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CS61C : Machine Structures

Lecture #3: C Pointers & Arrays

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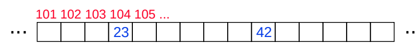
Andy Carle

Address vs. Value

- **What good is a bunch of memory if you can't select parts of it?**
  - **Each memory cell has an address associated with it.**
  - **Each cell also stores some value.**
- **Don't confuse the address referring to a memory location with the value stored in that location.**



Pointers

- **A pointer is just a C variable whose value is the address of another variable!**
- **After declaring a pointer:**

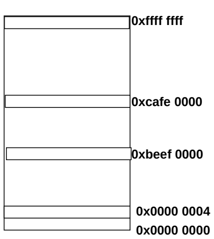
```
int *ptr;
```

`ptr` **doesn't actually point to anything yet. We can either:**
  - **make it point to something that already exists, or**
  - **allocate room in memory for something new that it will point to… (next time)**

Pointers

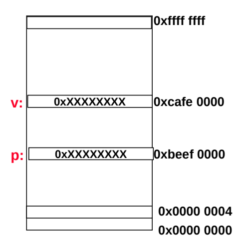
- **Declaring a pointer just allocates space to hold the pointer – it does not allocate something to be pointed to!**
- **Local variables in C are not initialized, they may contain anything.**

Pointer Usage Example



Memory and Pointers:

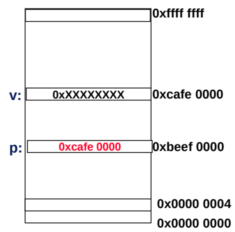
Pointer Usage Example



Memory and Pointers:

int *p, v;

Pointer Usage Example

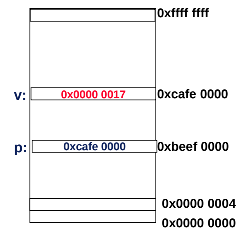


Memory and Pointers:

int *p, v;

p = &v;

Pointer Usage Example



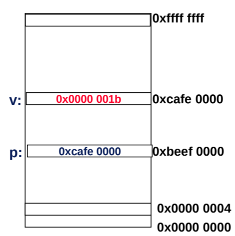
Memory and Pointers:

int *p, v;

p = &v;

v = 0x17;

Pointer Usage Example



Memory and Pointers:

int *p, v;

p = &v;

v = 0x17;

***p = *p + 4;**

V = *p + 4

Pointers in C

- **Why use pointers?**
  - **If we want to pass a huge struct or array, it's easier to pass a pointer than the whole thing.**
  - **In general, pointers allow cleaner, more compact code.**
- **So what are the drawbacks?**
  - **Pointers are probably the single largest source of bugs in software, so be careful anytime you deal with them.**
  - **Dangling reference (premature free)**
  - **Memory leaks (tardy free)**

C Pointer Dangers

- **What does the following code do?**

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```

- **S E G F A U L T ! (on my machine/os)**
  - **(Not a nice compiler error like you would hope!)**

C Pointer Dangers

- **Unlike Java, C lets you cast a value of any type to any other type <u>without</u> performing any checking.**

```
int x = 1000;
int *p = x;         /* invalid */
int *q = (int *) x; /* valid */
```

- **The first pointer declaration is invalid since the types do not match.**
- **The second declaration is valid C but is almost certainly wrong**
  - **Is it ever correct?**

Pointers and Parameter Passing

- Java and C pass a parameter "by value"
  - procedure/function gets a copy of the parameter, so changing the copy cannot change the original

```
void addOne (int x) {
   x = x + 1;
}
int y = 3;
addOne(y);
```

- y is still = 3

Pointers and Parameter Passing

- How to get a function to change a value?

```
void addOne (int *p) {
  *p = *p + 1;
}
int y = 3;

addOne(&y);
```

- y is now = 4

Arrays (1/7)

- **Declaration**:

```
int ar[2];
```

declares a 2-element integer array.

```
int ar[] = {795, 635};
```

declares <u>and fills</u> a 2-elt integer array.

- **Accessing elements**:

```
ar[num];
```

returns the `num`th element from 0.

Arrays (2/7)

- Arrays are (almost) identical to pointers
  - `char *string` and `char string[]` are nearly identical declarations
  - They differ in very subtle ways: incrementing, declaration of filled arrays
- **Key Difference**:

An array variable is a **CONSTANT** pointer to the first element.

Arrays (3/7)

- Consequences:
  - `ar` is a pointer
  - `ar[0]` is the same as `*ar`
  - `ar[2]` is the same as `*(ar+2)`
  - We can use pointer arithmetic to access arrays more conveniently.
- Declared arrays are only allocated while the scope is valid

```
char *foo() {
   char string[32]; ...;
   return string;
}
```

is incorrect

Arrays (4/7)

- Array size `n`; want to access from `0` to `n-1`:

```
int ar[10], i=0, sum = 0;
...
while (i < 10)
    /* sum = sum+ar[i];
       i = i + 1; */

    sum += ar[i++];
```

Arrays (5/7)

- Array size `n`; want to access from `0` to `n-1`, so you should use counter AND utilize a constant for declaration & incr
  - Wrong
    ```
    int i, ar[10];
    for(i = 0; i < 10; i++){ ... }
    ```
  - Right
    ```
    #define ARRAY_SIZE 10
    int i, a[ARRAY_SIZE];
    for(i = 0; i < ARRAY_SIZE; i++){ ... }
    ```
- Why? SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10

Arrays (6/7)

- Pitfall: An array in C does not know its own length, & bounds not checked!
  - Consequence: We can accidentally access off the end of an array.
  - Consequence: We must pass the array and its size to a procedure which is going to traverse it.
- Segmentation faults and bus errors:
  - These are VERY difficult to find; be careful!
  - You'll learn how to debug these in lab…

Arrays 7/7: In Functions

- An array parameter can be declared as an array or a pointer; an array argument can be passed as a pointer.
  - Can be incremented

```
int strlen(char s[])
{
    int n = 0;
    while (s[n] != 0)
        n++;
    return n;
}
```

```
int strlen(char *s)
{
    int n = 0;
    while (s[n] != 0)
        n++;
    return n;
}
```

Could be written: `while (s[n])`

Pointer Arithmetic (1/5)

- Since a pointer is just a mem address, we can add to it to traverse an array.
- `p+1` returns a ptr to the next array elt.
- `(*p)+1` vs `*p++` vs `*(p+1)` vs `*(p)++` ?
  - `x = *p++` ⇒ `x = *p ; p = p + 1;`
  - `x = (*p)++` ⇒ `x = *p ; *p = *p + 1;`
- What if we have an array of large structs (objects)?
  - C takes care of it: In reality, `p+1` doesn't add `1` to the memory address, it adds the size of the array element.

Pointer Arithmetic (2/5)

- So what's valid pointer arithmetic?
  - Add an integer to a pointer.
  - Subtract 2 pointers (in the same array).
  - Compare pointers (<, <=, ==, !=, >, >=)
  - Compare pointer to `NULL` (indicates that the pointer points to nothing).
- Everything else is illegal since it makes no sense:
  - adding two pointers
  - multiplying pointers
  - subtract pointer from integer

Pointer Arithmetic (3/5)

- We can use pointer arithmetic to "walk" through memory:

```
void copy(int *from, int *to, int n) {
    int i;
    for (i=0; i<n; i++) {
        *to++ = *from++;
    }
}
```

° C automatically adjusts the pointer by the right amount each time (i.e., 1 byte for a `char`, 4 bytes for an `int`, etc.)

Pointer Arithmetic (4/5)

- C knows the size of the thing a pointer points to – every addition or subtraction moves that many bytes.
- So the following are equivalent:

```
int get(int array[], int n)
{
    return  (array[n]);
    /* OR */
    return *(array + n);
}
```


Pointer Arithmetic (5/5)

- Array size `n`; want to access from `0` to `n-1`
  - test for exit by comparing to address one element past the array

```
int ar[10], *p, *q, sum = 0;
...
p = ar; q = &(ar[10]);
while (p != q)
    /* sum = sum + *p; p = p + 1; */
    sum += *p++;
```

  - Is this legal?
- C defines that one element past end of array must be a valid address, i.e., not cause an bus error or address error

Pointer Arithmetic Summary

- `x = *(p+1)` ?
  - ⇒ `x = *(p+1) ;`
- `x = *p+1` ?
  - ⇒ `x = (*p) + 1 ;`
- `x = (*p)++` ?
  - ⇒ `x = *p ; *p = *p + 1;`
- `x = *p++` ? `(*p++)` ? `*(p)++` ? `*(p++)` ?
  - ⇒ `x = *p ; p = p + 1;`
- `x = *++p` ?
  - ⇒ `p = p + 1 ; x = *p ;`
- Lesson?
  - These cause more problems than they solve!

Pointer Arithmetic Peer Instruction Q

How many of the following are invalid?

I. pointer + integer
II. integer + pointer
III. pointer + pointer
IV. pointer – integer
V. integer – pointer
VI. pointer – pointer
VII. compare pointer to pointer
VIII. compare pointer to integer
IX. compare pointer to 0
X. compare pointer to `NULL`

Pointer Arithmetic Peer Instruction A

- How many of the following are invalid?

I.	pointer + integer	ptr + 1
II.	integer + pointer	1 + ptr
III.	pointer + pointer	ptr + ptr
IV.	pointer – integer	ptr - 1
V.	integer – pointer	1 - ptr
VI.	pointer – pointer	ptr - ptr
VII.	compare pointer to pointer	ptr1 == ptr2
VIII.	compare pointer to integer	ptr == 1
IX.	compare pointer to 0	ptr == NULL
X.	compare pointer to NULL	ptr == NULL

"And in Conclusion…"

- Pointers and arrays are virtually same
- C knows how to increment pointers
- C is an efficient language, with little protection
  - Array bounds not checked
  - Variables not automatically initialized
- (Beware) The cost of efficiency is more overhead for the programmer.
  - "C gives you a lot of extra rope but be careful not to hang yourself with it!"