start (/home/a13579and2468/software_testing_2022/lab6/t4+0x112d)

Address 0x7fff5b745150 is located in stack of thread T0 at offset 64 in frame
    #0 0x5620428da1f8 in main (/home/a13579and2468/software_testing_2022/lab6/t4+0x11f8)

  This frame has 2 object(s):
    [32, 64) 'a' (line 6) <== Memory access at offset 64 overflows this variable
    [96, 128) 'b' (line 7)
HINT: this may be a false positive if your program uses some custom stack unwind mechanism, swapcontext or vfork
      (longjmp and C++ exceptions *are* supported)
SUMMARY: AddressSanitizer: stack-buffer-overflow (/home/a13579and2468/software_testing_2022/lab6/t4+0x1371) in main
Shadow bytes around the buggy address:
  0x10006b6e09d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e09e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e09f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a00: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a10: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
=>0x10006b6e0a20: 00 00 f1 f1 f1 f1 00 00 00 00[f2]f2 f2 f2 00 00
  0x10006b6e0a30: 00 00 f3 f3 f3 f3 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a40: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a50: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a60: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a70: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Shadow byte legend (one shadow byte represents 8 application bytes):
  Addressable:           00
  Partially addressable: 01 02 03 04 05 06 07
  Heap left redzone:       fa
  Freed heap region:       fd
  Stack left redzone:      f1
  Stack mid redzone:       f2
  Stack right redzone:     f3
  Stack after return:      f5
```

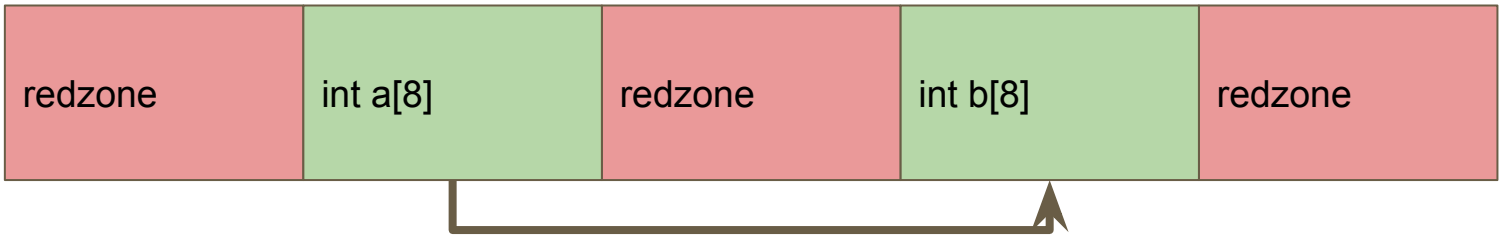
例子

```
Shadow bytes around the buggy address:
  0x10006b6e09d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e09e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e09f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a00: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a10: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
=>0x10006b6e0a20: 00 00 f1 f1 f1 f1 00 00 00 00[f2]f2 f2 f2 00 00
  0x10006b6e0a30: 00 00 f3 f3 f3 f3 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a40: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a50: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a60: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
  0x10006b6e0a70: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Shadow byte legend (one shadow byte represents 8 application bytes):
  Addressable:           00
  Partially addressable: 01 02 03 04 05 06 07
  Heap left redzone:       fa
  Freed heap region:       fd
  Stack left redzone:      f1
  Stack mid redzone:       f2
  Stack right redzone:     f3
  Stack after return:      f5
  Stack use after scope:   f8
  Global redzone:          f9
  Global init order:       f6
  Poisoned by user:        f7
  Container overflow:      fc
  Array cookie:            ac
  Intra object redzone:    bb
  ASan internal:           fe
  Left alloca redzone:     ca
  Right alloca redzone:    cb
  Shadow gap:              cc
==24698==ABORTING
```

Lab

Lab 6

- 下面是常見的記憶體操作問題，請分別寫出有下列記憶體操作問題的簡單程式，並說明 Valgrind 和 ASan 能否找的出來
  - Heap out-of-bounds read/write
  - Stack out-of-bounds read/write
  - Global out-of-bounds read/write
  - Use-after-free
  - Use-after-return
- 寫一個簡單程式 with ASan，Stack buffer overflow 剛好越過 redzone(並沒有對 redzone 做讀寫)，並說明 ASan 能否找的出來？



繳交格式

- 用 Markdown 格式寫，並匯出成 pdf 上傳
- 每個問題都需要附上程式碼和執行結果，並說明你用啥編譯器及版本
- example:
  - ### Heap out-of-bounds
  - ```
  - 有問題的程式碼
  - ```
  - ```
  - ASan report
  - ```
  - ```
  - valgrind report
  - ```
  - ASan 能/不能 , valgrind 能/不能

Reference

Reference

- Valgrind
  - https://access.redhat.com/documentation/zh-tw/red_hat_enterprise_linux/6/html/performance_tuning_guide/s-memory-valgrind
  - https://valgrind.org/
  - https://valgrind.org/docs/valgrind2007.pdf
- Sanitizer
  - https://github.com/google/sanitizers
  - https://gcc.gnu.org/onlinedocs/gcc-4.9.2/gcc/Debugging-Options.html#index-fsanitize_003daddress-593
  - https://en.wikipedia.org/wiki/Stack_buffer_overflow