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CS61C : Machine Structures

Lecture #3: C Pointers & Arrays

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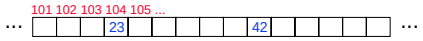
Address vs. Value

- 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;
```

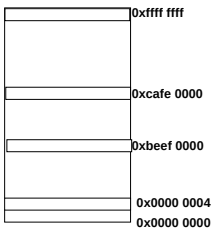
`ptr` doesn't actually point to anything yet. We can either:

  - make it point to something that already exists, or
  - allocate room in memory for something new that it will point to… (next time)

Pointers

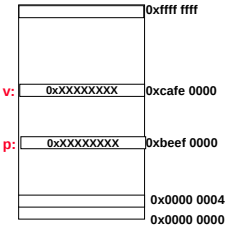
- Declaring a pointer just allocates space to hold the pointer – it does not allocate something to be pointed to!
- Local variables in C are not initialized, they may contain anything.

Pointer Usage Example



Memory and Pointers:

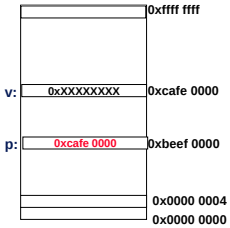
Pointer Usage Example



Memory and Pointers:

int *p, v;

Pointer Usage Example

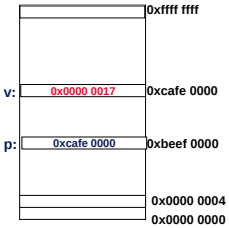


Memory and Pointers:

int *p, v;

p = &v;

Pointer Usage Example



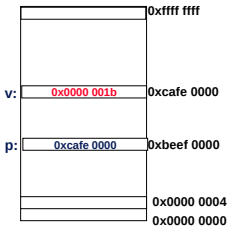
Memory and Pointers:

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 without 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 and fills 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])`

C Strings (1/3)

- A string in C is just an array of characters.

```
char string[] = "abc";
```

- How do you tell how long a string is?
  - Last character is followed by a 0 byte (null terminator)

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

C Strings Headaches (2/3)

- One common mistake is to forget to allocate an extra byte for the null terminator.
- More generally, C requires the programmer to manage memory manually (unlike Java or C++).
  - When creating a long string by concatenating several smaller strings, the programmer must insure there is enough space to store the full string!
  - What if you don't know ahead of time how big your string will be?
- String constants are immutable:
  - char *f = "abc"; f[0]++; /* illegal */
    - Because section of mem where "abc" lives is immutable.
  - char f [ ] = "abc"; f[0]++; /* Works! */
    - Because, in declaration, c copies abc into space allocated for f.

C String Standard Functions (3/3)

- `int strlen(char *string);`
  - compute the length of `string`
- `int strcmp(char *str1, char *str2);`
  - return 0 if `str1` and `str2` are identical (how is this different from `str1 == str2`?)

`char *strcpy(char *dst, char *src);`

- copy the contents of string `src` to the memory at `dst` and return `dst`. The caller must ensure that `dst` has enough memory to hold the data to be copied.

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!