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CS61C : Machine Structures

Lecture #3 – More C intro, C Strings, Arrays, & Malloc

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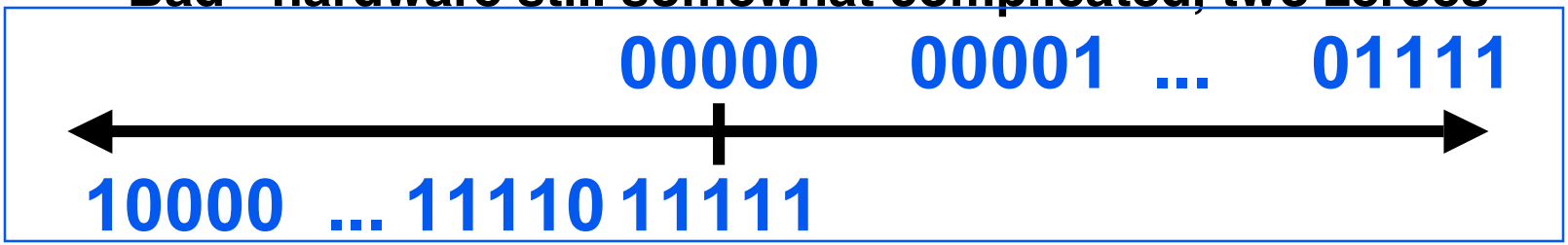
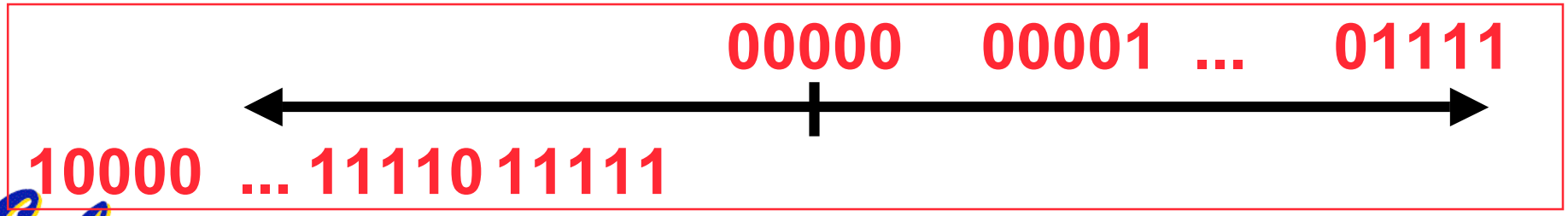
Instructor

Number Review

- Sign and magnitude
  - Bad - makes hardware complicated
  - Bad - counts down when increasing negatives
- 1's complement - mostly abandoned
  - Good - fixes counting down problem
  - Bad - hardware still somewhat complicated, two zeroes



- 2's complement universal in computing: cannot avoid, so learn



Clarification about "counting down"

- Decimal

  -6 + 1 = -5 -5 > -6

- Binary (sign and magnitude)

  -6 = 0b1110

  0b1110 + 0b0001 = 0b1111 ==> -7_{ten}

  Adding one got us a smaller number?!

- One's and two's complement fixes this. Hardware can ignore sign when doing arithmetic.

Variables

- Variables must be declared
  - unlike Scheme, but like Java
- Variables must be typed
  - unlike Scheme, but like Java

```
type varname;
```

e.g. `int x;`

Initialize variables before using them!

Can combine initialization with declaration:

```
int x = 5;
```

Declarations go at beginning of function

Functions

- Specify return type
  - If no return type, use `void`
- Formal parameters declared after function name
- Function body goes between `{ }`

e.g.

```
int subone(int x) {
    return x - 1;
}
```

main function

- Special function where any C program starts
- Should be type `int`
  - http://users.aber.ac.uk/auj/voidmain.shtml for more details
- `return 0;` at end means program terminated without problems.
- For arguments, use

```
int main (int argc, char *argv[])
```

  - `argc` is argcount, `argv` is array of strings

flow control

- Within a function, remarkably close to Java constructs in methods (shows its legacy) in terms of flow control
  - Branches
    - `if-else`
    - `switch`
  - Loops
    - `while and for`
    - `do-while`
- Even if you don't know Java, you are probably familiar with the concepts from another programming language.
  - Check K&R Chapter 3 for details

Assignment

- Use = sign for assignment
  - set! in Scheme

CORRECTION from yesterday's lecture

- The value of an assignment expression is the RHS, while the type is the LHS.

  e.g. `x = y = 5;`

  Same as `y = 5; x = 5;` (not `x = y`)

  `(x = 5)++;` ILLEGAL

  same as `x = 5; 5++;` which isn't allowed

Peer Instruction Answer

This slide has been corrected from the one presented in lecture

flip-sign prototype (or function itself) not declared before first use

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 10;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,*p);
}
flip-sign(int *n){*n = -(*n);}
```

How many errors? I get 8.

#Errors
1
2
3
4
5
6
7
8
9
(1) 0

Review

- Only 0 and NULL evaluate to FALSE.
- All data is in memory. Each memory location has an address to use to refer to it and a value stored in it.
- A pointer is a C version of the address.
  - * "follows" a pointer to its value
  - & gets the address of a value

Pointers & Allocation (1/2)

- After declaring a pointer:

```
int *ptr;
```

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

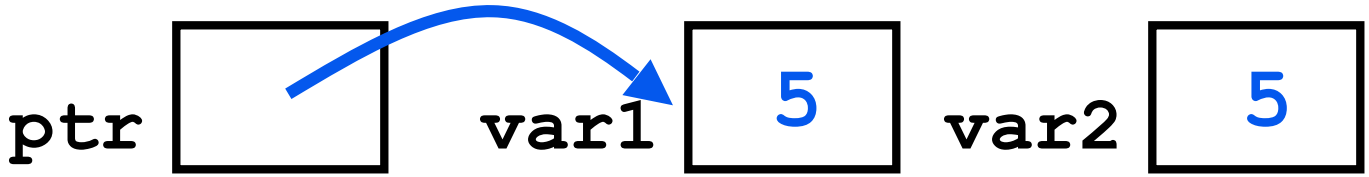
  - make it point to something that already exists, or
  - allocate room in memory for something new that it will point to… (later)

Pointers & Allocation (2/2)

- Pointing to something that already exists:

```
int *ptr, var1, var2;
var1 = 5;
ptr  = &var1;
var2 = *ptr;
```

- `var1` and `var2` have room implicitly allocated for them.



More C Pointer Dangers

- 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.
- What does the following code do?

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

Arrays (1/6)

- **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.

Arrays (2/6)

- 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 Concept: An array variable is a "pointer" to the first element.

Arrays (3/6)

- Consequences:
  - `ar` is an array variable but looks like a pointer in many respects (though not all)
  - `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 (4/6)

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

```
int ar[10], *p, *q, sum = 0;
...
p = &ar[0]; 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

Arrays (5/6)

- 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 (6/6)

- Pitfall: An array in C does <u>not</u> know its own length, & bounds not checked!
  - Consequence: We can accidentally access off the end of an array.
  - Consequence: We must pass the array <u>and its size</u> 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 2…)

Pointer Arithmetic (1/4)

- 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++` 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 <u>size of the array element</u>.

Pointer Arithmetic (2/4)

- 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 (3/4)

- C knows the size of the thing a pointer points to – every addition or subtraction moves that many bytes.
  - 1 byte for a char, 4 bytes for an int, etc.
- So the following are equivalent:

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

Pointer Arithmetic (4/4)

- 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++;
    }
}
```

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

- 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?

Segmentation Fault vs Bus Error?

- `http://www.hyperdictionary.com/`
- Bus Error
  - A fatal failure in the execution of a machine language instruction resulting from the processor detecting an anomalous condition on its bus. Such conditions include invalid address alignment (accessing a multi-byte number at an odd address), accessing a physical address that does not correspond to any device, or some other device-specific hardware error. A bus error triggers a processor-level exception which Unix translates into a "SIGBUS" signal which, if not caught, will terminate the current process.
- Segmentation Fault
  - An error in which a running Unix program attempts to access memory not allocated to it and terminates with a segmentation violation error and usually a core dump.

Administrivia

- Labs due in lab or by end of next lab
- Waitlist should be resolved
- Newsgroup (details on website)
- Homework expectations
  - Readers don't have time to fix your programs which have to run on lab machines.
  - Code that doesn't compile or fails <u>all</u> of the autograder tests ⇒ 0

Administrivia

- **Homework submission**
  - Guide on website, as well as within hw spec
  - You can submit as many times as you like, we will only grade the latest one.
- **Upcoming due dates**
  - HW0 out by tomorrow (sorry for delay)
    - Due 7/1 in lab or to my office
    - Picture + signed agreement to academic honesty policy
  - Quiz 1 due Friday 6/27, based on reading
  - HW1 due Monday 6/30
    - Start today!
  - HW2 due Saturday 7/5, should be out by end of this week

C Strings

- 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++;
    return n;
}
```

Arrays vs. Pointers

- An array name is a read-only pointer to the 0th element of the array.
- An array parameter can be declared as an array <u>or</u> a pointer; an array argument can be passed as a pointer.

```
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 Headaches

- 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?
  - Buffer overrun security holes!

Common C Errors

- There is a difference between assignment and equality
  - `a = b` is assignment
  - `a == b` is an equality test
- This is one of the most common errors for beginning C programmers!

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`

#invalid
1
2
3
4
5
6
7
8
9
(1) 0

Pointer Arithmetic Peer Instruction Ans

- 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

#invalid
1
2
3
4
5
6
7
8
9
(1) 0

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?**
  - Using anything but the standard `*p++`, `(*p)++` causes more problems than it solves!

- **Wednesday's lecture ended here. Following slides will be presented in next lecture.**

C String Standard Functions

- `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`. The caller must ensure that `dst` has enough memory to hold the data to be copied.

Pointers to pointers (1/4) …review…

- Sometimes you want to have a procedure increment a variable?
- What gets printed?

```
void AddOne(int  x)
{      x =  x + 1;   }

int y = 5;
AddOne( y);
printf("y = %d\n", y);
```

y = 5

Pointers to pointers (2/4) …review…

- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```
void AddOne(int *p)
{     *p = *p + 1;    }

int y = 5;
AddOne(&y);
printf("y = %d\n", y);
```

y = 6

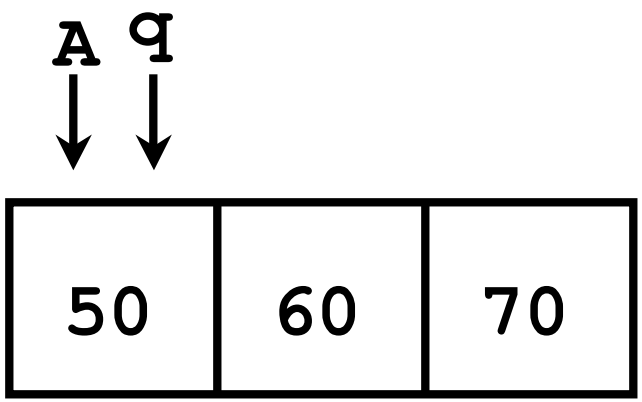
Pointers to pointers (3/4)

- But what if what you want changed is a pointer?
- What gets printed?

```
void IncrementPtr(int  *p)
{    p =  p + 1;   }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf("*q = %d\n", *q);
```

*q = 50



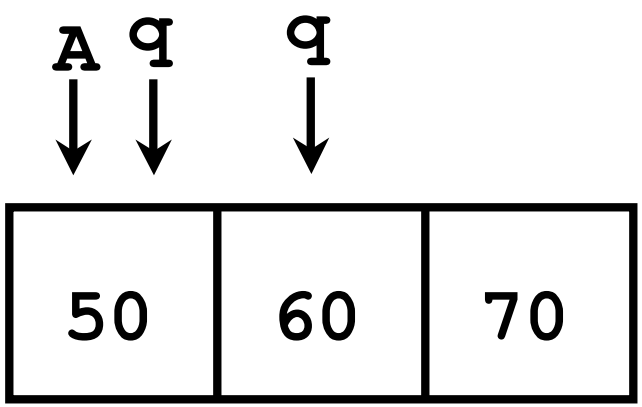
Pointers to pointers (4/4)

- Solution! Pass a pointer to a pointer, called a handle, declared as `**h`
- Now what gets printed?

```
void IncrementPtr(int **h)
{    *h = *h + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr(&q);
printf("*q = %d\n", *q);
```

*q = 60



Dynamic Memory Allocation (1/3)

- C has operator `sizeof()` which gives size in bytes (of type or variable)
- Assume size of objects can be misleading & is bad style, so use `sizeof(type)`
  - Many years ago an `int` was 16 bits, and programs assumed it was 2 bytes

Dynamic Memory Allocation (2/3)

- To allocate room for something new to point to, use `malloc()` (with the help of a typecast and `sizeof`):

```
ptr = (int *) malloc (sizeof(int));
```

  - Now, `ptr` points to a space somewhere in memory of size `(sizeof(int))` in bytes.
  - `(int *)` simply tells the compiler what will go into that space (called a typecast).

- `malloc` is almost never used for 1 var

```
ptr = (int *) malloc (n*sizeof(int));
```

  - This allocates an array of `n` integers.

Dynamic Memory Allocation (3/3)

- Once `malloc()` is called, the memory location contains garbage, so don't use it until you've set its value.
- After dynamically allocating space, we must dynamically free it:

```
free(ptr);
```

- Use this command to clean up.

"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!"
- Use handles to change pointers