Integer Overflows

Software Security

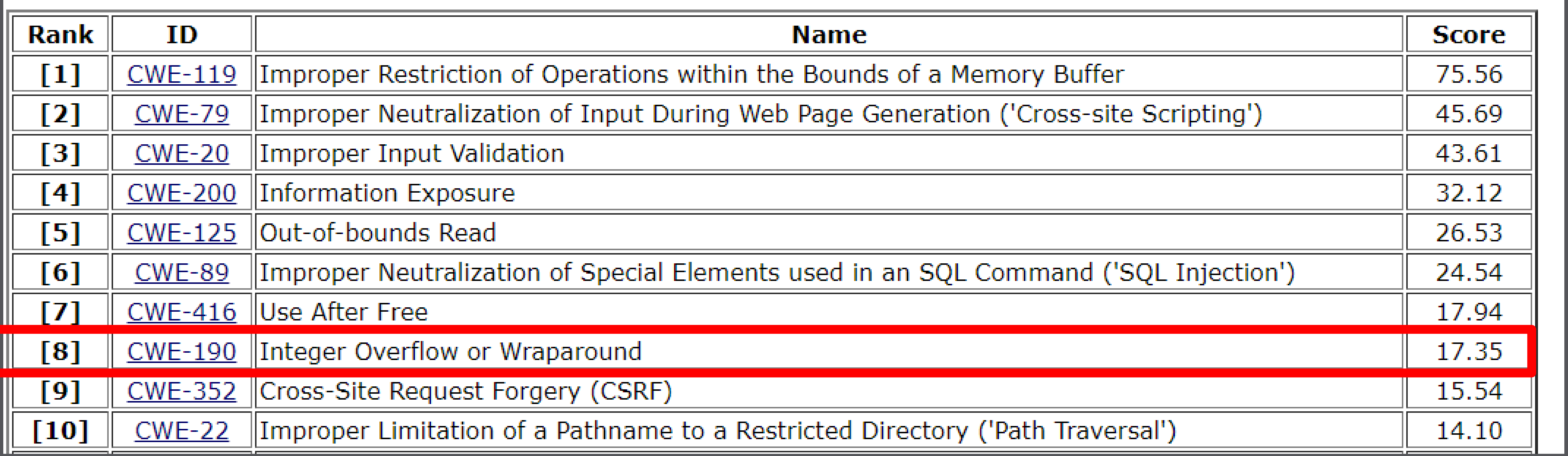
Goals

- Identify integer overflows and understand the associated risks
- Triage and remediate integer overflows in software

Integer Overflow

- an integer overflow occurs when an arithmetic operation attempts to create a numeric value that is outside of the range that can be represented with a given number of bits – either larger than the maximum or lower than the minimum representable value

Integer Overflow in CWE Top 25



Rank	ID	Name	Score
[1]	CWE-119	Improper Restriction of Operations within the Bounds of a Memory Buffer	75.56
[2]	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')	45.69
[3]	CWE-20	Improper Input Validation	43.61
[4]	CWE-200	Information Exposure	32.12
[5]	CWE-125	Out-of-bounds Read	26.53
[6]	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')	24.54
[7]	CWE-416	Use After Free	17.94
[8]	CWE-190	Integer Overflow or Wraparound	17.35
[9]	CWE-352	Cross-Site Request Forgery (CSRF)	15.54
[10]	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')	14.10

Explained

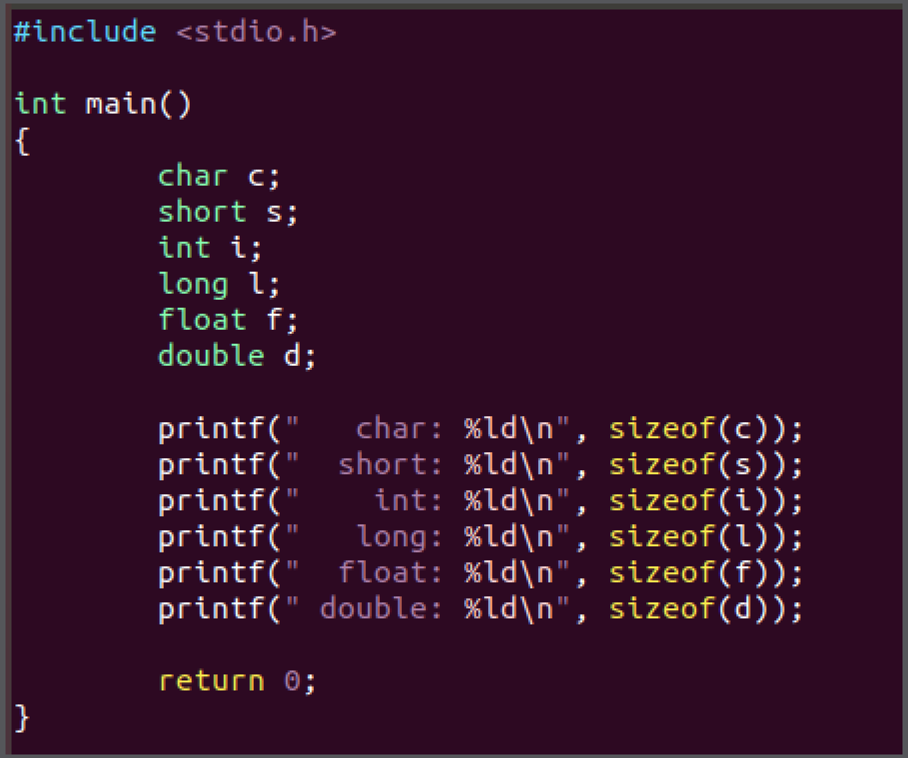
First – Type Sizes

- C has a few basic data types

Type	Notes
char	Single byte; holds a single character of the local set
int	integer of natural size on the host
float	single-precision floating point
double	double-precision floating point
short	at least 16 bits
long	at least 32 bits

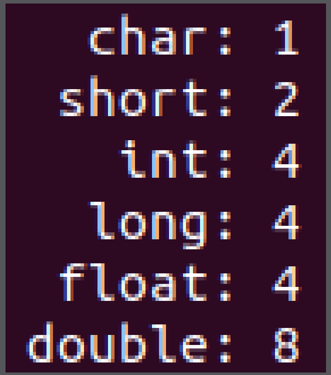
- long >= 32 bits > int > short

Type Sizes in an Environment

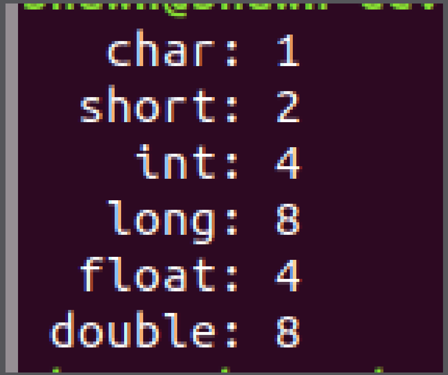


```c
#include <stdio.h>

int main()
{
        char c;
        short s;
        int i;
        long l;
        float f;
        double d;

        printf("   char: %ld\n", sizeof(c));
        printf("  short: %ld\n", sizeof(s));
        printf("    int: %ld\n", sizeof(i));
        printf("   long: %ld\n", sizeof(l));
        printf("  float: %ld\n", sizeof(f));
        printf(" double: %ld\n", sizeof(d));

        return 0;
}
```

32 bit vs 64 bit



```
  char: 1
 short: 2
   int: 4
  long: 4
 float: 4
double: 8
```



```
  char: 1
 short: 2
   int: 4
  long: 8
 float: 4
double: 8
```

Binary (base-2)

significance	128	64	32	16	8	4	2	1
bool	1	1	1	0	0	1	1	0

Unsigned int or char

- Value is limited to 2^n where n is bits in type
- Example
  - char – 8 bits
  - $2^8 = 256$
  - 0 – 255 can be represented with an unsigned char
- Overflows occur when an operation results in value > 255

Examples 1 & 2

unsigned and signed char

Signed int or char

- Value is limited to range from -(2^{n-1}) to 2^{n-1} - 1 where n is bits in type
- Example
  - char – 8 bits
  - 2^{8-1} = 128
  - -128 – 127 can be represented with a signed char
- Overflows occur when an operation results in value < -128 or > 127

How negative chars/ints work typically

1. Take positive value in binary
2. Invert all positions 0 -> 1 and 1-> 0
3. Add 1

Two’s Complement

Integer	Binary	Invert	Add 1	Result
0	0000	1111	0000	0
1	0001	1110	1111	-1
2	0010	1101	1110	-2
3	0011	1100	1101	-3
4	0100	1011	1100	-4
5	0101	1010	1011	-5
6	0110	1001	1010	-6
7	0111	1000	1001	-7

https://en.wikipedia.org/wiki/Two%27s_complement

Ex: 2 + -5

Integer	Binary	Invert	Add 1	Result
0	0000	1111	0000	0
1	0001	1110	1111	-1
2	0010	1101	1110	-2
3	0011	1100	1101	-3
4	0100	1011	1100	-4
5	0101	1010	1011	-5
6	0110	1001	1010	-6
7	0111	1000	1001	-7

Example 3

together now

What’s Happening

int i	unsigned char a	binary	int i	signed char b	binary
250	250	11111010	125	125	01111101
251	251	11111011	126	126	01111110
252	252	11111100	127	127	01111111
253	253	11111101	128	-128	10000000
254	254	11111110	129	-127	10000001
255	255	11111111	130	-126	10000010
256	0	00000000	131	-125	10000011
257	1	00000001	132	-124	10000100
258	2	00000010	133	-123	10000101
259	3	00000011	134	-122	10000110
260	4	00000100	135	-121	10000111

Problem 1: Wraparound (+ or -)

- Manifests with addition and subtraction operations resulting in
  - less than the minimum or
  - greater than maximum

- Generally, malicious input would lead to another flaw allowing code execution
  - Ex: User controlled output buffer

Examples 4, 5, 6

asterisks, percent, forward slashes oh my

Multiplication

significance	256	128	64	32	16	8	4	2	1
100	0	0	1	1	0	0	1	0	0
300	1	0	0	1	0	1	1	0	0

Division

significance	128	64	32	16	8	4	2	1
-128	1	0	0	0	0	0	0	0
one's compliment	0	1	1	1	1	1	1	1
two's compliment								

Division

- a = -128;
- a /= -1;
- -(-128)
  - Negation is just two’s compliment

significance	128	64	32	16	8	4	2	1
-128	1	0	0	0	0	0	0	0
one's compliment	0	1	1	1	1	1	1	1
two's compliment								

Modulus

Example 7

Casting tomfoolery

Problem 2: Wraparound (*, /, or %)

- Manifests with multiplication or division operations with results implicitly cast larger and outside the bounds of the type

- Generally, malicious input would lead to another flaw allowing code execution
  - Ex: User controlled output buffer

Discovery

- Code review
  - Any arithmetic operations, especially
    - With user input
    - Manipulating memory
  - Review of both your functions and called functions
    - Be sure you’re not implicitly casting a type incorrectly
- Compiler Output
  - Warnings for certain comparisons
- Testing
  - Fuzz with inputs of sizes around edges of types

Remediation / Defense

- Use unsigned numbers where possible
- Verify with math
  - Assert your own min and max within the constraints of your application and the types you're using
  - Validate against limit for the type in your case
- Use explicit casts for ease of review and to work through problems
- Use compiler flags to warn on implicit casts and trap on signed integer overflows

Remediation / Defense

- Use compiler assistance
  - gcc builtins (ex9_builtin.c)

Summary (From Book)

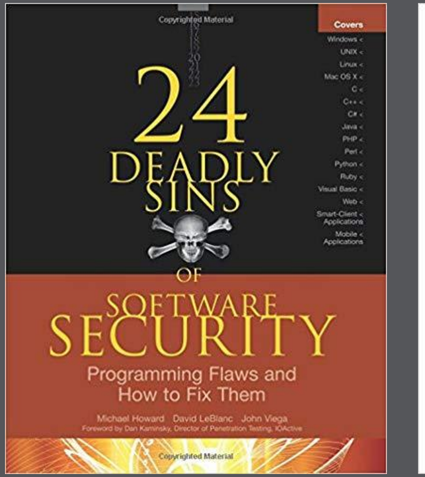
- Check all calculations used for memory allocations or array access
- Use unsigned integers (size_t) for memory and array access
- Check for truncation issues with unsigned types when subtracting
- Don’t think that this only happens in C/C++

Example

- Subtraction overflow

References

- https://Wikipedia.org
- 24 Deadly Sins of Software Security
  - ISBN-13: 978-0071626750
- The C Programming Language
  - ISBN-13: 978-0131103627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