CS 61C: Great Ideas in Computer Architecture *Introduction to C, Part II*

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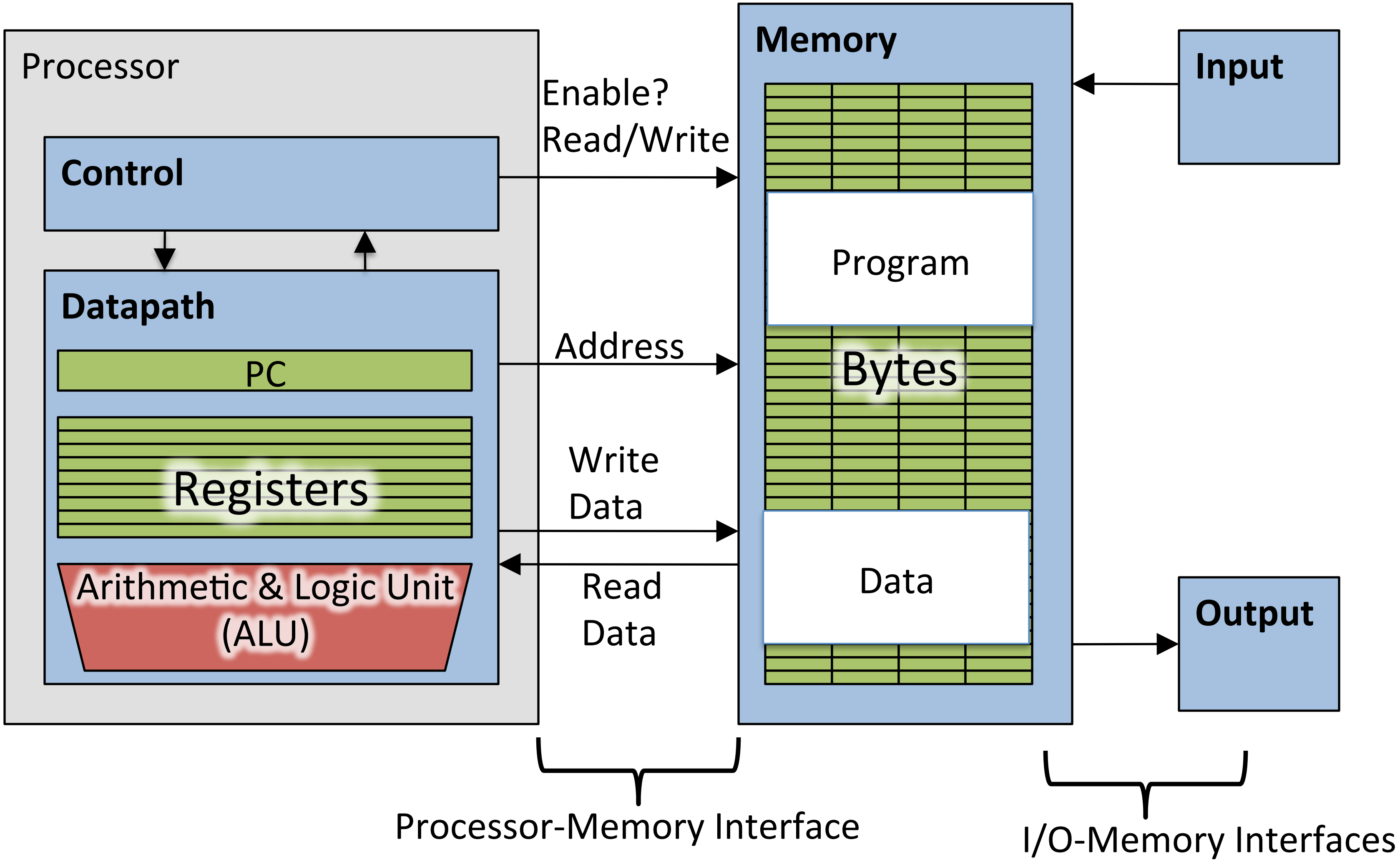
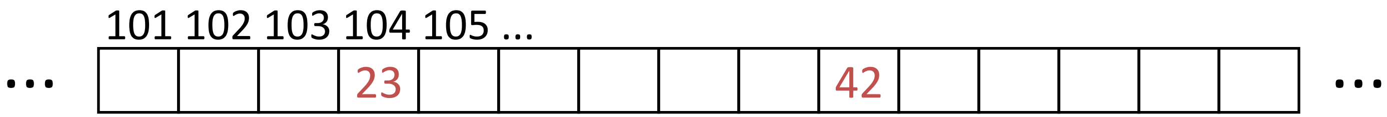
Review: Components of a Computer



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 there

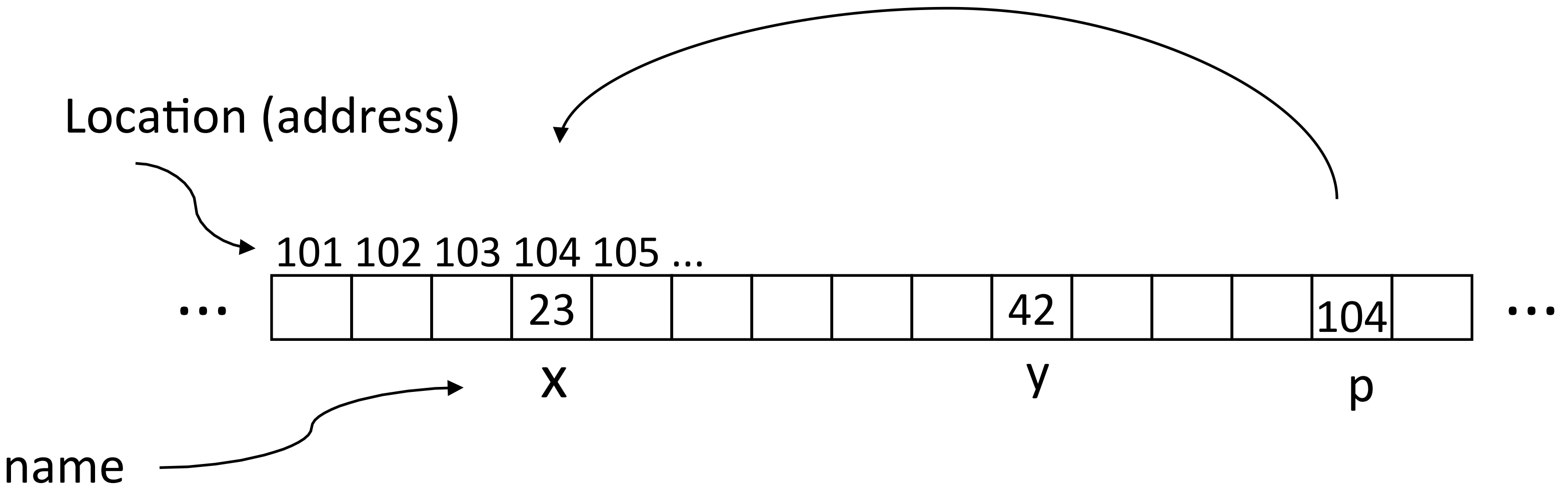


101 102 103 104 105 …

… 23 42 …

Pointers

- An *address* refers to a particular memory location; e.g., it points to a memory location
- *Pointer*: A variable that contains the address of a variable



Location (address)

101 102 103 104 105 …

… | | | 23 | | | | | | 42 | | | | 104 | …

x y p

name

Pointer Syntax

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

Creating and Using Pointers

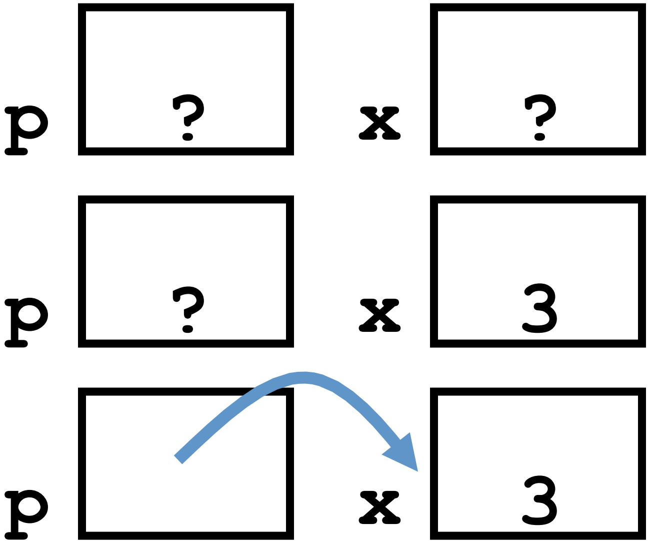
- How to create a pointer:

& 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**.

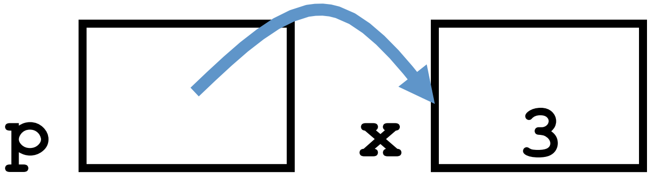
- How get a value pointed to?

"*" (dereference operator): get the value that the pointer points to

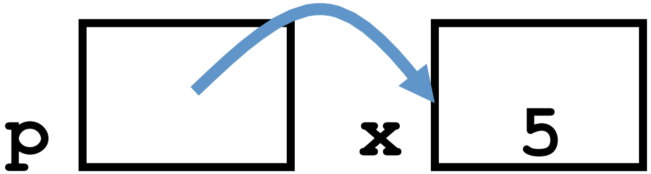
```
printf("p points to %d\n",*p);
```

Using Pointer for Writes

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



```
*p = 5;
```



Pointers and Parameter Passing

- 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 add_one (int x) {
    x = x + 1;
  }
int y = 3;
add_one(y);
```

y remains equal to 3

Pointers and Parameter Passing

- How can we get a function to change the value held in a variable?

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

add_one(&y);
```

y is now equal to 4

Types of Pointers

- Pointers are used to point to any kind of data (**`int`**, **`char`**, a **`struct`**, a pointer, etc.)
- Normally a pointer only points to one type (**`int`**, **`char`**, a **`struct`**, etc.).
  - **`void *`** is a type that can point to anything (generic pointer)
  - Use **`void *`** sparingly to help avoid program bugs, and security issues, and other bad things!

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – does not allocate thing being pointed to!
- Local variables in C are not initialized, they may contain anything (aka “garbage”)
- What does the following code do?

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

Pointers and Structures

```
tyepdef 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;

/*structure assignment*/
p2 = p1;
```

Note, C structure assignment is not a “deep copy”. All members are copied, but not things pointed to by members.

Pointers in C

- 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
  - Want to modify an object, not just pass its value
  - 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 lecture
    - *Dangling references* and *memory leaks*

Why Pointers in C?

- At time C was invented (early 1970s), compilers often didn't produce efficient code
  - Computers 25,000 times faster today, compilers better
- C designed to let programmer say what they want code to do without compiler getting in way
  - Even give compiler hints which registers to use!
- Today, many applications attain acceptable performance using higher-level languages without pointers
- Low-level system code still needs low-level access via pointers, hence continued popularity of C

Clickers/Peer Instruction Time

```
void foo(int *x, int *y)
{  int t;
   if ( *x > *y ) { t = *y; *y = *x; *x = t; }
}
int a=3, b=2, c=1;
foo(&a, &b);
foo(&b, &c);
foo(&a, &b);
printf("a=%d b=%d c=%d\n", a, b, c);
```

Result is:

A: **a=3 b=2 c=1**

B: **a=1 b=2 c=3**

C: **a=1 b=3 c=2**

D: **a=3 b=3 c=3**

E: **a=1 b=1 c=1**

Administrivia

- We can accommodate all those on the wait list, but you have to enroll in a lab section with space!
  - Lab section is important, but you can attend different discussion section
  - Enroll into lab with space, and try to swap with someone later
- HW0 due 11:59:59pm Sunday 2/1
  - Right after the Superbowl…
- Midterm-II now Thursday April 9 in class

C Arrays

- Declaration:

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

declares a 2-element integer array: just a block of memory

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

declares and initializes a 2-element integer array

returns the numth element

C Strings

- 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 (aka “null terminator”)

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

Array Name / Pointer Duality

- *Key Concept*: Array variable is a "pointer" to the first (0th) element
- So, array variables almost identical to pointers
  - **`char *string`** and **`char string[]`** are nearly identical declarations
  - Differ in subtle ways: incrementing, declaration of filled arrays
- Consequences:
  - **`ar`** is an array variable, but looks like a pointer
  - **`ar[0]`** is the same as **`*ar`**
  - **`ar[2]`** is the same as **`*(ar+2)`**
  - Can use pointer arithmetic to conveniently access arrays

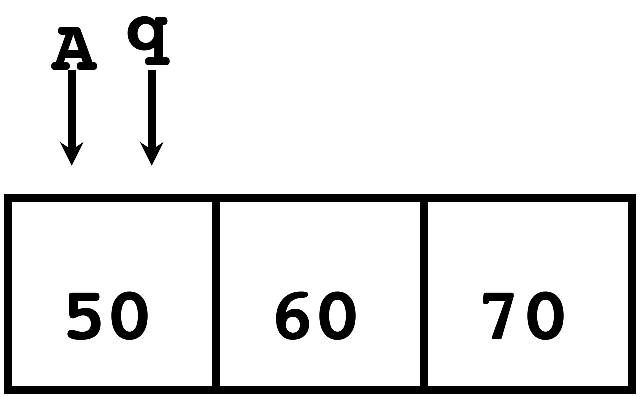
Changing a Pointer Argument?

- What if want function to change a pointer?
- What gets printed?

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

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

```
*q = 50
```



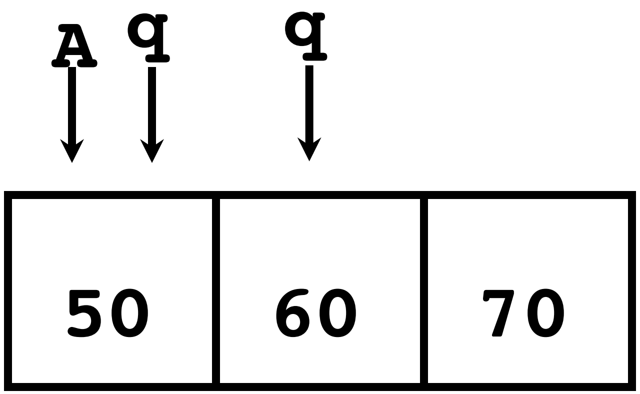
Pointer to a Pointer

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

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

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

`*q = 60`



C Arrays are Very Primitive

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

Use Defined Constants

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

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

  - Better pattern

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

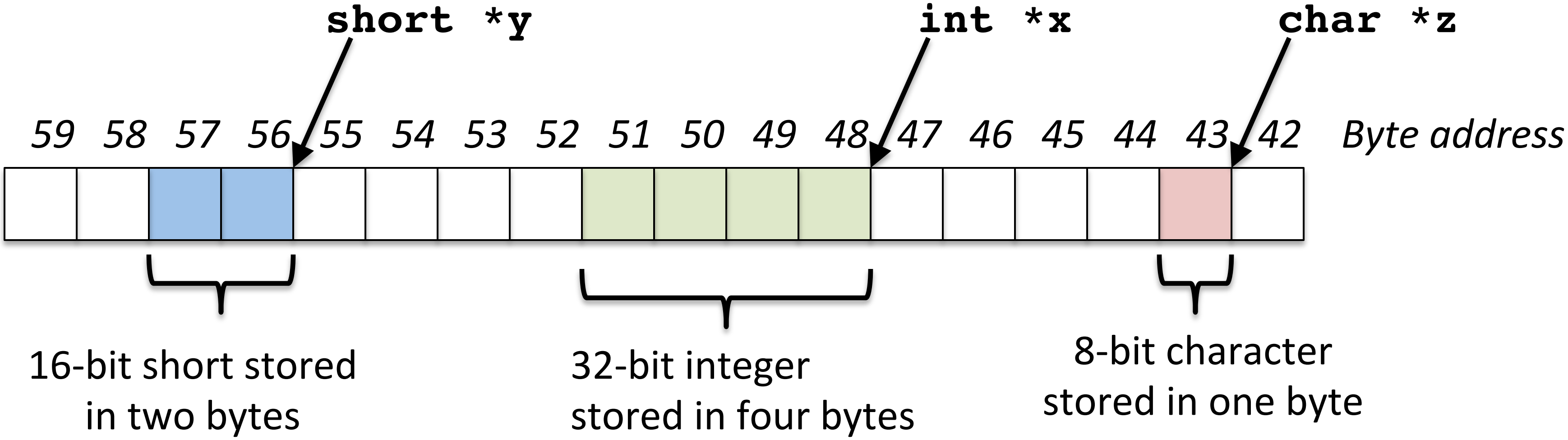
- Accessing elements:

  ```
  ar[num]
  ```

- SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10
  - DRY: "Don't Repeat Yourself"

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
  - E.g., 32-bit integer stored in 4 consecutive 8-bit bytes


short *y
int *x
char *z
59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42
Byte address
16-bit short stored in two bytes
32-bit integer stored in four bytes
8-bit character stored in one byte

sizeof() operator

- sizeof(type) returns number of bytes in object
  - But number of bits in a byte is not standardized
    - In olden times, when dragons roamed the earth, bytes could be 5, 6, 7, 9 bits long
- By definition, sizeof(char)==1
- Can take sizeof(arr), or sizeof(structtype)
- We'll see more of sizeof when we look at dynamic memory management

Pointer Arithmetic

pointer + number   *pointer – number*

e.g., *pointer* **`+ 1`**   adds 1 something to a pointer

```
char    *p;
char     a;
char     b;

p = &a;
p += 1;
```

```
int    *p;
int     a;
int     b;

p = &a;
p += 1;
```

In each, p now points to b
(Assuming compiler doesn't
reorder variables in memory.
Never code like this!!!!)

Adds **`1*sizeof(char)`**
to the memory address

Adds **`1*sizeof(int)`**
to the memory address

Pointer arithmetic should be used cautiously

Arrays and Pointers

- Array ≈ pointer to the initial (0th) array element

```
a[i] ≡ *(a+i)
```

- An array is passed to a function as a pointer
  - The array size is lost!

- Usually bad style to interchange arrays and pointers
  - Avoid pointer arithmetic!

Passing arrays:

Really `int *array`

Must explicitly pass the size

```
int
foo(int array[],
    unsigned int size)
{
   … array[size - 1] …
}


int
main(void)
{
   int a[10], b[5];
   … foo(a, 10)… foo(b, 5) …
}
```

Arrays and Pointers

```
int
foo(int array[],
    unsigned int size)
{
   …
   printf(“%d\n”, sizeof(array));
}

int
main(void)
{
   int a[10], b[5];
   … foo(a, 10)… foo(b, 5)  …
   printf(“%d\n”, sizeof(a));
}
```

What does this print? **8**

... because **`array`** is really a pointer (and a pointer is architecture dependent, but likely to be 8 on modern machines!)

What does this print? **40**

Arrays and Pointers

```
int  i;
int  array[10];

for (i = 0; i < 10; i++)
{
  array[i] = …;
}
```

```
int *p;
int  array[10];

for (p = array; p < &array[10]; p++)
{
  *p = …;
}
```

These code sequences have the same effect!

Clickers/Peer Instruction Time

```
int x[5] = { 2, 4, 6, 8, 10 };
int *p = x;
int **pp = &p;
(*pp)++;
(*(*pp))++;
printf("%d\n", *p);
```

Result is:

A: 2

B: 3

C: 4

D: 5

E: None of the above

In the News (1/23/2015): Google Exposing Apple Security Bugs

- Google security published details of three bugs in Apple OS X (90 days after privately notifying Apple)
  - One network stack problem fixed in Yosemite, all in next beta
  - One is dereferencing a null pointer !
  - One is zeroing wrong part of memory !
- Separately, Google announces it won't patch WebKit vulnerability affecting Android 4.3 and below (only about 930 million active users)

Concise strlen()

```
int strlen(char *s)
{
    char *p = s;
    while (*p++)
        ; /* Null body of while */
    return (p - s - 1);
}
```

What happens if there is no zero character at end of string?

Point past end of array?

- 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 error

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 illegal since makes no sense:

- adding two pointers
- multiplying pointers
- subtract pointer from integer

Arguments in `main()`

- To get arguments to the main function, use:
  - `int main(int argc, char *argv[])`
- What does this mean?
  - `argc` contains the number of strings on the command line (the executable counts as one, plus one for each argument). Here `argc` is 2:

    unix% sort myFile
  - `argv` is a *pointer* to an array containing the arguments as strings

Example

- `foo hello 87`
- `argc = 3 /* number arguments */`
- `argv[0] = "foo",`
  `argv[1] = "hello",`
  `argv[2] = "87"`
  - Array of pointers to strings

And In Conclusion, …

- Pointers are abstraction of machine memory addresses
- Pointer variables are held in memory, and pointer values are just numbers that can be manipulated by software
- In C, close relationship between array names and pointers
- Pointers know the type of the object they point to (except void *)
- Pointers are powerful but potentially dangerous