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CS61C

Great Ideas in Computer Architecture

(a.k.a. Machine Structures)

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Introduction to the C Programming Language

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Bugs, and Pointers

C Syntax: Variable Declarations

- **Similar to Java, but with a few minor but important differences**
  - All variable declarations must appear before they are used
  - All must be at the beginning of a block.
  - A variable may be initialized in its declaration; *if not, it holds garbage!*
    - the contents are undefined…
- **Examples of declarations:**
  - Correct: `{ int a = 0, b = 10; …`
  - Incorrect in ANSI C: `for (int i=0; …`
  - Correct in C99 (and beyond): `for (int i=0;…`

An Important Note: Undefined Behavior…

- **A lot of C has "Undefined Behavior"**
  - This means it is often unpredictable behavior
    - It will run one way on one computer…
    - But some other way on another
    - Or even just be different each time the program is executed!
- **Often characterized as "Heisenbugs"**
  - Bugs that seem random/hard to reproduce, and seem to disappear or change when debugging
  - Cf. "Bohrbugs" which are repeatable

Address vs. Value

- **Consider memory to be a single huge array:**
  - Each cell of the array has an address associated with it.
  - Each cell also stores some value.
  - Do you think they use signed or unsigned numbers? Negative address?!
- **Don't confuse the address referring to a memory location with the value stored in that location.**
- **For now, the abstraction lets us think we have access to ∞ memory, numbered from 0…**

Pointers

- An address refers to a particular memory location. In other words, it points to a memory location.
- **Pointer**: A variable that contains the address of a variable.

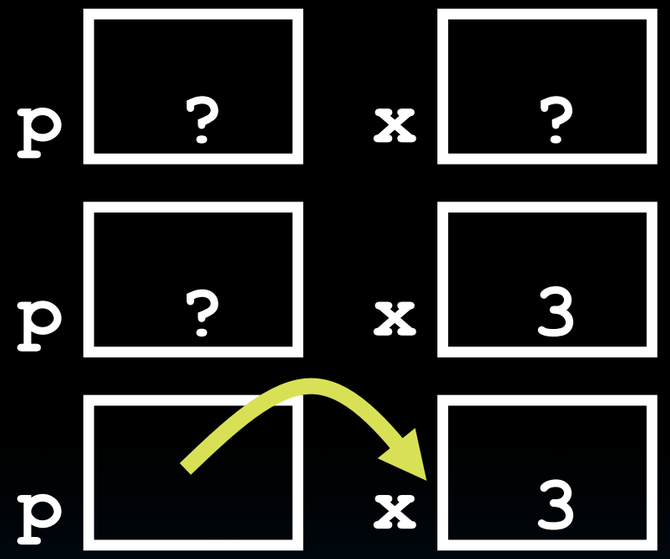
Pointer Syntax

- `int *p;`
  - Tells compiler that variable `p` is address of an `int`
- `p = &y;`
  - Tells compiler to assign address of `y` to `p`
  - `&` called the “address operator” in this context
- `z = *p;`
  - Tells compiler to assign value at address in `p` to `z`
  - `*` called the “dereference operator” in this context

Pointers

- **How to create a pointer:**
  - & operator: get address of a variable

```
int *p, x;

x = 3;

p =&x;
```



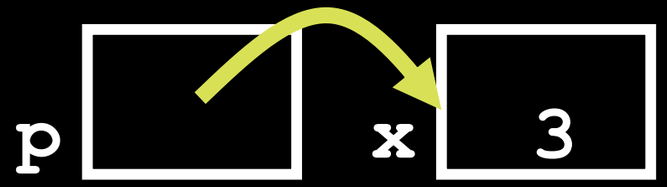
Note the "*" gets used 2 different ways in this example. In the declaration to indicate that `p` is going to be a pointer, and in the `printf` to get the value pointed to by `p`.

- **How get a value pointed to?**
  - * "dereference operator": get value pointed to

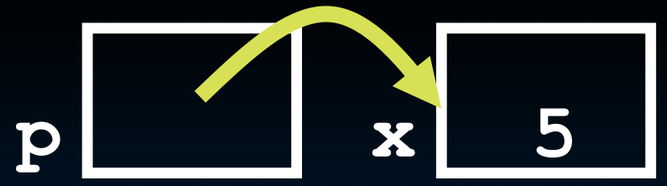
```
printf("p points to %d\n",*p);
```

Pointers

- **How to change a variable pointed to?**
  - Use dereference * operator on left of =




```
*p = 5;
```



Pointers and Parameter Passing (1/2)

- **Java and C pass parameters "by value"**
  - procedure/function/method 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 (2/2)

- 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

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;
}
```

Pointers in C … The Good, Bad, and the Ugly

- **Why use pointers?**
  - If we want to pass a large struct or array, it's easier / faster / etc. to pass a pointer than the whole thing
    - Otherwise we'd need to copy a huge amount of data
  - In general, pointers allow cleaner, more compact code
- **So what are the drawbacks?**
  - Pointers are probably the single largest source of bugs in C, so be careful anytime you deal with them
    - Most problematic with dynamic memory management—coming up next time
    - Dangling references and memory leaks

Using Pointers Effectively

Pointers

- **Pointers are used to point to any data type (`int`, `char`, a `struct`, etc.).**
- **Normally a pointer can only point to one type (`int`, `char`, a `struct`, etc.).**
  - `void *` is a type that can point to anything (generic pointer)
  - Use sparingly to help avoid program bugs… and security issues… and a lot of other bad things!
- **You can even have pointers to functions…**
  - `int (*fn) (void *, void *) = &foo`
    - `fn` is a function that accepts two `void *` pointers and returns an `int` and is initially pointing to the function `foo`.
  - `(*fn)(x, y)` will then call the function

Pointers and Structures

```
typedef struct {
    int x;
    int y;
} Point;

Point p1;
Point p2;
Point *paddr;
```

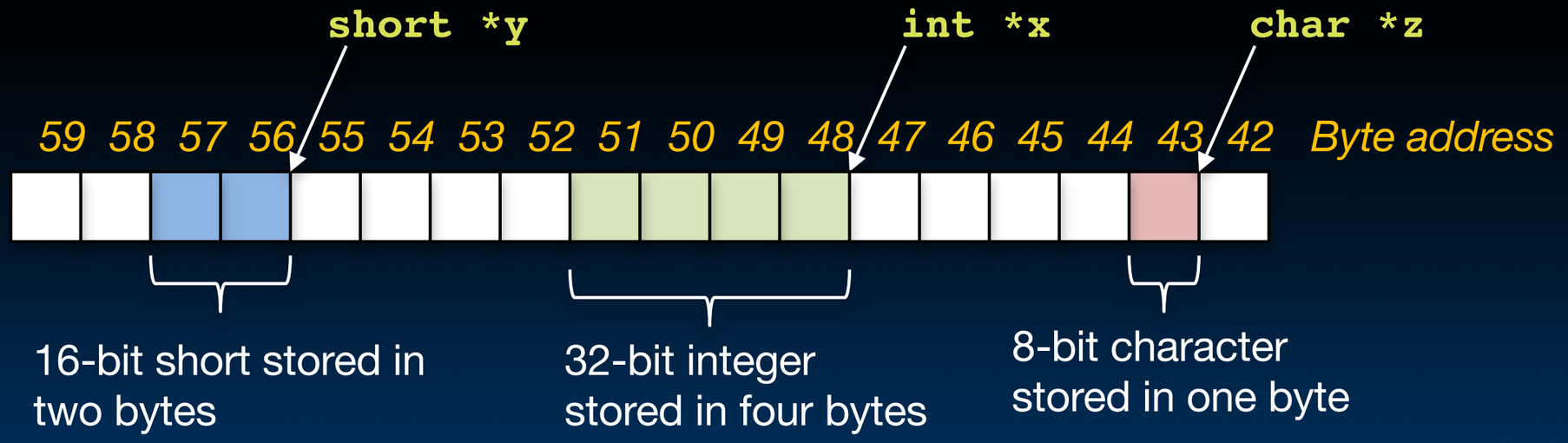
```
/* dot notation */
int h = p1.x;
p2.y = p1.y;

/* arrow notation */
int h = paddr->x;
int h = (*paddr).x;

/* This works too */
p1 = p2;
```

NULL pointers...

- **The pointer of all 0s is special**
  - The "NULL" pointer, like in Java, python, etc...
- **If you write to or read a null pointer, your program should crash**
- **Since "0 is false", its very easy to do tests for null:**
  - `if(!p) { /* P is a null pointer */ }`
  - `if(q) { /* Q is not a null pointer */ }`

Pointing to Different Size Objects

- **Modern machines are "byte-addressable"**
  - Hardware's memory composed of 8-bit storage cells, each has a unique address
- **A C pointer is just abstracted memory address**
- **Type declaration tells compiler how many bytes to fetch on each access through pointer**
  - Eg., 32-bit integer stored in 4 consecutive 8-bit bytes
- **But we actually want "word alignment"**
  - Some processors will not allow you to address 32b values without being on 4 byte boundaries
  - Others will just be very slow if you try to access "unaligned" memory.



Arrays

Arrays (1/5)

- **Declaration:**
  - `int ar[2];`
  - …declares a 2-element integer array
  - An array is really just a block of memory
- **Declaration and initialization**
  - `int ar[] = {795, 635};`
  - declares and fills a 2-elt integer array
- **Accessing elements:**
  - `ar[num]`
  - returns the numth element.

Arrays (2/5)

- **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 (3/5)

- **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 (4/5)

- Array size n; want to access from 0 to n-1, so you should use counter AND utilize a variable for declaration & incr
  - Wrong

```
int i, ar[10];
for(i = 0; i < 10; i++){ ... }
```

  - Right

```
int 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 (5/5)

- **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…

Pointer Arithmetic

- **pointer + n**
  - Adds `n*sizeof(`"whatever pointer is pointing to"`)` to the memory address

- **pointer – n**
  - Adds `n*sizeof(`"whatever pointer is pointing to"`)` to the memory address

Pointers (1/4) …review…

- Java and C pass parameters "by value"
  - procedure/function/method 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 (2/4) …review…

- How to get a function to change a value?

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

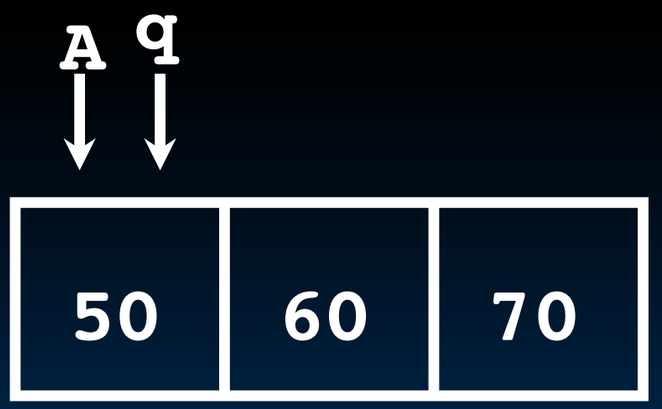
y is now = 4

Pointers (3/4)

- But what if you want to change 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);
```

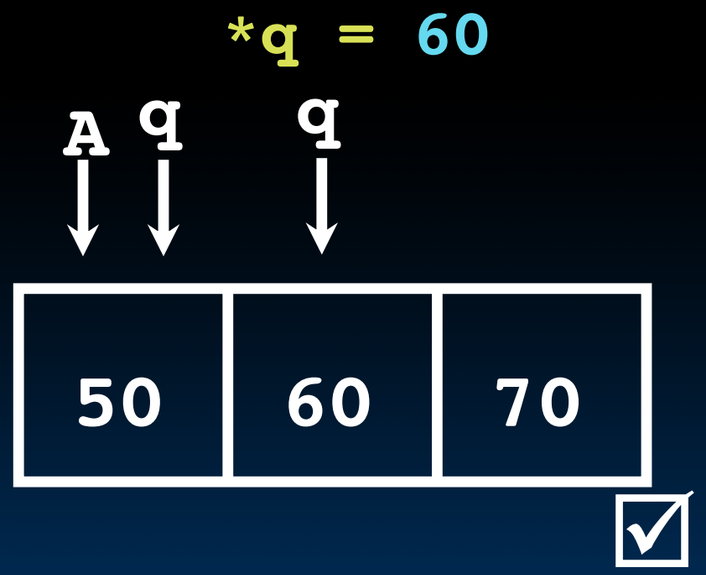
*q = 50



Pointers (4/4)

- **Idea! Pass a pointer to a pointer!**
  - 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);
```



Function Pointer Example

map (actually mutate_map easier)

```
#include <stdio.h>

int x10(int), x2(int);
void mutate_map(int [], int n, int(*)(int));
void print_array(int [], int n);

int x2 (int n) {    return 2*n;    }
int x10(int n) {    return 10*n;   }

void mutate_map(int A[], int n, int(*fp)(int)) {
    for (int i = 0; i < n; i++)
        A[i] = (*fp)(A[i]);
}

void print_array(int A[], int n) {
    for (int i = 0; i < n; i++)
        printf("%d ",A[i]);
    printf("\n");
}
```

```
% ./map
3 1 4
6 2 8
60 20 80
```

```
int main(void)
{
    int A[] = {3,1,4}, n = 3;
    print_array(A, n);
    mutate_map (A, n, &x2);
    print_array(A, n);
    mutate_map (A, n, &x10);
    print_array(A, n);
}
```