Version 2.11

UCSD CSE 30

Computer Organization and Systems Programming

Lecture - 8

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Vax 11/780 1980

Example of a hard-to-understand pointer statement

```
int array[] = {2, 5, 7, 9, 11, 13};
int *ptr = array;
int x;
```

common	With Parentheses	Meaning
`*p++`	`*(p++)`	(1) The Rvalue is the object that p points at (2) increment pointer p to next element ++ is higher than *
`(*p)++`		(1) Rvalue is the object that p points at (2) increment the object
`*++p`	`*(++p)`	(1) Increment pointer p first to the next element (2) Rvalue is the object that the incremented pointer points at
`++*p`	`++(*p)`	Rvalue is the incremented value of the object that p points at

```
x = 1 + (*ptr++)++; // yuck!!
```

```
/* Same as the one line above */
x = 1 + *ptr;       // x = 1 + 2 = 3;
*ptr = *ptr + 1;    // (*ptr)++ is array[0]=2+1;=3;
ptr = 1 + ptr;      // ptr = &array[1] = ptr points at 5
```

```
x = 1 + ++(*ptr++);
```

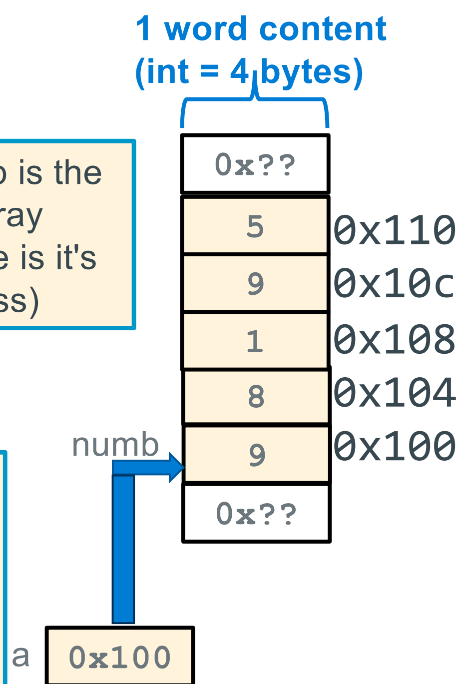
```
*ptr = *ptr + 1;    // (*ptr)++ is array[0]=2+1=3
x = 1 + *ptr;       // x = 1 + 3 = 4;
ptr = 1 + ptr;      // ptr = &array[1]; ptr ->5
```

X

Arrays As Parameters: What is the size of the array?

- It’s tricky to use arrays as parameters, as **they are passed as pointers to the start of the array**
  - In C, **Arrays do not know their own size** and at runtime there is no “bounds” checking on indexes

Observe numb is the name of an array (whose Rvalue is it's starting address)



Remember a is parameter copy so is a separate variable that contains a pointer to num

```
int sumAll(int *);

int main(void)
{
  int numb[] = {9, 8, 1, 9, 5};
  int sum = sumAll(numb);

  return EXIT_SUCCESS;
}

int sumAll(int *a)
{
  int i, sum = 0;
  int sz = (int) (sizeof(a)/sizeof(*a));
  for (i = 0; i < sz; i++) // this does not work
      sum += a[i];
  }
}
```

this is a POINTER to the first element…..
so sizeof(a) is the size of a pointer, not the array it points at
Net result: sz is a 1 on picluster

x

The NULL Constant and Pointers

- **NULL is a constant** that **evaluates to zero (0)**
- You assign a pointer variable to contain NULL to indicate that the pointer does not point at anything
- A pointer variable with a value of NULL is called a "NULL pointer" (invalid address!)
- Memory location 0 (address is 0) is not a valid memory address in any C program
- Dereferencing NULL at runtime will cause a program fault (segmentation fault)!

```
p = NULL;
i = *p;                  /* segmentation fault! */
*(int *)900000 = 25;     /* cast 900000 to a pointer */
                         /* if writeable address space, it works */
                         /* that memory location just changed */
```


x

Pointer returns from a function call (NULL Examples)

This function returns a pointer to the character that follows the first comma ','

```
char *next(char *ptr)
{
    if (ptr == NULL)
        return NULL;

    while ((*ptr != '\0') && (*ptr != ','))
        ptr++;

    if (*ptr == ',')
        return ++ptr;
    return NULL;
}
```

```
#include <stdlib.h>
#include <stdio.h>
#define BUFSZ 512
char *next(char *);

int main()
{
    char buf[BUFSZ];
    char *ptr;

    while (fgets(buf, BUFSZ, stdin) != NULL) {
        printf("buf: %s\n", buf);

        if ((ptr = next(buf)) != NULL)
            printf("after: %s\n", ptr);
        else
            printf("no comma found\n");
    }
    return EXIT_SUCCESS;
}
```

Returning a Pointer To a Local Variable (Dangling Pointer)

- There are many situations where a function will return a pointer, but a function must never return a pointer to a memory location that is no longer valid such as:

1. Address of a passed parameter copy as the caller may or will deallocate it after the call
2. Address of a local variable (automatic) that is invalid on function return

- These errors are called a dangling pointer

n is a parameter with the scope of bad_idea it is no longer valid after the function returns

```
int *bad_idea(int n)
{
    return &n; // NEVER do this
}
```

a is an automatic (local) with a scope and **<u>lifetime</u>** within bad_idea2
a is no longer a valid location after the function returns

```
int *bad_idea2(int n)
{
    int a = n * n;
    return &a; // NEVER do this
}
```

```
/*
 * this is ok to do
 * it is NOT a dangling
 * pointer
 */

int *ok(int n)
{
    static int a = n * n;
    return &a; // ok
}
```


X

String Literals (Read-Only) in Expressions

- When strings in quotations (*e.g.*, "string") are **part of** an **expression** (*i.e.*, *not* part of an *array initialization*) they are called ***string literals***

```
printf("literal\n");
printf("literal %s\n", "another literal");
```

- What is a ***string literal:***
  - Is a null-terminated string in a `const char array`
  - Located in the **read-only data** segment of memory
  - Is not assigned a variable name by the compiler, so it is only accessible by the location in memory where it is stored
- **String literals** are a type of ***anonymous variable***
  - Memory containing data without a name bound to them (only the address is known)
- The *string literal* in the printf()'s, are replaced with the starting address of the corresponding array (first or [0] element) when the code is compiled

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String Literals, Mutable and Immutable arrays - 1

- mess1 is a **mutable** array (type is char [ ]) with enough space to hold the string + '\0'

```
char mess1[] = "Hello World";
*(mess1 + 5) = '\0'; // shortens string to "Hello"
```

mess1[ ] `Hello World\0`

- mess2 is a **pointer** to an **immutable** array with space to hold the string + '\0'

```
char *mess2 = "Hello World";      // "Hello World" read only string literal
                                  // mess2 is a pointer NOT an array!
*(mess2 + 1)  = '\0';             // Not OK (bus error)
```

mess2 → `Hello World\0` ← read only string literal

- mess3 is a pointer to a mutable array

```
char *mess3 = (char []) {"Hello World"};  // mutable string
*(mess3 + 1)  = '\0';                     // ok
```

using the cast (char [ ]) makes it mutable

mess3 → `Hello World\0` ← mutable string

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2D Array of Char (where elements may contain strings)

- 2D array of chars (where rows may include strings)
- Each row has the same fixed number of memory allocated
- All the rows are the same length regardless of the actual string length
- The **column size must be large enough for the longest string**

```
char aos[3][22] = {"my", "two dimensional", "char array"};
```

high memory

aos[2]	c	h	a	r		a	r	r	a	y	'\0'											
aos[1]	t	w	o		d	i	m	e	n	s	i	o	n	a	l		a	r	r	a	y	'\0'
aos[0]	m	y	'\0'																			

low memory

high memory

```
#define ROWS 3
char aos[ROWS][22] = { "my", "two dimensional", "char array"};
char (*ptc)[22] = aos;  // ptr points at a row of 22 chars

for (int i = 0; i < ROWS; i++)
    printf("%s\n", *(ptc + i));
```


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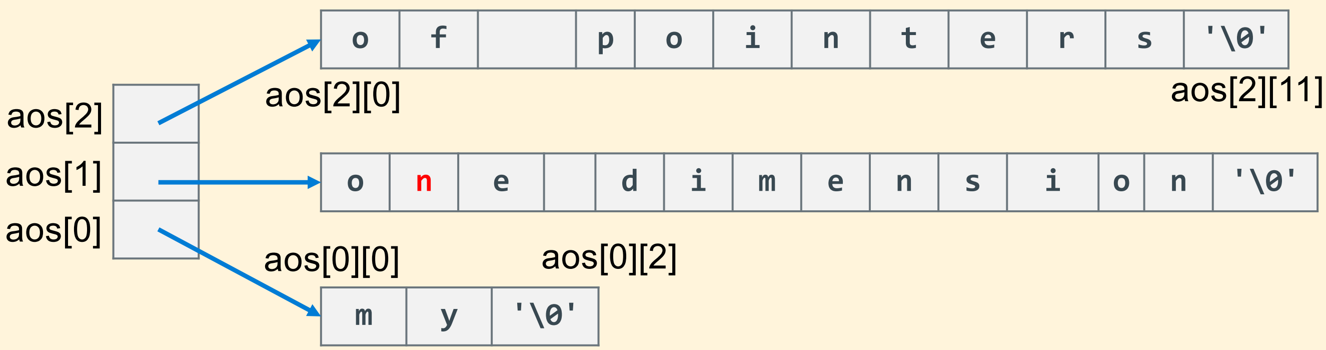
Array of Pointers to Strings (This is NOT a 2D array)

- 2D char arrays are an inefficient way to store strings (wastes memory) unless all the strings are similar lengths, so 2D char arrays *are rarely used* with string elements
- **An array of pointers** is common for strings as *"rows"* can very in length
- char *aos[3];



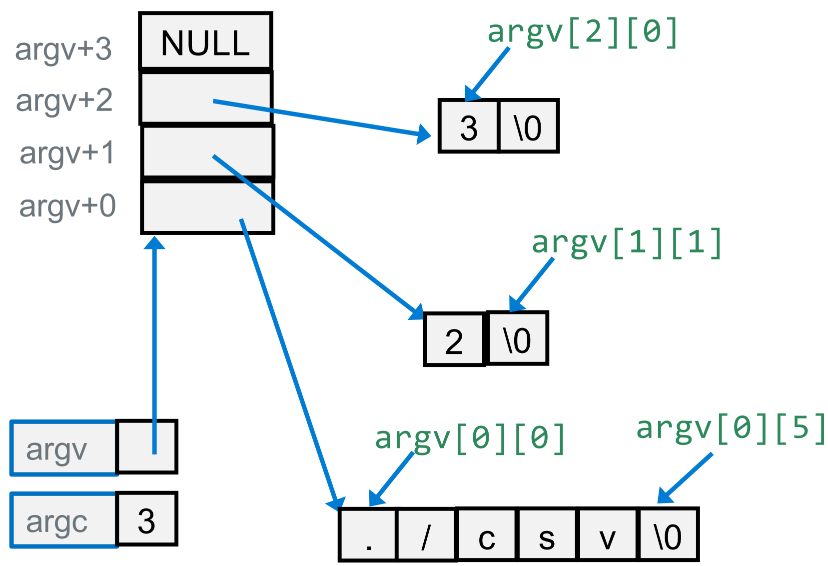
- `aos` is an array of pointers; each pointer points at a character array (also a string here)
- Not a 2D array, but any char can be accessed as if it was in a 2D array of chars
  - When I was learning, this was the most confusing syntax aspects of C

x

main() Command line arguments: argc, argv

- Arguments are passed to main() as a pointer to an array of pointers to char arrays (strings)`(**argv)`

  `Conceptually: % *argv[0] *argv[1] *argv[2] ….`
- `argc` is the number of VALID elements (they point at something)
- `*argv (argv[0]) is` **usually** is the name of the executable file (% ./vim file.c)
- `*(argv + argc)` always contains a NULL (0) sentinel
- `*argv[] (or **argv)` elements point at **mutable strings**!



% ./csv 2 3

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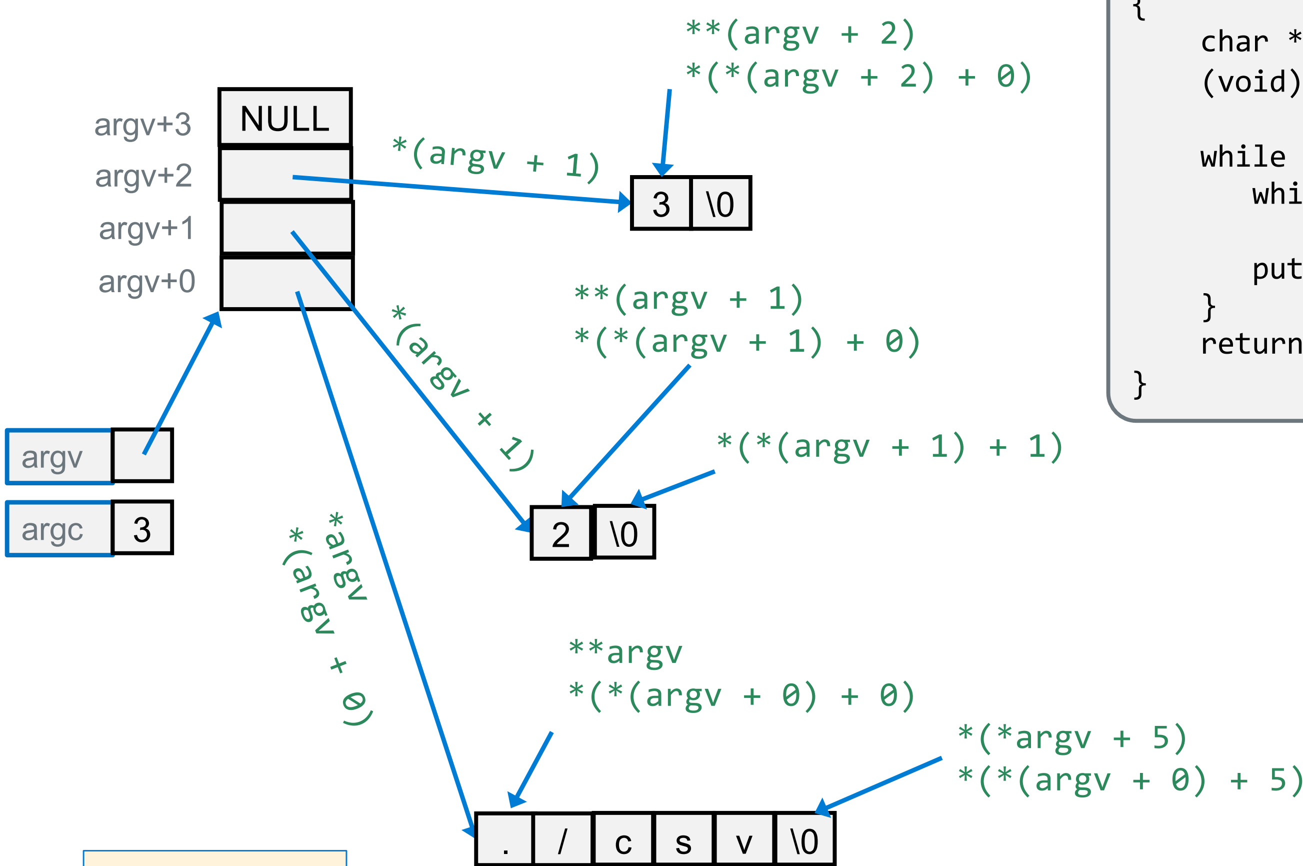
Printing argv char at a time



% ./csv 2 3

```
int main(int argc, char **argv)
{
    char *pt;
    (void)argc; // shut up the compiler

    while ((pt = *argv++) != NULL) {
       while (*pt != '\0')
           putchar(*pt++);
       putchar('\n');
    }
    return EXIT_SUCCESS;
}
```

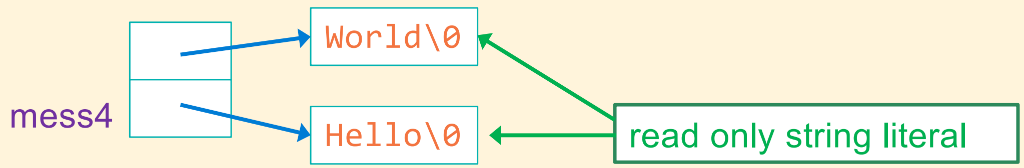

x

Defining an Array of Pointer to Strings

- mess4 is an array of pointers to immutable arrays

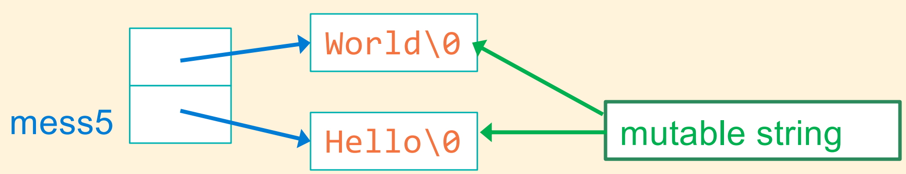
```
char *mess4[] = {"Hello","World"};  // immutable string
*(*mess4 + 1)  = '\0';              // bus error
```

Bus error: writing read only memory
Seg fault: writing unallocated memory



- mess5 is an array of pointers to mutable arrays

```
char *mess5[] = { (char []){"Hello"}, (char []){"World"}};
*(*mess5 + 1)  = '\0';                  // OK!
```



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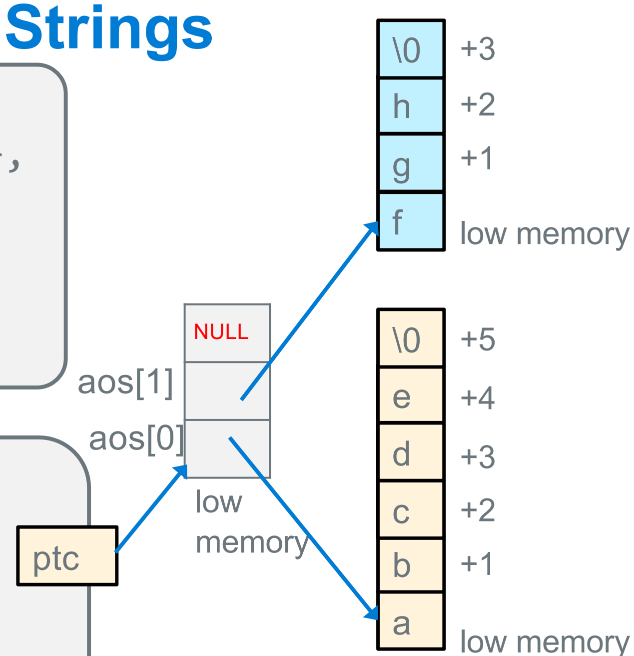
Defining an Array of Pointers to Mutable Strings

- Make an array of pointers to mutable strings requires using a cast to an array (char [ ])
- Add a NULL sentinel at the end to indicate the end of the array

```
char *aos[] = {
   (char []) {"abcde"},
   (char []) {"fgh"},
   (char *)  {NULL}
};
char **ptc = aos;
```




```
printf("%c\n", *(*(aos + 1) + 1));

while (*ptc != NULL) {
    printf("%s\n", *ptc);     // prints string

    for (int j = 0; *(*ptc + j); j++)
        putchar(*(*ptc + j)); // char in string

    putchar('\n');
    ptc++;
}
```

```
%./a.out
abcde
abcde
fgh
fgh
```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Pointers to Functions (Function Pointers)

- Similar in concept to an array name, a function name ends up being the address of the first instruction in a function
- A function pointer variable contains the address of a function
- Generic format:

```
returnType (*name)(type1, …, typeN)
```

  - Looks like a function prototype with extra `*` in front of name
  - Why are parentheses around `(*name)` needed?

```
returnType *name(type1, …, typeN) //wrong
```

    - Above says name is a function returning a pointer to returnType
- Using the function:

```
(*name)(arg1, …, argN)
```

```
name(arg1, …, argN)
```

Calls the pointed-to function with the given arguments and returns the return value

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Pointers to Function Example

```
int add1(int);
int sqr(int);
void array_update(int (*)(int), int *, int);
void print_array(int *, int);

int main(void)
{
    int array[] = {4, 8, 15, 16, 23, 42};
    int cnt = sizeof(array)/sizeof(array[0]);

    print_array(array, cnt);
    array_update(add1, array, cnt);
    print_array(array, cnt);
    array_update(sqr, array, cnt);
    print_array(array, cnt);
    return EXIT_SUCCESS;
}
```

```
void array_update(int (*f)(int), int *a, int cnt)
{
    while (a < endpt) {
        *a = f(*a);
        a++;
    }
}
```

```
void print_array(int *a, int cnt)
{
    int *endpt = a + cnt;

    while (a < endpt)
        printf("%d ", *a++);
    printf("\n");
}
```

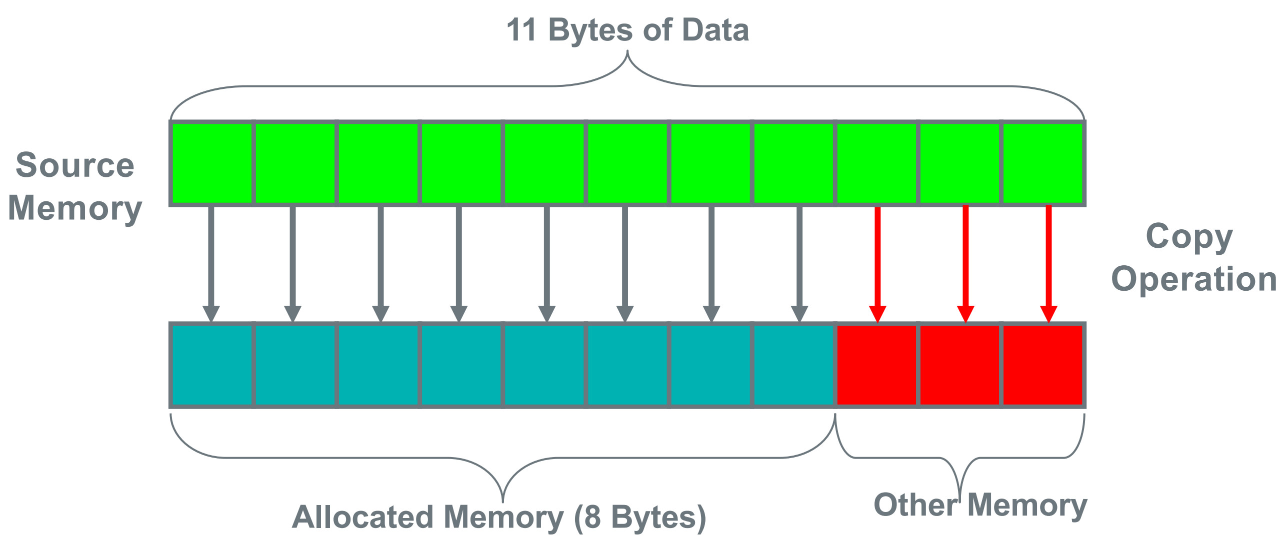
```
int add1(int i)
{
    return i + 1;
}

int sqr(int i)
{
    return i * i;
}
```

```
%./a.out
4 8 15 16 23 42
5 9 16 17 24 43
25 81 256 289 576 1849
```


x

string buffer overflow: common security flaw

- A buffer overflow occurs when data is written outside the boundaries of the memory allocated to target variable (or target buffer)
- `strcpy()` is a very *common source of buffer overrun security flaws*:
  - always ensure that the destination array is **large enough** (and don't forget the null terminator)
- `strcpy()` can cause problems when the ***destination*** and **source** regions ***overlap***



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strcpy() buffer overflow: over-write of an adjacent variable

```
int main(void)
{
    char s1[] = "before";
    char r2[] = "xyz";
    char s2[] = "after";

    printf("s2: %s\nr2: %s\nr2: %s\n", s2, r2, s1);

    strcpy(r2,"hello");

    printf("\ns2: %s\nr2: %s\nr2: %s\n",s2,r2,s1);
    return EXIT_SUCCESS;
}
```

these are mutable arrays, not literals

compile on pi-cluster with gcc test.c

```
./a.out
s2: after
r2: xyz
s1: before

s2: after
r2: hello
s1: o
```

s2[0]	s2[1]	s2[2]	s2[3]	s2[4]	s2[5]	r2[0]	r2[1]	r2[2]	r2[3]	s1[0]	s1[1]	s1[2]	s1[3]	s1[4]	s1[5]	s1[6]
'a'	'f'	't'	'e'	'r'	'\0'	'x'	'y'	'z'	'\0'	'b'	'e'	'f'	'o'	'r'	'e'	'\0'

low memory address

before strcpy() overflow

high memory address

s2[0]	s2[1]	s2[2]	s2[3]	s2[4]	s2[5]	r2[0]	r2[1]	r2[2]	r2[3]	s1[0]	s1[1]	s1[2]	s1[3]	s1[4]	s1[5]	s1[6]
'a'	'f'	't'	'e'	'r'	'\0'	'h'	'e'	'l'	'l'	'o'	'\0'	'f'	'o'	'r'	'e'	'\0'

after strcpy() overflow

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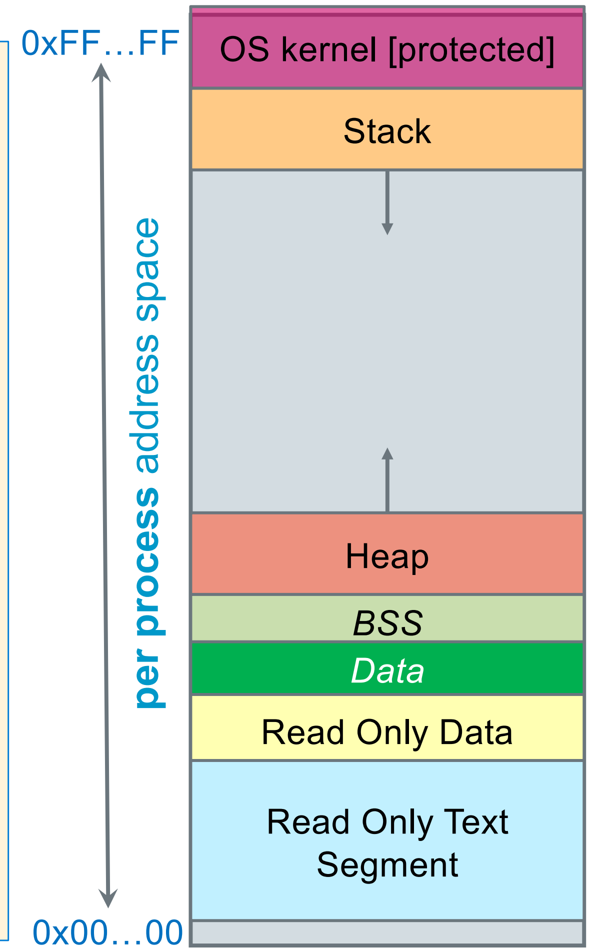
Process Memory Under Linux

- When your program is running it has been loaded into memory and is called a process
- *Stack segment: Stores Local* variables
    - Allocated and freed at function call entry & exit
- *Data segment + BSS: Stores Global* and *static* variables
    - Allocated/freed when the process starts/exits
    - BSS - Static variables with an implicit initial value
    - Static Data - Initialized with an explicit initial value
- Heap segment: *Stores dynamically-allocated* variables
    - Allocated with a function call
    - Managed by the stdio library malloc() routines
- *Read Only Data: Stores immutable* Literals
- *Text*: Stores your code in machine language + libraries



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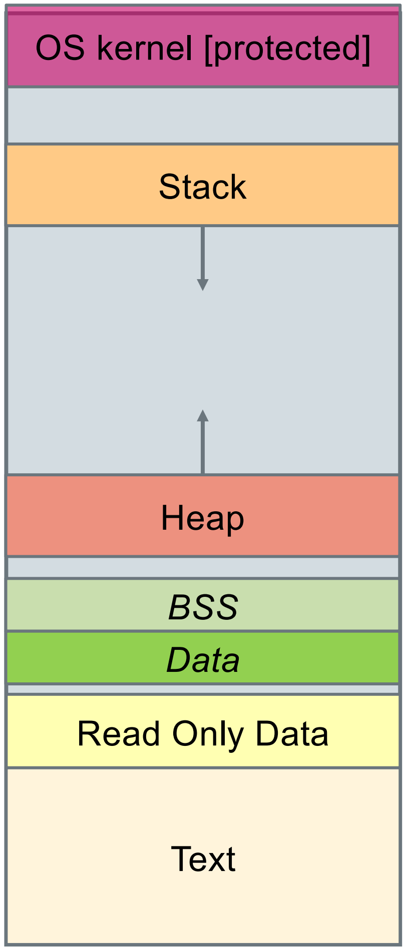
The Heap Memory Segment

- **Heap**: "pool" of memory that is available to a program
  - Managed by C runtime library and linked to your code; **not managed by the OS**
- Heap memory is **dynamically** *"borrowed"* *or "allocated"* by calling a library function
- When heap memory is no longer needed, it is *"returned" or deallocated for* **reuse**
- Heap memory has a lifetime from allocation until it is deallocated
  - Lifetime is independent of the scope it is allocated in (it is like a static variable)
- If too much memory has already been allocated, the library will attempt to borrow additional memory from the OS and will fail, returning a NULL



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Heap Dynamic Memory Allocation Library Functions

#include <stdlib.h>	args	Clears memory
void *malloc(…)	size_t size	no
void *calloc(…)	size_t nmemb, size_t memsize	yes
void free(...)	void *ptr	no

- **void *** means these library functions return a pointer to generic (untyped) memory
  - Be careful with void * pointers and pointer math as void * points at untyped memory
  - The assignment to a typed pointer *"converts"* it from a void *
- **size_t is** an unsigned integer data type, the result of a sizeof() operator

```
int *ptr = malloc(sizeof(*ptr) * 100); // allocate an array of 100 ints
```

- **please read: % man 3 malloc**

x

Use of Malloc

`void *malloc(size_t size)`

- Returns a pointer to a **contiguous** block of **`size`** bytes **of uninitialized memory** from the heap
  - The block is **aligned to an 8-byte (arm32) or 16-byte (64-bit arm/intel) boundary**
  - returns **`NULL`** if allocation failed (also sets **`errno`**) **always CHECK for NULL RETURN!**
- Blocks returned on different calls to malloc() are not necessarily adjacent
- **`void *`** is implicitly cast into any pointer type on assignment to a pointer variable

```
char *bufptr;

/* ALWAYS CHECK THE RETURN VALUE FROM MALLOC!!!! */

if ((bufptr = malloc(cnt * sizeof(*bufptr))) == NULL) {
    fprintf(stderr, "Unable to malloc memory");
    return NULL;
}
```


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Using and Freeing Heap Memory

- `void free(void *p)`
  - Deallocates the whole block pointed to by **`p`** to the pool of available memory
  - Freed memory is used in future allocation (expect the contents to change after freed)
  - Pointer **`p`** must be the same address as *originally returned* by one of the heap allocation routines **`malloc()`**, **`calloc()`**, **`realloc()`**
  - Pointer argument to free() is not changed by the call to free()
- Defensive programming: set the pointer to NULL after passing it to free()

```
free(bufptr);                    // returns memory to the heap
bufptr = NULL;                  // set bufptr to NULL
```


x

Heap Memory "Leaks"

- A memory leak is when you **allocate memory** on the heap, **but never free it**

```
void
leaky_memory (void)
{
    char *bytes = malloc(BLKSZ * sizeof(*bytes));
…
    /* code that never deallocates the memory */
    return;  // you lose the address in bytes when leaving scope
}
```

- Best practice: free up memory you allocated when you no longer need it
  - If you keep allocating memory, you may run out of memory in the heap!
- Memory leaks may cause long running programs to fault when they exhaust OS memory limits
- Valgrind is a tool for finding memory leaks (not pre-installed in all linux distributions though!)

x

Valgrind – Finding Buffer Overflows and Memory leaks

```c
 1 #define SZ 50
 2 #include <stdlib.h>
 3 int main(void)
 4 {
 5     char *buf;
 6     if ((buf = malloc(SZ * sizeof(*buf))) == NULL)
 7         return EXIT_FAILURE;
 8     *(buf + SZ) = 'A';
 9     return EXIT_SUCCESS;
10 }
```

```
% valgrind -q --leak-check=full --leak-resolution=med -s ./valgexample
==651== Invalid write of size 1
==651==    at 0x10444: main (valg.c:8)
==651==  Address 0x49d305a is 0 bytes after a block of size 50 alloc'd
==651==    at 0x484A760: malloc (vg_replace_malloc.c:381)
==651==    by 0x1041B: main (valg.c:6)
==651==
==651== 50 bytes in 1 blocks are definitely lost in loss record 1 of 1
==651==    at 0x484A760: malloc (vg_replace_malloc.c:381)
==651==    by 0x1041B: main (valg.c:6)
==651==
==651== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 0 from 0)
```

Writing outside of allocated buffer space

Memory not freed

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More Dangling Pointers: Reusing "freed" memory

- When a pointer points to a memory location that is no longer “valid”
- Really hard to debug as the use of the return pointers may not generate a seg fault

```
char *dangling_freed_heap(void)
{
    char *buff = malloc(BLKSZ * sizeof(*buff));
…
    free(buff);
    return buff;
}
```

- `dangling_freed_heap()` type code often causes the allocators (**`malloc()`**and friends) to **seg fault**
  - Because it corrupts data structures the heap code uses to manage the memory pool

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strdup(): Allocate Space and Copy a String

```
char *strdup(char *s);
```

- **`strdup`** is a function that returns a **null-terminated**, heap-allocated string copy of the provided text
- Alternative: **`malloc`** and copy the string

```
char *str = strdup("Hello, world!");
*str = 'h';

free(str);
str = NULL;
```

Calloc()

```
void *calloc(size_t elementCnt, size_t elementSize)
```

`calloc()` variant of **`malloc()`** but zeros out every byte of memory before returning a pointer to it (so this has a runtime cost!)

- First parameter is the number of elements you would like to allocate space for
- Second parameter is the size of each element

```
// allocate 10-element array of pointers to char, zero filled
char **arr;
arr = calloc(10, sizeof(*arr));
if (arr == NULL)
  // handle the error
```

- Originally designed to allocate arrays but works for any memory allocation
  - **`calloc()`** multiplies the two parameters together for the total size
- **`calloc()`** is more expensive at runtime (uses both cpu and memory bandwidth) than **`malloc()`** because it must zero out memory it allocates at runtime
- Use `calloc()` only when you need the buffer to be zero filled prior to FIRST use

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Introduction to Structs – An Aggregate Data Type

- **Structs** are a **collection (or aggregation) of values** grouped under a **single name**
  - Each variable in a struct is called a **member** (sometimes **field** is used)
  - Each member is identified with a name
  - Each member can be (and quite often are) different types, include other structs
  - Like a Java class, but no associated methods or constructors with a struct
- Structure definition **does not** define a variable instance, nor does it allocate memory:
  - It creates a new variable type uniquely identified by its tagname:

    "struct tagname" includes the keyword struct and the tagname for this type

Easy to forget semicolon!

```c
struct tagname {
  type1 member1;
  ...
  typeN memberN;
};
```

```c
struct vehicle {
  char *state;
  char *plate;
  char *make;
  int year;
};
```


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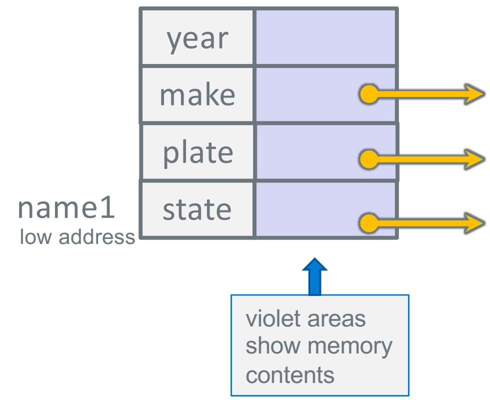
Struct Variable Definitions

```
struct vehicle {
  char *state;
  char *plate;
  char *make;
  int year;
};
struct vehicle name1;
```



- Variable definitions like any other data type:

```
struct vehicle name1, *pn, ar[3];
```

type: "struct vehicle"

single variable instance

pointer

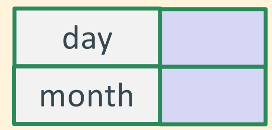
array

x

Accessing members of a struct

- Like arrays, struct variables are aggregated contiguous objects in memory
- The `.` structure operator which *"selects"* the requested field or member

```c
struct date {// defining struct type
    int month;
    int day; // members date struct
};
```



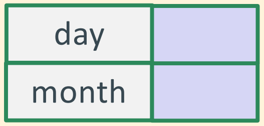

```c
struct date bday; // struct instance
bday.month = 1;
bday.day = 24;

// shorter initializer syntax
struct date new_years_eve = {12, 31};
struct date final = {.day= 24, .month= 1};
```

struct date bday

x

Accessing members of a struct with pointers

```
struct date {// defining struct type
    int month;
    int day; // members date struct
};
```



- Now create a *pointer* to a struct

```
struct date *ptr = &bday;
```

- Two options to reference a member via a struct pointer (. is higher precedence than *):
- Use `*` and `.` operators: `(*ptr).month = 11;`
- Use `->` operator for shorthand: `ptr->month = 11;`

Operator	*Description*	*Associativity*
() **[]** **.** **->** **++ --**	Parentheses or function call Brackets or array subscript Dot or Member selection operator Arrow operator Postfix increment/decrement	left to right
++ -- **+ -** **! ~** **(type)** ***** **&** **sizeof**	Prefix increment/decrement Unary plus and minus not operator and bitwise complement type cast Indirection or dereference operator Address of operator Determine size in bytes	right to left

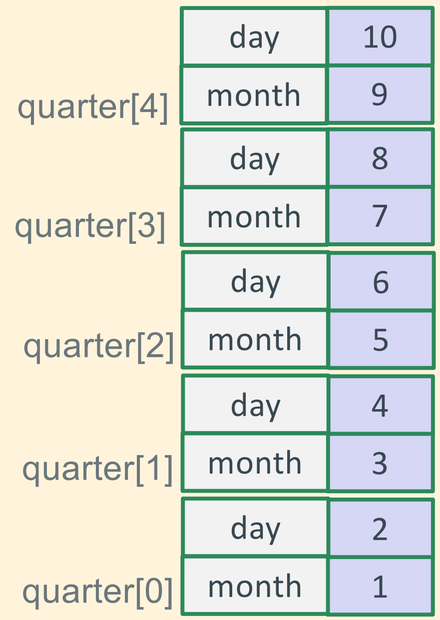
x

Accessing members of a struct

```
struct date {     // defining struct type
    int month;
    int day;      // members date struct
};
```

- You can create an array of structs and initialize them

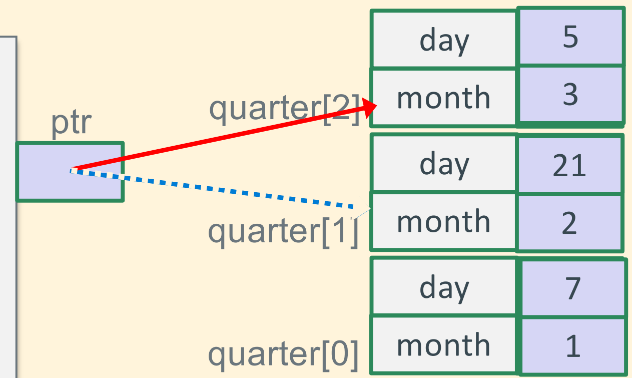
```
struct date quarter[] =
             { {1,2}, {3,4}, {5,6}, {7,8}, {9,10} };

int cnt = sizeof(quarter)/sizeof(*quarter);  // = 5
```



x

Accessing members of a struct

```
struct date quarter[3];
struct date *ptr;

ptr = quarter + 1;  // array name = address
ptr->month = 2;
ptr->day = 21;   // or (*ptr).day = 21;

(ptr-1)->month = 1; // or (*(ptr-1)).month = 4;
(ptr-1)->day = 7;

(++ptr)->month = 3;
ptr->day = 5;
```



Operator	*Description*	*Associativity*
() [] . -> ++ --	Parentheses or function call Brackets or array subscript Dot or Member selection operator Arrow operator Postfix increment/decrement	left to right
++ -- + - ! ~ (type) * & sizeof	Prefix increment/decrement Unary plus and minus not operator and bitwise complement type cast Indirection or dereference operator Address of operator Determine size in bytes	right to left

x

Typedef usage with Struct – Another Style Conflict

- *Typedef* is a way to create an *alias* for another data type (not limited to just structs)

  `typedef <data type> <alias>;`

  - After typedef, the alias can be used interchangeably with the original data type
  - *e.g.*, `typedef unsigned long int size_t;`
- *Many claim typedefs* are easier to understand than tagged struct variables
  - typedef with structs are not allowed in the cse30 style guidelines (Linux kernel standards)

```
struct nm {
  /* fields */
};
typedef struct nm item;

item n1;
struct nm n2;
item *ptr;
struct nm *ptr2;
```

```
typedef struct name2_s {
    int a;
    int b;
} name2_s;

name2_s var2;
name2_s *ptr2;
```

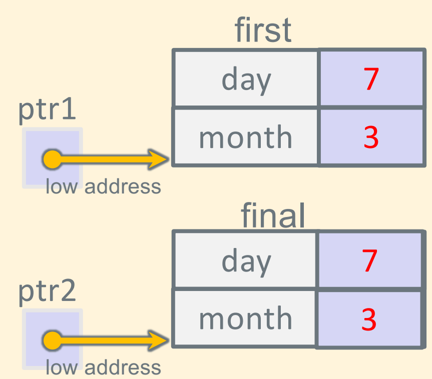
```
typedef struct {
    int a;
    int b;
} pair;

pair var3;
pair *ptr3;
```


x

Copying Structs

- You can assign the member value(s) of the whole struct from a struct of the same type – *this copies the entire contents!*
- Individual fields can also be copied

```
struct date first = {1, 1};
struct date final = {.day= 31, .month= 12};

struct date *pt1 = &first;
struct date *pt2 = &final;

final.day = first.day; // both day are 1
final = first;         // copies whole struct

pt2->month = 3;
*pt1 = *pt2;           // copies whole struct
pt2->day = 7;
pt1->day = pt2->day;  // both days are now 7
```



x

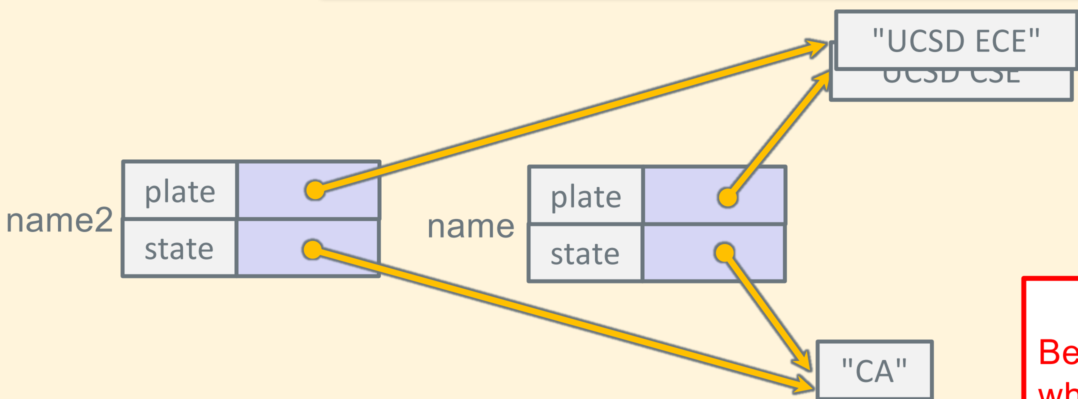
Struct: Copy and Member Pointers

```c
struct vehicle {
  char *state;
  char *plate;
};
```

```c
struct vehicle name  = {"CA", "UCSD CSE"};
struct vehicle name2;
```

- When you assign one struct to another it just copies the member fields!

```c
name2 = name;   // copies members Only
```




```c
name2.plate = "UCSD ECE";
```

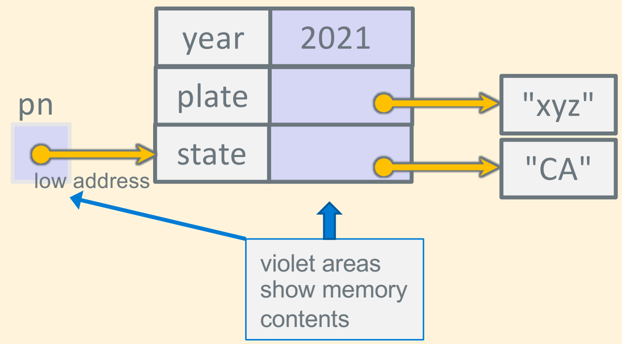
Warning
Be **very careful** with "shallow copies" in C
when pointers are involved

x

Memory Allocation Structs with Pointer Members

- **Safety first:** Allocate anything that is pointed at by a struct member independently (they are not part of the struct, only the pointers are)

```
struct vehicle {
  char *state;
  char *plate;
  int year;
};
struct vehicle name1;
pn = &name1;
```




```
name1.state = strdup("CA");
pn->plate = strdup("xyz");
pn->year = 2021;
```

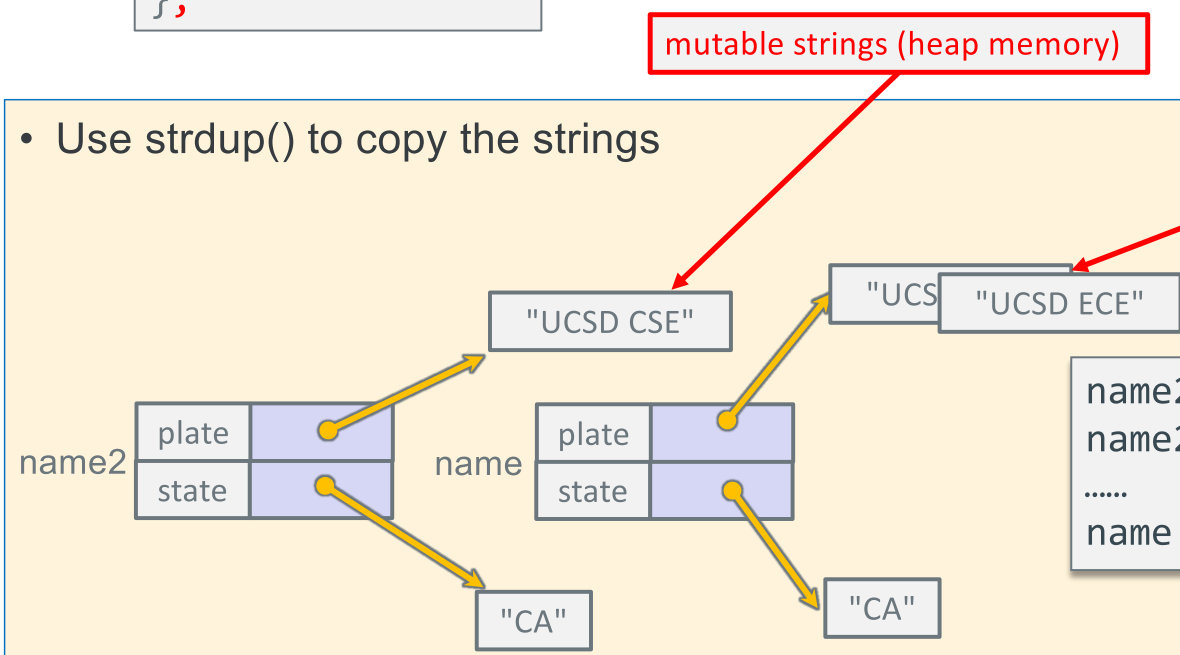

x

Struct: Copy and Member Pointers --- "Deep Copy"

```c
struct vehicle {
  char *state;
  char *plate;
};
```

```c
struct vehicle name  = {"CA", "UCSD CSE"};
struct vehicle name2;
```

- Use strdup() to copy the strings




```c
name2.plate = strdup(name.plate);
name2.state = strdup(name.state);
……
name.plate = "UCSD ECE";
```

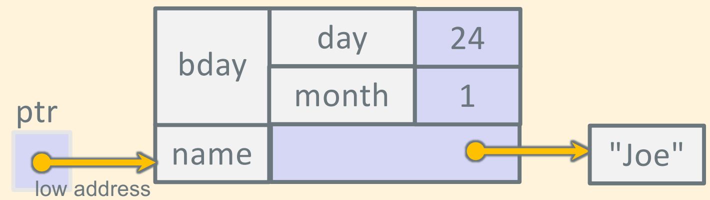

x

Nested Structs

- Structs like any other variable can be a member of a struct, this is called a nested struct

```
struct date {
    int month;
    int day;
};
```

```
struct person {
    char *name;
    struct date bday;
};
```



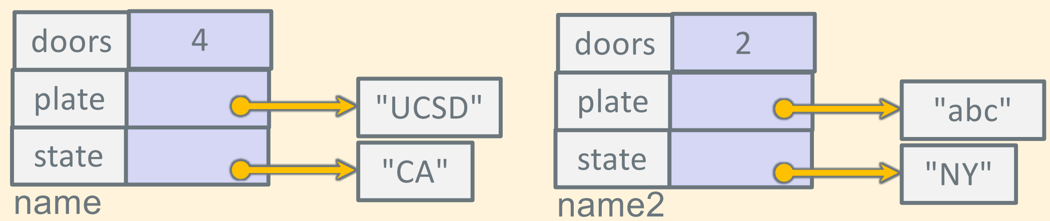

```
struct person first;
struct person *ptr;
ptr = &first;

first.name = "Sam";               // immutable string
first.name = (char []) {"Joe"}; // mutable string, lost address to Sam

first.bday.month = 1;
first.bday.day = 24;

// below is the same as above
ptr->bday.month = 1;
ptr->bday.day = 24;
```


X

Comparing Two Structs

- You cannot compare entire structs, you must compare them one member at a time

```
struct vehicle {
  char *state;
  char *plate;
  int doors;
};
```




```
struct vehicle name  = {"CA", "UCSD", 4};
struct vehicle name2 = { (char []) {"NY"}, (char []) {"abc"}, 2};
```

```
if ((strcmp(name.state, name2.state) == 0) &&
    (strcmp(name.plate, name2.plate) == 0) &&
    (name.doors == name2.doors)) {
    printf("Same\n");
} else {
    printf("Different\n");
}
```

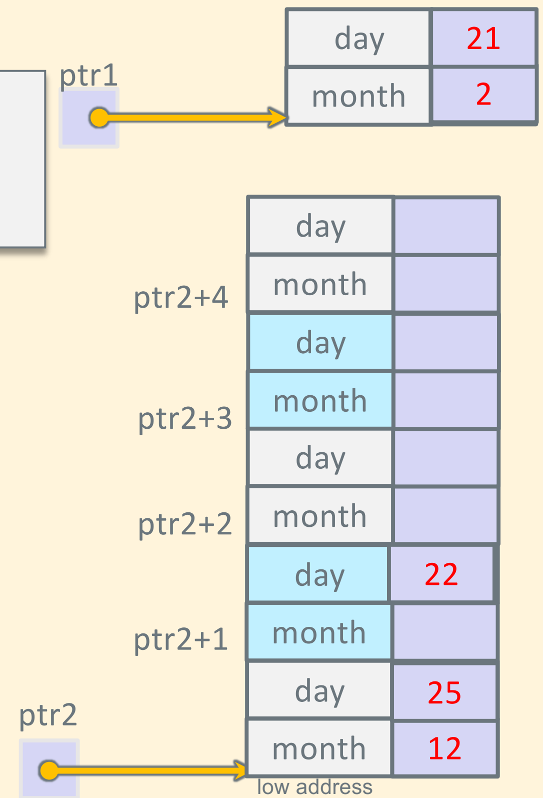

x

Struct: Arrays and Dynamic Allocation

- Allocate individual structs and arrays of structs using malloc()
  - Remember . is higher precedence than *:

```
#define HOLIDAY 5
struct date *pt1 = malloc(sizeof(*pt1));
struct date *pt2 = malloc(sizeof(*pt2) * HOLIDAY);
```

```
(*ptr1).month = 2;
(*ptr1).day = 21;

pt2->month = 12;
pt2->day = 25;
(pt2+1)->day = 22;   //or (*(pt2+1)).month

free(pt1);
pt1 = NULL;
free(pt2);
pt2 = NULL;
```



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Struct As A Parameter to Functions

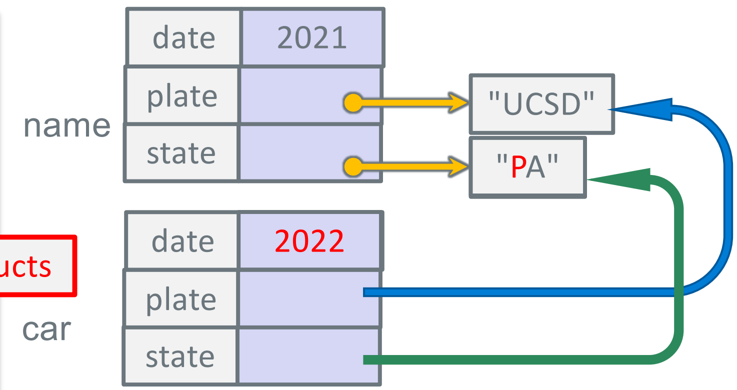
- WARNING: When you pass a struct, **you pass a copy** of all the struct members
  - This is a shallow copy (shallow copy – so if you have members that are pointers watch out)
- More often code will pass the pointer to a struct to avoid the copy costs
  - Be careful and not modify what the pointer points to (unless it is an output parameter)
- Tradeoffs:
  - Passing a pointer is cheaper and takes less space unless struct is small
  - Member access cost: indirect accesses through pointers to a struct member may be a bit more expensive and might be harder for compiler to optimize
- For small structs like a struct date passing a copy is fine
- For large structs always use pointers (arrays of struct, being an array is always a pointer)
  - For me, I always use pointers regardless of size, but that is just maybe a decades old habit…

x

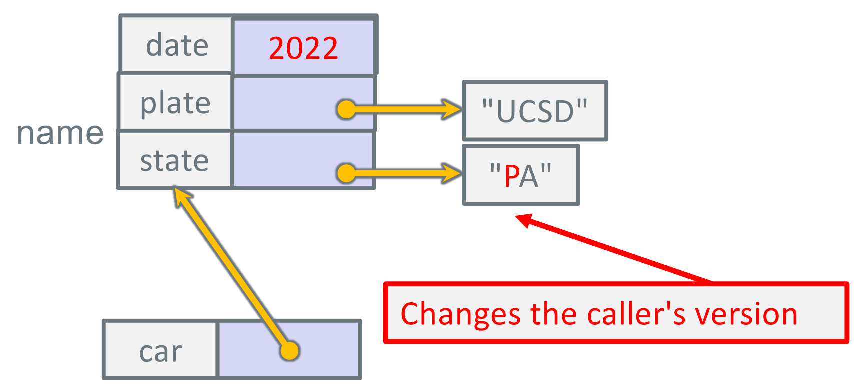
Struct as a Parameter to Functions – Be Careful it is not like arrays

```
void change1(struct vehicle car)
{
    car.date = 2022; // oops!
   *(car.state) = "P";
}
…
change1(name);
```

Changes two different structs



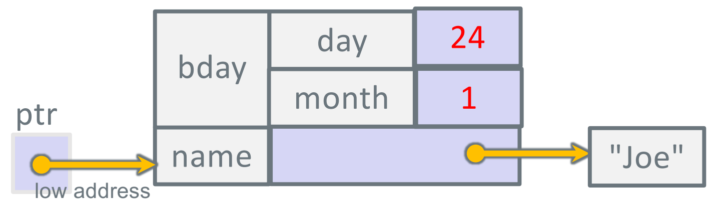

```
void change2(struct vehicle *car)
{
    car->date = 2022;
   *(car->state) = "P";
}
…
change2(name);
```



Struct as an Output Parameter: Deep Copy Example

```
struct date {
    int month;
    int day;
};
```

```
struct person {
    char *name;
    struct date bday;
};
```




```
int fill(struct person *ptr, char *name, int month, int day)
{
    ptr->bday.month = month;
    ptr->bday.day = day;
    if ((ptr->name = strdup(name)) == NULL)
        return -1;
    return 0;
}
…-----------------calling function ----------
    struct person first;
    if (fill(&first, "Joe", 1, 24) == 0)
        printf("%s %d %d\n", first.name, first.bday.month, first.bday.day);
…
```


x