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Secure by default Anti-exploit techniques and hardenings in SUSE products

Johannes Segitz, SUSE security team

SUSE

Who am I?

Johannes Segitz, security engineer (Nuremberg, Germany)

- Code review
- Product pentesting

Outline

Buffer overflows and protections:

- Stack canaries
- Fortify source
- Address space layout randomization
- No-execute memory (NX, W^X)
- Stack clash protection without example
- RELRO

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This is short overview of what we're doing

General mechanism

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A problem in languages in which you manage your own memory (primary example is C)

Really simple example:

```
1 #include <string.h>
2
3 int main(int argc, char **argv) {
4   char buffer[20];
5
6   strcpy(buffer, argv[1]);
7
8   return EXIT_SUCCESS;
9 }
```

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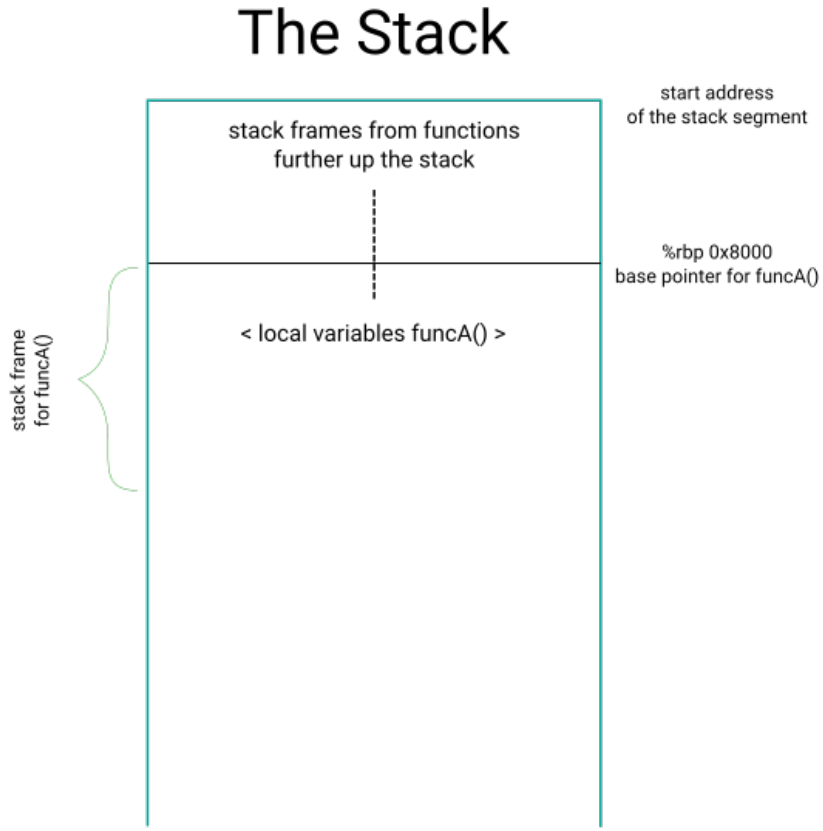
Usually a size check is just missing

Sometimes the check is there but faulty or can be circumvented (think integer overflows)

Why is this a problem?

Because in data of the application and control information about execution is mixed




```c
/*
 * some simple, fuzzy code for explaining
 * the stack frame setup
 *
 * hex addresses are just rounded samples
 * for better readability
 */

void funcB(uint32_t num)
{
    uint64_t local_var;
    register uint32_t index;

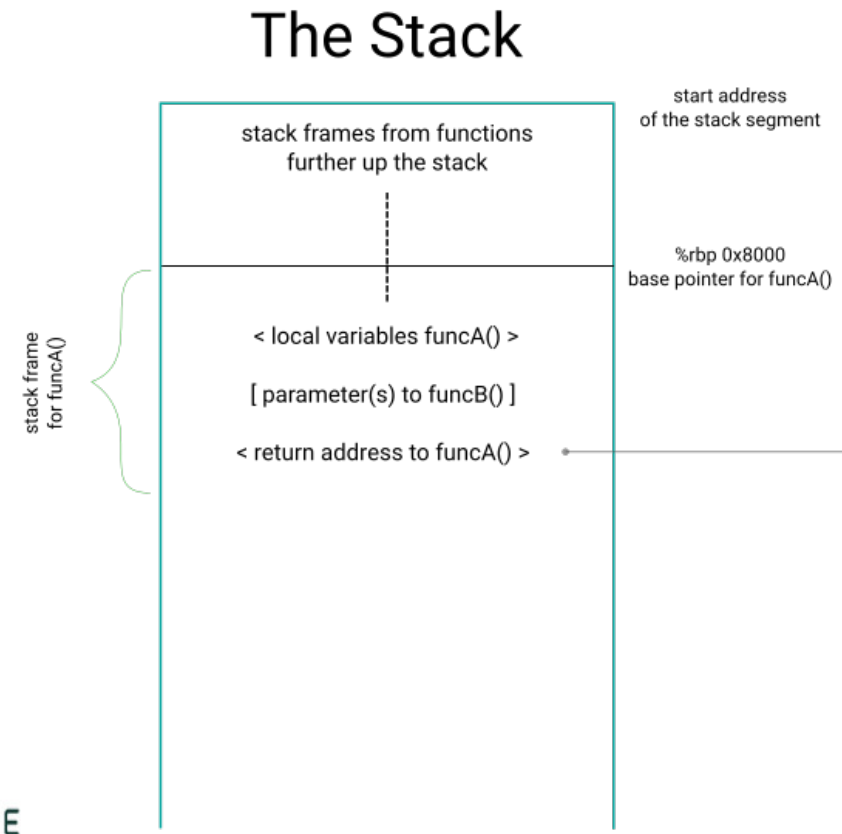
    /* some more code */
}

void funcA()
{
    /* some local vars */
    funcB(some_num);

    /* some more code */
}
```

Why is this a problem?

Part of the control information (saved instruction pointer RIP/EIP) is the address where execution will continue after the current function

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If a buffer overflow happens this control information can be overwritten

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If this is done carefully arbitrary code can be executed

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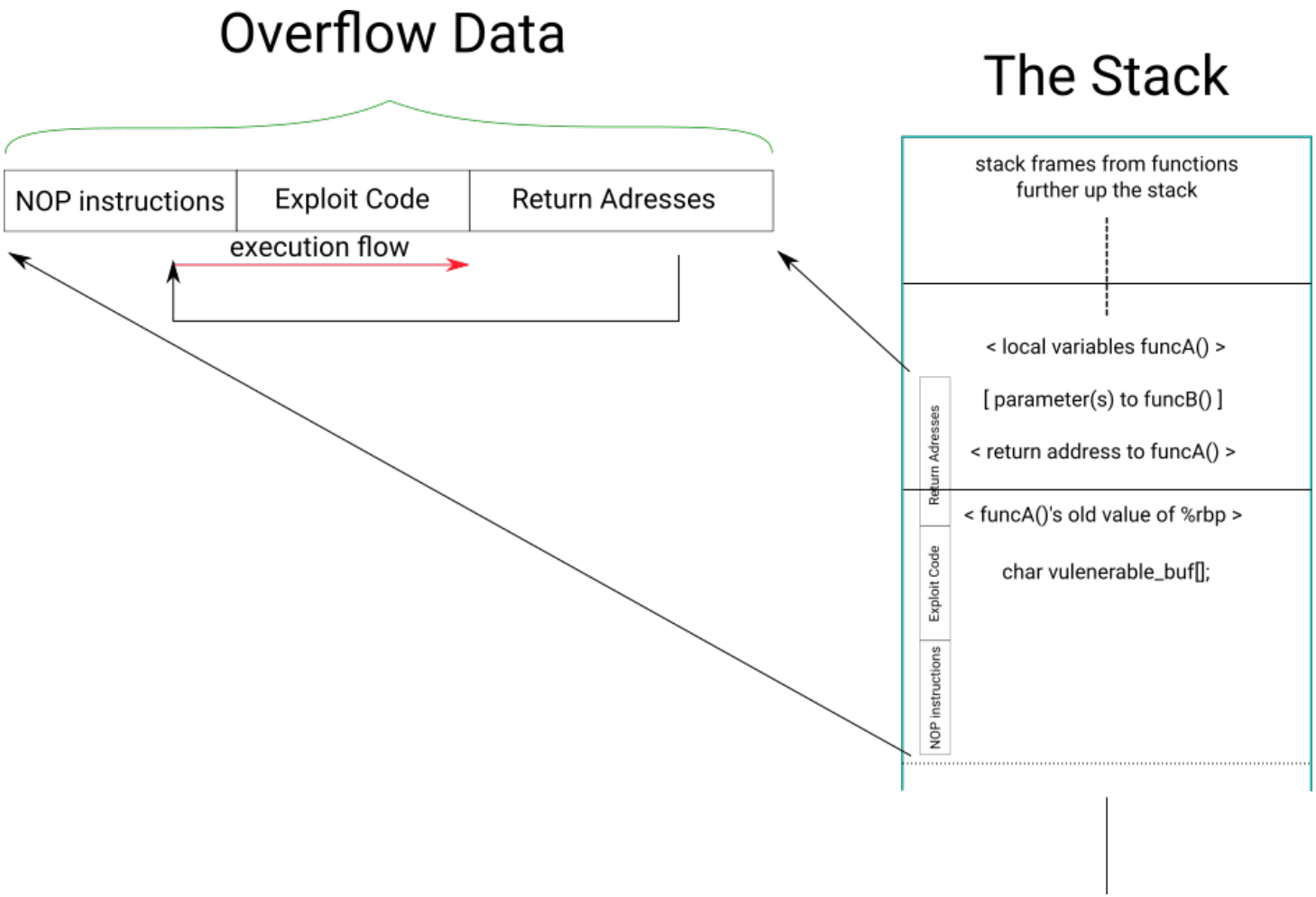

Other overwrites

Not only saved RIP/EIP can be highjacked. Think of

- Function pointers
- Exceptions handlers
- Other application specific data (`is_admin` flag ...)

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- Function pointers
- Exceptions handlers
- Other application specific data (`is_admin` flag ...)

So what can be done against these problems?

Just use Java for everything. Done! We're safe ;)

32 bit exploitation

```
1  #include <unistd.h>
2
3  void vulnerable( void ) {
4    char buffer[256];
5
6    read(0, buffer, 512);
7
8    return;
9  }
10
11 int main(int argc, char **argv) {
12   vulnerable();
13
14   return EXIT_SUCCESS;
15 }
```

32 bit exploitation

Demo time

Stack canaries

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General idea: Compiler generates extra code that puts a *canary* value at predefined locations within a stack frame

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- Random canaries
- Random XOR canaries

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- `-fstack-protector-strong`: additional criteria
- `-fstack-protector-all`: extra code for each and every function
- `-fstack-protector-explicit`: extra code every function annotated with `stack_protect`

Stack canaries

Short reminder of the example code:

```
1  #include <string.h>
2
3  int main(int argc, char **argv)
4  {
5    char buffer[20];
6
7    strcpy(buffer, argv[1]);
8
9    return EXIT_SUCCESS;
10 }
```

Stack canaries

```
00000000000006b0 <main>:
 6b0:   55                              push   rbp
 6b1:   48 89 e5                        mov    rbp,rsp
 6b4:   48 83 ec 30                     sub    rsp,0x30
 6b8:   89 7d dc                        mov    DWORD PTR [rbp-0x24],edi
 6bb:   48 89 75 d0                     mov    QWORD PTR [rbp-0x30],rsi
 6bf:   48 8b 45 d0                     mov    rax,QWORD PTR [rbp-0x30]
 6c3:   48 83 c0 08                     add    rax,0x8
 6c7:   48 8b 10                        mov    rdx,QWORD PTR [rax]
 6ca:   48 8d 45 e0                     lea    rax,[rbp-0x20]
 6ce:   48 89 d6                        mov    rsi,rdx
 6d1:   48 89 c7                        mov    rdi,rax
 6d4:   e8 87 fe ff ff                  call   560 <strcpy@plt>
 6d9:   b8 00 00 00 00                  mov    eax,0x0
 6de:   c9                              leave
 6df:   c3                              ret
```

Stack canaries

```
0000000000000720 <main>:
 720:   55                          push   rbp
 721:   48 89 e5                    mov    rbp,rsp
 724:   48 83 ec 30                 sub    rsp,0x30
 728:   89 7d dc                    mov    DWORD PTR [rbp-0x24],edi
 72b:   48 89 75 d0                 mov    QWORD PTR [rbp-0x30],rsi
 72f:   64 48 8b 04 25 28 00        mov    rax,QWORD PTR fs:0x28
 736:   00 00
 738:   48 89 45 f8                 mov    QWORD PTR [rbp-0x8],rax
 73c:   31 c0                       xor    eax,eax
 73e:   48 8b 45 d0                 mov    rax,QWORD PTR [rbp-0x30]
 742:   48 83 c0 08                 add    rax,0x8
 746:   48 8b 10                    mov    rdx,QWORD PTR [rax]
 749:   48 8d 45 e0                 lea    rax,[rbp-0x20]
 74d:   48 89 d6                    mov    rsi,rdx
 750:   48 89 c7                    mov    rdi,rax
 753:   e8 68 fe ff ff              call   5c0 <strcpy@plt>
 758:   b8 00 00 00 00              mov    eax,0x0
 75d:   48 8b 4d f8                 mov    rcx,QWORD PTR [rbp-0x8]
 761:   64 48 33 0c 25 28 00        xor    rcx,QWORD PTR fs:0x28
 768:   00 00
 76a:   74 05                       je     771 <main+0x51>
 76c:   e8 5f fe ff ff              call   5d0 <__stack_chk_fail@plt>
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- Does not protect data *before* the canary (especially function pointers). Some implementations reorder variables to minimize this risk
- Does not protect against generic write primitives
- Can be circumvented with exeption handlers
- Chain buffer overflow with information leak

Stack canaries

Limitations:

- No protection for inlined functions

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- Can be used to cause DoS

ASLR

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Memory segments (stack, heap and code) are loaded at random locations

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Memory segments (stack, heap and code) are loaded at random locations

Atttackers don't know return addresses into exploit code or C library code reliably any more

ASLR

```
bash -c 'cat /proc/$$/maps'
56392d605000-56392d60d000 r-xp 00000000 fe:01 12058638  /bin/cat
<snip>
56392dd05000-56392dd26000 rw-p 00000000 00:00 0         [heap]
7fb2bd101000-7fb2bd296000 r-xp 00000000 fe:01 4983399
     /lib/x86_64-linux-gnu/libc-2.24.so
<snip>
7fb2bd6b2000-7fb2bd6b3000 r--p 00000000 fe:01 1836878
     /usr/lib/locale/en_AG/LC_MESSAGES/SYS_LC_MESSAGES
<snip>
7fffd5c36000-7fffd5c57000 rw-p 00000000 00:00 0         [stack]
7fffd5ce9000-7fffd5ceb000 r--p 00000000 00:00 0         [vvar]
7fffd5ceb000-7fffd5ced000 r-xp 00000000 00:00 0         [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0 [vsyscall]
```

ASLR

```
for i in `seq 1 5`; do bash -c 'cat /proc/$$/maps | grep stack'; done
7ffcb8e0f000-7ffcb8e30000 rw-p 00000000 00:00 0 [stack]
7fff64dc9000-7fff64dea000 rw-p 00000000 00:00 0 [stack]
7ffc3b408000-7ffc3b429000 rw-p 00000000 00:00 0 [stack]
7ffcee799000-7ffcee7ba000 rw-p 00000000 00:00 0 [stack]
7ffd4b904000-7ffd4b925000 rw-p 00000000 00:00 0 [stack]
```

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- 5 - 10% performance loss on i386 machines
- Limited entropy on 32 bit systems
- Brute forcing still an issue if restart is not handled properly.
- Can be circumvented by chaining an information leak into the exploit

ASLR

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- Sometimes you have usable memory locations in registers

No-execute memory

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The most interesting memory regions for this feature to use are the stack and heap memory regions

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```
bash -c 'cat /proc/$$/maps | grep stack'
7ffcb8e0f000-7ffcb8e30000 rw-p 00000000 00:00 0 [stack]
```

NX

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Limitations

- Use existing code in the exploited program
- Return to libc: Use existing functions
- ROP (Return Oriented Programming): Structure the data on the stack so that instruction sequences ending in `ret` can be used

Stack clash protection

Heap and stack live both in the address space of the process and they grow dynamically

```
bash -c 'cat /proc/$$/maps | egrep "(heap|stack)"'
55dc4ffbe000-55dc4ffdf000 rw-p 00000000 00:00 0
      [heap]
7ffce8c2b000-7ffce8c4c000 rw-p 00000000 00:00 0
      [stack]
```

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So what happens if those two meet?

Guard page is inserted between stack and heap, causes an segmentation fault if they clash

Stack clash protection

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Bring stack and heap close, then use an allocation $>$ one page to jump the guard page

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Bring stack and heap close, then use an allocation $>$ one page to jump the guard page

After that you can write to the stack to modify data on the heap or the other way around

Stack clash protection

To prevent this compile code with:
`-fstack-clash-protection`

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Ensures access to every page when doing large allocations

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Stack clash protection

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High value mitigation with almost no downsides.
See CVE-2018-16864 ("System down")

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Exploitation got harder, but this is an ongoing struggle

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- Shadow stacks
- (Hardware) control flow integrity (CFI)

These mitigations are currently rather costly, hard to convince users to take the hit

So keep your systems updated

Q&A

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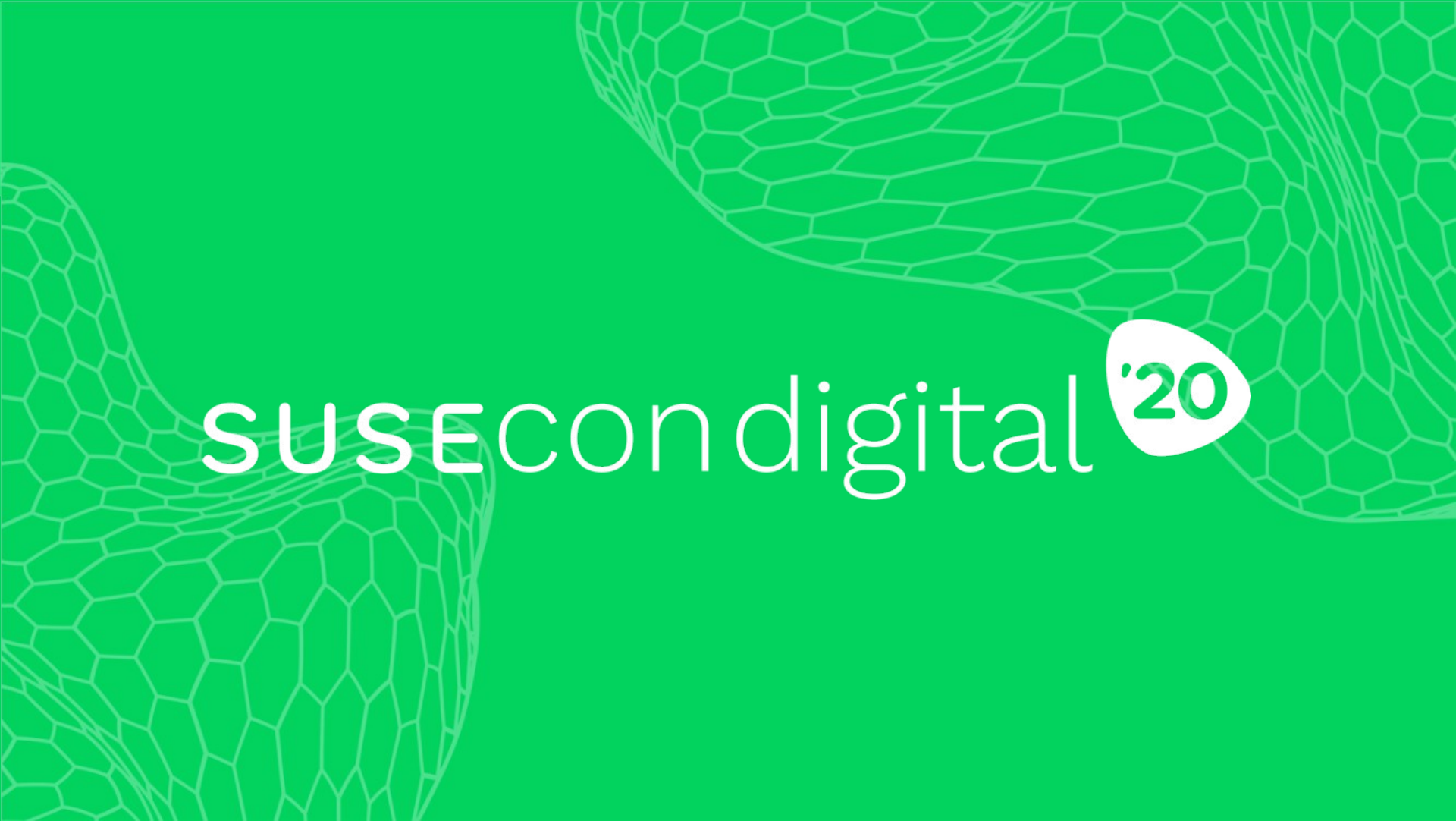
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