C, Memory

CS 2130: Computer Systems and Organization 1

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Announcements

- Homework 9 due Monday on Gradescope
- Final Exam Thursday April 30, 2026 at 7pm

Common Memory Bugs (reading)

string.h manual page and examples

strcmp(), mcp(), strcat()

man string.h

```
DESCRIPTION
       Some  of  the  functionality described on this reference page extends the ISO C standard. Applications shall define
       the appropriate feature test macro (see the System Interfaces volume of POSIX.1-2017, Section 2.2, The  Compilation
       Environment) to enable the visibility of these symbols in this header.

       The <string.h> header shall define NULL and size_t as described in <stddef.h>.

       The <string.h> header shall define the locale_t type as described in <locale.h>.

       The  following  shall be declared as functions and may also be defined as macros. Function prototypes shall be pro-
       vided for use with ISO C standard compilers.
```

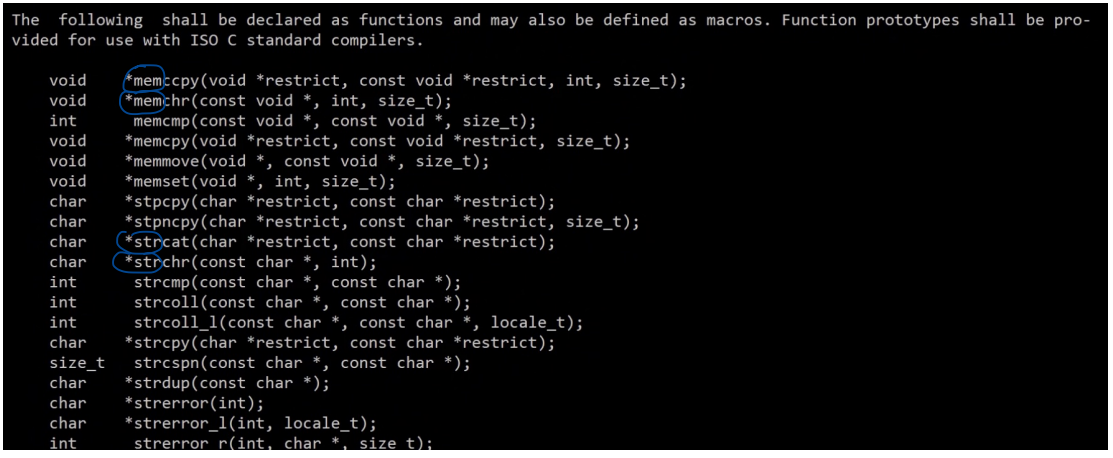
① ISO: International Standards Orgnization. They standarlized the C language.

② There might be things that are not in the standard, but meet the standard, and possibly extend it.

③. NULL: A pointer to memory position zero.

④. size_t: the size of size_t depends on the system. It always the same width as a pointer.

⑤. locale_t: the user's locale, meaning regional settings.



```
The  following  shall be declared as functions and may also be defined as macros. Function prototypes shall be pro-
vided for use with ISO C standard compilers.

    void    *memccpy(void *restrict, const void *restrict, int, size_t);
    void    *memchr(const void *, int, size_t);
    int      memcmp(const void *, const void *, size_t);
    void    *memcpy(void *restrict, const void *restrict, size_t);
    void    *memmove(void *, const void *, size_t);
    void    *memset(void *, int, size_t);
    char    *stpcpy(char *restrict, const char *restrict);
    char    *stpncpy(char *restrict, const char *restrict, size_t);
    char    *strcat(char *restrict, const char *restrict);
    char    *strchr(const char *, int);
    int      strcmp(const char *, const char *);
    int      strcoll(const char *, const char *);
    int      strcoll_l(const char *, const char *, locale_t);
    char    *strcpy(char *restrict, const char *restrict);
    size_t   strcspn(const char *, const char *);
    char    *strdup(const char *);
    char    *strerror(int);
    char    *strerror_l(int, locale_t);
    int      strerror_r(int, char *, size_t);
```

1. What is a char in C? a 1-byte integer.
A string is just an array of chars ending in a '\0' byte. Memory itself is also an array of bytes.

So fundamentally: 👉 Strings and raw memory are the same thing: sequences of bytes.
This is why C can freely treat strings as pointers to bytes, and why some memory functions live inside string.h."

2. Why does string.h contain both str and mem functions?

String functions (str*) operate on null-terminated byte arrays
→ They do NOT require a size parameter.

Memory functions (mem*) operate on arbitrary byte arrays
→ They MUST take a size parameter, because raw memory has no terminator.

Both sets of functions operate on bytes, so they are grouped together in string.h.

3. strcmp and strncmp — string comparison functions

"strcmp(s1, s2) compares two strings until one hits the null terminator: returns 0 if the strings are equal, negative if s1 < s2, positive if s1 > s2.

strncmp(s1, s2, n) compares only the first n characters. It will stop early if either string hits the null terminator ('\0').

These functions only work on C strings, meaning they must be null-terminated."

4. memcmp — compare ANY memory block (including structs)

"memcmp(ptr1, ptr2, size) compares two memory regions byte by byte.

It does not care about: null terminators, structure layout, data types. It only looks at bytes.

You can use memcmp to compare two structs. However, you must be careful:
Structs may contain padding bytes. Padding bytes may contain uninitialized values, so two structs with identical fields may still compare as 'not equal' if the padding differs.

5. memset — initialize raw memory

memset(ptr, value, size) writes a byte value to every byte of a memory block.

The most common use is: memset(&s, 0, sizeof(s));

This clears all fields and also clears padding bytes.
It ensures that structs initialized this way can be safely compared using memcmp.

6. memcpy — copy raw memory

memcpy(dest, src, size) copies exactly size bytes from one memory region to another.

For simple structs (without internal dynamic memory), memcpy works perfectly:

memcpy(&s2, &s1, sizeof(s1));

This is equivalent to s2 = s1; but works for any data type. Because C treats everything as bytes, memcpy becomes a universal tool for duplicating data.

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

void pick_a_string(char *s, size_t length);

int main() {
    char a[20];
    char b[40];
    pick_a_string(a,20);
    pick_a_string(b,40);

    // Warm up! Is there an issue with
    // this code? Can you think of a
    // possible problem?

    int c = strcmp(a,b);

    if (c < 0) puts(a);
    else if (c > 0) puts(b);
    else puts("both the same");

    return 0;
}
```

strncmp(a, b, 20);

Do you see any potential issues in this code?

strcmp compares two strings by looking at each byte until it hits a '\0'.

If the string is not null-terminated, it keeps reading... possibly into garbage memory, return addresses, or stack frames.

If pick_a_string forgets to add a null terminator, strcmp(a, b) might scan off the edge of the buffer. That's undefined behavior, and it can crash your program—or worse, allow malicious code to hijack your program.

How to Be Safe — Use strncmp

This limits the number of characters strncmp will compare. Even if there's no null terminator, it won't read past the 20th byte.

It's a safety net — use it when you're dealing with manually built strings or unsure input.

20 a's

if I have a = aaa .... a

b = aaa .... az

20 a's

C == 0? a and b are the same.?

No! I cannot have 20 a's in array a. I need a '\0'

'\0' == 0

so a is smaller

```c
#include <stdlib.h>

void *mcp(void *dest, const void *src, size_t n) {
    for (size_t i = 0; i < n; i += 1)
        ((char *)dest)[i] = ((char *)src)[i];
    return dest;
}
```

```
clang -O1 -S mcp.c
```

```
.LBB0_4:                                # =>This Inner Loop Header: Depth=1
        movzbl  (%rsi,%r10), %ecx
        movb    %cl, (%rax,%r10)
        addq    $1, %r10
        addq    $-1, %rdi
        jne     .LBB0_4
```

The implementation is correct, but that it is slow, for several reasons:

Reason 1 — Each loop iteration only transfers 1 byte.

But each iteration also requires multiple instructions: load 1 byte, store 1 byte, increment index, decrement counter, branch/jump

So the majority of the work is loop overhead, not data copying.
This is fundamentally inefficient for large memory blocks.

Reason 2 — Using cl means you are doing 8-bit work

cl is the lowest 8 bits of the 64-bit register rcx

Because you cast to char*, the compiler assumes it's doing byte-by-byte operations, so it uses:
movzbl → load a single byte
movb → store a single byte

Why is that bad?

Because:
The CPU can copy 8 bytes in one 64-bit move
Or 16 bytes using SSE
Or 32 bytes using AVX
Or 64 bytes using AVX-512

Using cl means you're only using 8 bits of your register bandwidth, wasting the CPU's natural 64-bit or 128-bit capabilities.

Reason 3 — The loop overhead is too large

addq $1, %r10
addq $-1, %rdi
jne .LBB0_4

These are not doing useful copying—they exist only to keep the loop going.
When the loop runs millions of times, this overhead dominates the runtime.

The standard library versions use advanced optimizations such as:

1. loop unrolling
2. copying 4, 8, 16, 32 bytes per iteration
3. SIMD vectorized instructions
4. alignment optimizations
5. architecture-specific strategies
6. cache-friendly techniques

if you use -O3 instead of -O1, you can see loop unrolling and vectorization.

```
.LBB0_6:                                # =>This Inner Loop Header: Depth=1
        movzbl  (%rsi,%r10), %ecx
        movb    %cl, (%rax,%r10)
        movzbl  1(%rsi,%r10), %ecx
        movb    %cl, 1(%rax,%r10)
        movzbl  2(%rsi,%r10), %ecx
        movb    %cl, 2(%rax,%r10)
        movzbl  3(%rsi,%r10), %ecx
        movb    %cl, 3(%rax,%r10)
        addq    $4, %r10
        cmpq    %r10, %rdx
        jne     .LBB0_6
        jmp     .LBB0_17
```

```
.LBB0_12:                               # =>This Inner Loop Header: Depth=1
        movups  (%rsi,%rdi), %xmm0
        movups  16(%rsi,%rdi), %xmm1
        movups  %xmm0, (%rax,%rdi)
        movups  %xmm1, 16(%rax,%rdi)
        movups  32(%rsi,%rdi), %xmm0
        movups  48(%rsi,%rdi), %xmm1
        movups  %xmm0, 32(%rax,%rdi)
        movups  %xmm1, 48(%rax,%rdi)
        movups  64(%rsi,%rdi), %xmm0
        movups  80(%rsi,%rdi), %xmm1
        movups  %xmm0, 64(%rax,%rdi)
        movups  %xmm1, 80(%rax,%rdi)
        movups  96(%rsi,%rdi), %xmm0
        movups  112(%rsi,%rdi), %xmm1
        movups  %xmm0, 96(%rax,%rdi)
        movups  %xmm1, 112(%rax,%rdi)
        subq    $-128, %rdi
        addq    $-4, %r9
        jne     .LBB0_12
```

there are special registers that do vector math so they can load multiple values in at a time.

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

int main() {
    char buffer[100];
    const char *s1 = "This is a test";
    const char *s2 = " of string.h";
    buffer[0] = '\0';
    strcat(buffer, s1);
    strcat(buffer, s2);
    puts(buffer);
    return 0;
}
```

strcat only works correctly when the destination already contains a valid null-terminated string.

1. strcat does NOT check the size of the destination buffer

char buffer[100];
buffer[0] = '\0';
strcat(buffer, s1);
strcat(buffer, s2);
strcat assumes:

- buffer is a valid, null-terminated C string
- There is enough space to append the new data

But it never verifies this.
If the combined length of s1 + s2 is > 99 bytes, strcat will overflow the buffer.

This is one of the most common causes of buffer overflow bugs in real C code.

2. If we forget buffer[0] = '\0', the program becomes dangerous

char buffer[100];
strcat(buffer, s1);

buffer contains uninitialized garbage.
strcat will search through that garbage looking for a '\0', which can result in:

- writing past the end of the array
- reading uninitialized memory
- a crash
- completely undefined behavior

So although this code works, it relies on the programmer manually doing the right thing.

strcat example

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

int main() {
    char buffer[100];
    const char *s1 = "This is a test";
    const char *s2 = " of string.h";
    buffer[0] = '\0';
    strcat(buffer, s1);
    strcat(buffer, s2);
    puts(buffer);
    return 0;
}
```

Issues:

① May Segmentation fault if s1 or s2 are long. (buffer overflow).

② If I forgot '\0', strcat doesn't work.

" clang problem.c -fstack-protector "

it will show " stack smashing detected " (It gives more error information, some systems do this by default)