CS 61C:
Great Ideas in Computer Architecture
C *Pointers*

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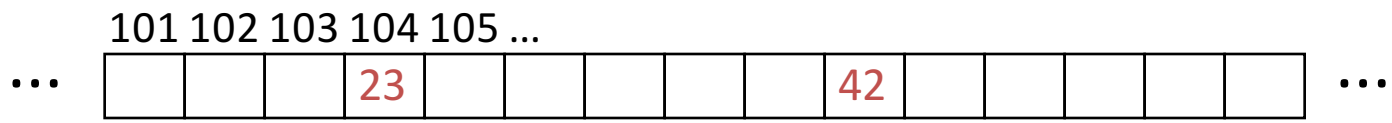
Agenda

- Pointers
- Arrays in C

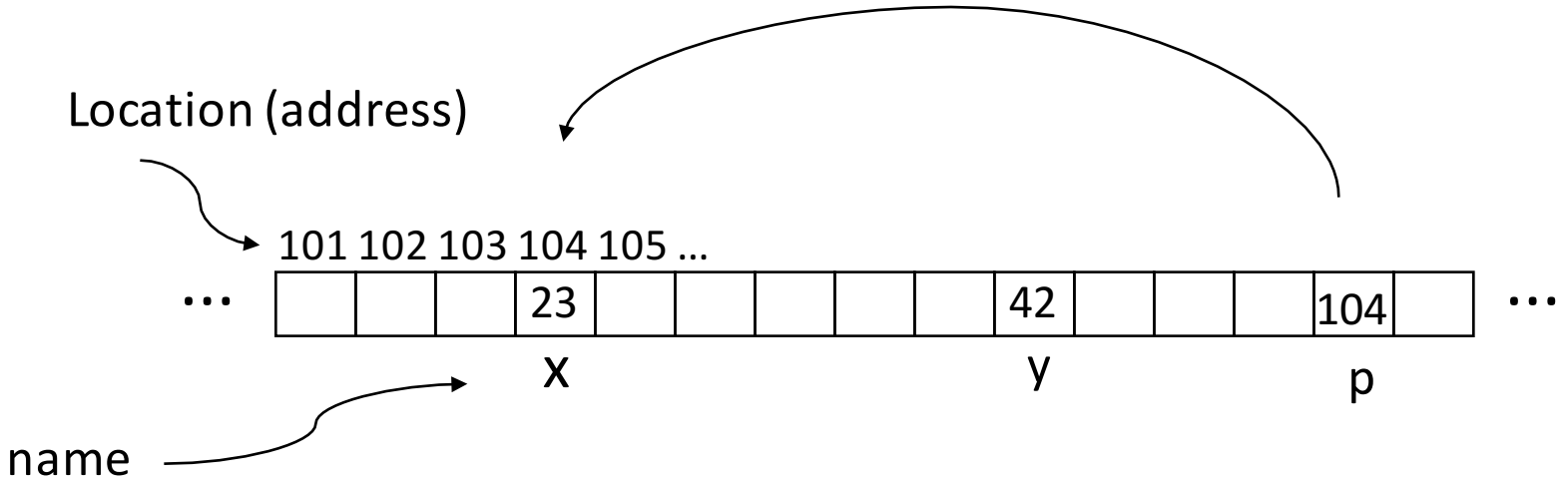
Address vs. Value

- 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
  - For addresses do we use signed or unsigned numbers? Negative address?!
- Don't confuse the address referring to a memory location with the value stored there



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



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

Creating and Using Pointers

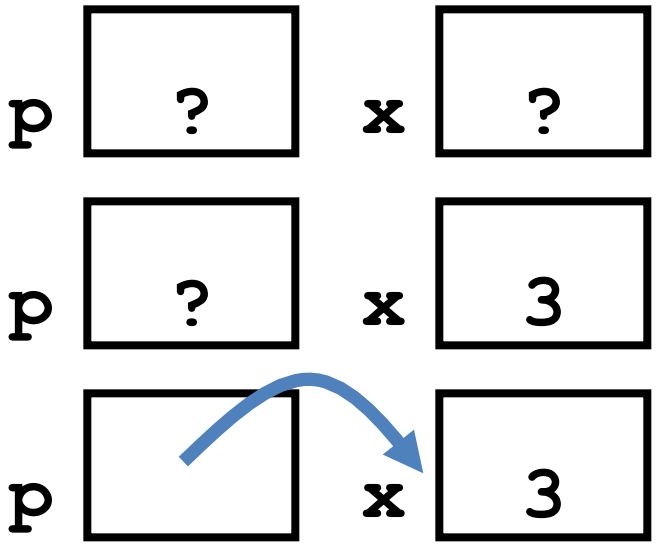
- How to create a pointer:

  & 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**.

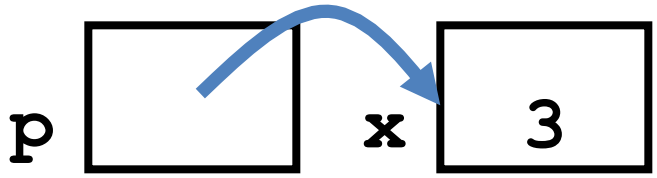
- How get a value pointed to?

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

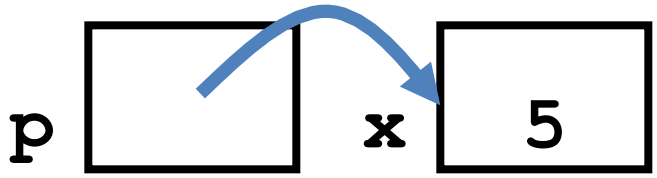
```
printf("p points to %d\n",*p);
```

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`**, 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 – it does not allocate the 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

```
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;
```

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
  - 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 week
    - *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 compilers hints which registers to use!
- Today's compilers produce much better code, so may not need to use pointers in application code
- Low-level system code still needs low-level access via pointers

Video: Fun with Pointers

- https://www.youtube.com/watch?v=6pmWojisM_E

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

- HW0 out, due: Sunday 1/31 @ 11:59:59pm
- Give paper copy of mini-bio to your TA
- Get iClickers and register on bCourses! Participation points start today!
- People with *university-related time conflict* with lectures should contact the head GSIs. We will waive the clicker points but need to document conflict.
- Let head GSIs know about exam conflicts by the end of this week

Agenda

- Pointers
- Arrays in C

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

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 (0^{th}) 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 works 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

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)
  - But also "fun" to exploit:
    - "Stack overflow exploit", maliciously write off the end of an array on the stack
    - "Heap overflow exploit", maliciously write off the end of an array on the heap

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++){ ... }
```

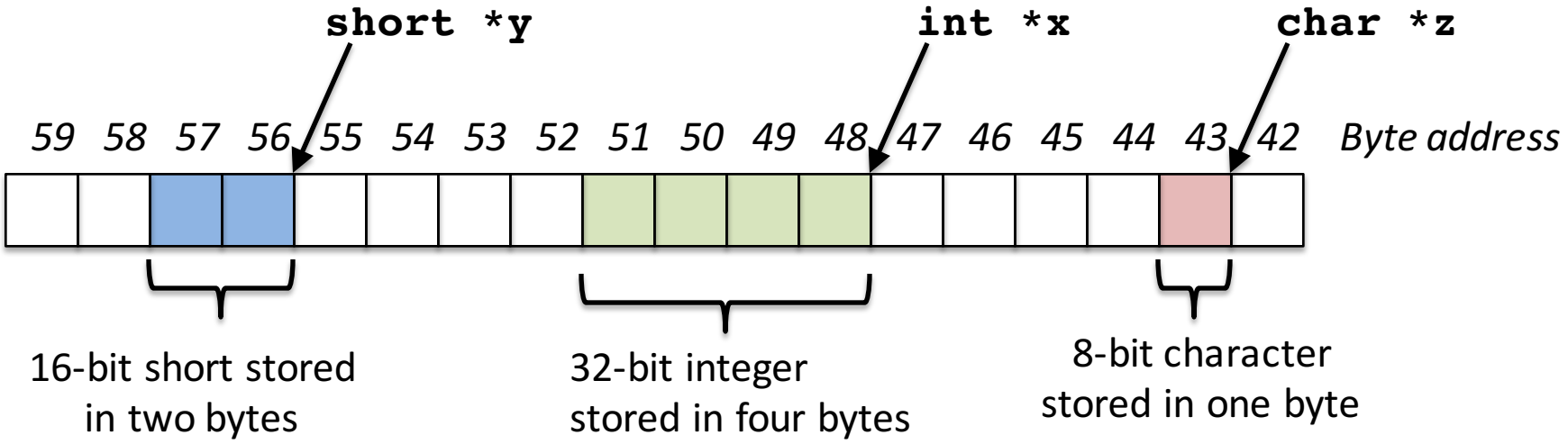
  - Better pattern

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

- SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10
  - DRY: "Don't Repeat Yourself"
  - And don't forget the < rather than <=:
    When Nick took 60c, he lost a day to a "segfault in a malloc called by printf on large inputs": Had a <= rather than a < in a single array initialization!

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



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(arg), 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;
```

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

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

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

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

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

Pointer arithmetic should be used cautiously

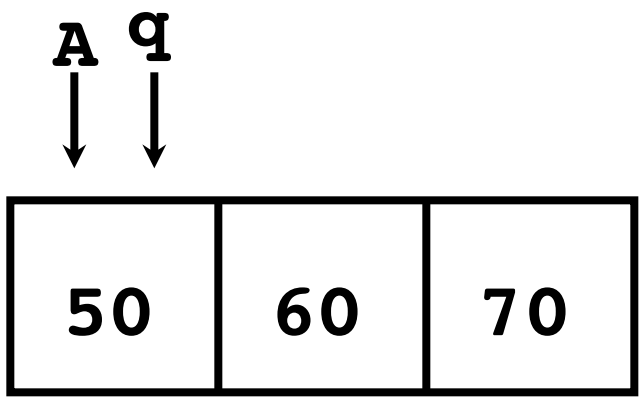
Changing a Pointer Argument?

- 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

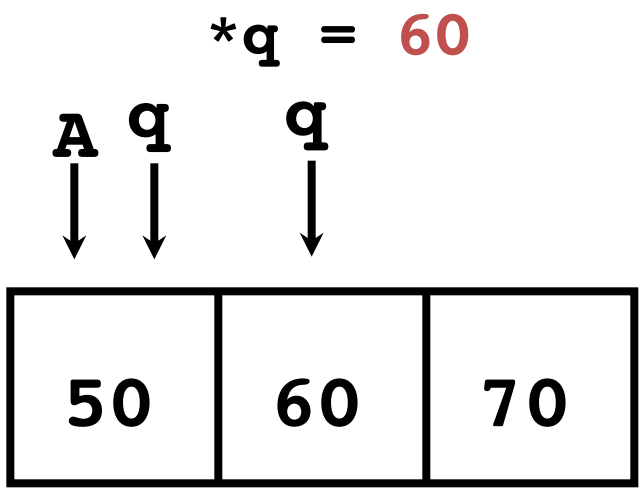


Pointer to a Pointer

- 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);
```



And In Conclusion, …

- All data is in memory
  - Each memory location has an address to use to refer to it and a value stored in it
- Pointer is a C version (abstraction) of a data address
  - `*` "follows" a pointer to its value
  - `&` gets the address of a value
  - Arrays and strings are implemented as variations on pointers
- C is an efficient language, but leaves safety to the programmer
  - Variables not automatically initialized
  - Use pointers with care: they are a common source of bugs in programs