

15-213
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**Memory Management III:
 Perils and pitfalls
 Mar 13, 2001**

Topics

- Memory-related bugs
- Debugging versions of malloc

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C operators

Operators	Associativity
() [] -> .	left to right
! ~ ++ -- + - * & (type) sizeof	right to left
* / %	left to right
+ -	left to right
<< >>	left to right
< <= > >=	left to right
== !=	left to right
&	left to right
^	left to right
	left to right
&&	left to right
	left to right
?:	right to left
= += -= *= /= %= &= ^= != <<= >>=	right to left
,	left to right

Note: Unary +, -, and * have higher precedence than binary forms

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C pointer declarations

int *p	p is a pointer to int
int *p[13]	p is an array[13] of pointer to int
int *(p[13])	p is an array[13] of pointer to int
int **p	p is a pointer to a pointer to an int
int (*p)[13]	p is a pointer to an array[13] of int
int *f()	f is a function returning a pointer to int
int (*f)()	f is a pointer to a function returning int
int (*(f())[13])()	f is a function returning ptr to an array[13] of pointers to functions returning int
int (*(x[3])())[5]	x is an array[3] of pointers to functions returning pointers to array[5] of ints

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Memory-related bugs

- Dereferencing bad pointers
- Reading uninitialized memory
- Overwriting memory
- Referencing nonexistent variables
- Freeing blocks multiple times
- Referencing freed blocks
- Failing to free blocks

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Dereferencing bad pointers

The classic scanf bug

```
scanf("%d", val);
```

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Reading uninitialized memory

*Assuming that heap data is
initialized to zero*

```
/* return y = Ax */
int *matvec(int **A, int *x) {
    int *y = malloc(N*sizeof(int));
    int i, j;

    for (i=0; i<N; i++)
        for (j=0; j<N; j++)
            y[i] += A[i][j]*x[j];
    return y;
}
```

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Overwriting memory

*Allocating the (possibly) wrong
sized object*

```
int **p;
p = malloc(N*sizeof(int));
for (i=0; i<N; i++) {
    p[i] = malloc(M*sizeof(int));
}
```

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Overwriting memory

Off-by-one

```
int **p;
p = malloc(N*sizeof(int *));
for (i=0; i<=N; i++) {
    p[i] = malloc(M*sizeof(int));
}
```

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Overwriting memory

Off-by-one redux

```
int i=0, done=0;
int s[4];

while (!done) {
    if (i > 3)
        done = 1;
    else
        s[++i] = 10;
}
```

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Overwriting memory

Forgetting that strings end with '\0'

```
char t[7];
char s[8] = "1234567";

strcpy(t, s);
```

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Overwriting memory

Not checking the max string size

```
char s[8];
int i;

gets(s); /* reads "123456789" from stdin */
```

Basis for classic buffer overflow attacks

- 1988 Internet worm
- modern attacks on Web servers

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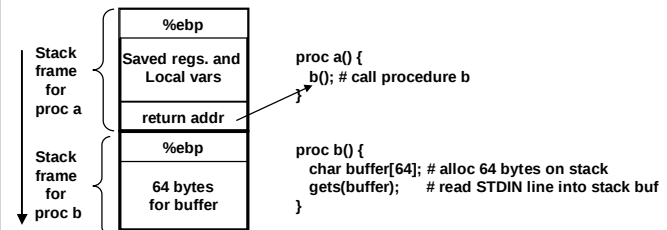
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Buffer overflow attacks

Description of hole:

- Servers that use C library routines such as gets() that don't check input sizes when they write into buffers on the stack.
- The following description is based on the IA32 stack conventions. The details will depend on how the stack is organized, which varies between machines



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Overwriting memory

Referencing a pointer instead of the object it points to

```
int *BinheapDelete(int **binheap, int *size) {
    int *packet;
    packet = binheap[0];
    binheap[0] = binheap[*size - 1];
    *size--;
    Heapify(binheap, *size, 0);
    return(packet);
}
```

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Overwriting memory

Misunderstanding pointer arithmetic

```
int *search(int *p, int val) {
    while (*p && *p != val)
        p += sizeof(int);
    return p;
}
```

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Referencing nonexistent variables

Forgetting that local variables disappear when a function returns

```
int *foo () {
    int val;
    return &val;
}
```

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Freeing blocks multiple times

Nasty!

```
x = malloc(N*sizeof(int));
<manipulate x>
free(x);

y = malloc(M*sizeof(int));
<manipulate y>
free(x);
```

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Referencing freed blocks

Evil!

```
x = malloc(N*sizeof(int));
<manipulate x>
free(x);
...
y = malloc(M*sizeof(int));
for (i=0; i<M; i++)
    y[i] = x[i]++;
```

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Failing to free blocks (memory leaks)

slow, long-term killer!

```
foo() {
    int *x = malloc(N*sizeof(int));
    ...
    return;
}
```

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Failing to free blocks (memory leaks)

Freeing only part of a data structure

```
struct list {
    int val;
    struct list *next;
};

foo() {
    struct list *head =
        malloc(sizeof(struct list));
    head->val = 0;
    head->next = NULL;
    <create and manipulate the rest of the list>
    ...
    free(head);
    return;
}
```

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Dealing with memory bugs

Conventional debugger (gdb)

- good for finding bad pointer dereferences
- hard to detect the other memory bugs

Debugging malloc (CSRI UToronto malloc)

- wrapper around conventional malloc
- detects memory bugs at malloc and free boundaries
 - memory overwrites that corrupt heap structures
 - some instances of freeing blocks multiple times
 - memory leaks
- Cannot detect all memory bugs
 - overwrites into the middle of allocated blocks
 - freeing block twice that has been reallocated in the interim
 - referencing freed blocks

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Dealing with memory bugs (cont.)

Binary translator (Atom, Purify)

- powerful debugging and analysis technique
- rewrites text section of executable object file
- can detect all errors as debugging malloc
- can also check each individual reference at runtime
 - bad pointers
 - overwriting
 - referencing outside of allocated block

Garbage collection (Boehm-Weiser Conservative GC)

- let the system free blocks instead of the programmer.

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Debugging malloc

mymalloc.h:

```
#define malloc(size) mymalloc(size, __FILE__, __LINE__)
#define free(p) myfree(p, __FILE__, __LINE__)
```

Application program:

```
#ifdef DEBUG
#include <mymalloc.h>
#endif

main() {
    ...
    p = malloc(128);
    ...
    free(p);
    ...
    q = malloc(32);
    ...
}
```

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Debugging malloc (cont.)

Debugging malloc library:

```
void *mymalloc(int size, char *file, int line) {
    <prologue code>
    p = malloc(...);
    <epilogue code>
    return q;
}

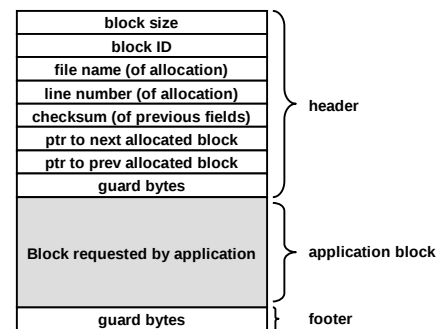
void myfree(void *p, char *file, int line) {
    <prologue code>
    free(p);
    <epilogue code>
}
```

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Debugging malloc (cont.)



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Debugging malloc (cont.)

mymalloc(size):

- `p = malloc(size + sizeof(header) + sizeof(footer));`
- add `p` to list of allocated blocks
- initialize application block to 0xdeadbeef
- return pointer to application block

myfree(p):

- already free (line # = 0xfefefefefefefe)?
- checksum OK?
- guard bytes OK?
- `free(p - sizeof(hdr));`
- line # = 0xfefefefefefefe;