CSE 31
Computer Organization

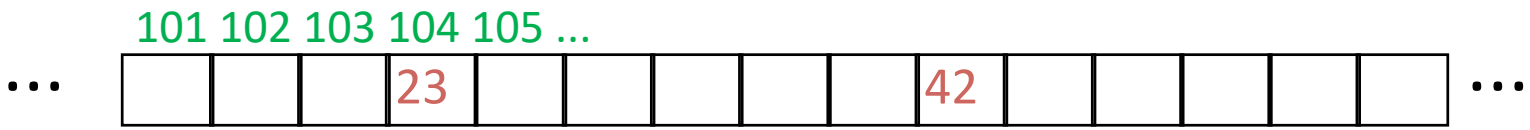
Lecture 3 – C Pointers

Announcement

- Lab #0 starts this week
  - Due in one week
- HW #1 this Friday (8/31)
  - Due Monday (9/10)
- Reading assignment
  - Chapter 4-6 of K&R (C book) to review on C/C++ programming

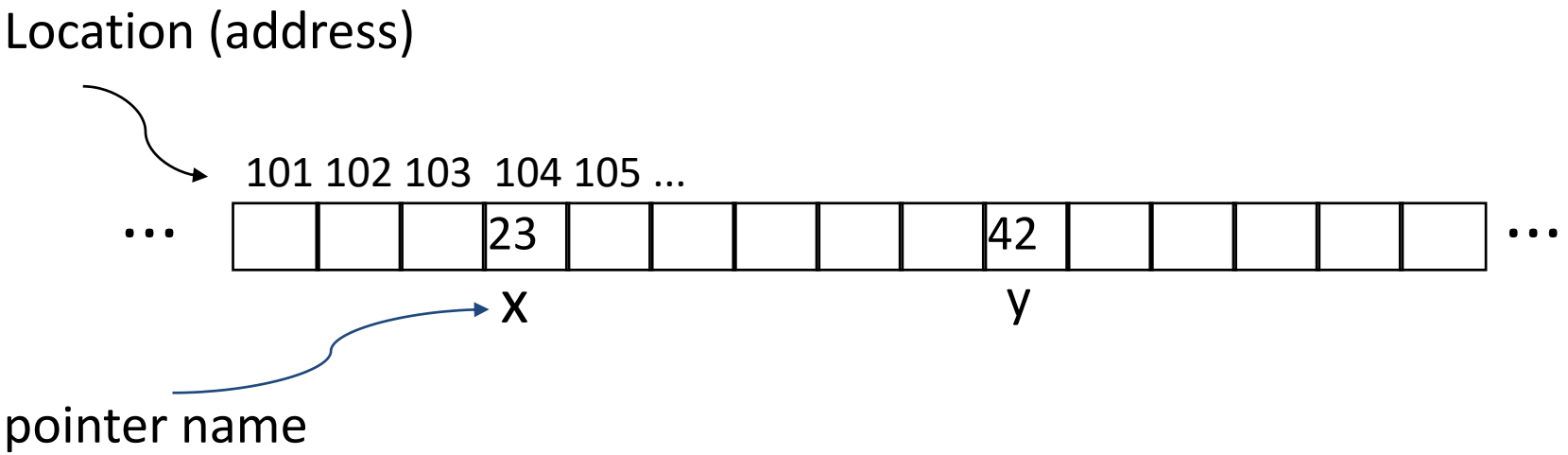
Address vs. Value

- 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 addresses use signed or unsigned numbers?
    - Negative address?!
- Don't confuse the address referring to a memory location with the value stored in that location.



Pointers

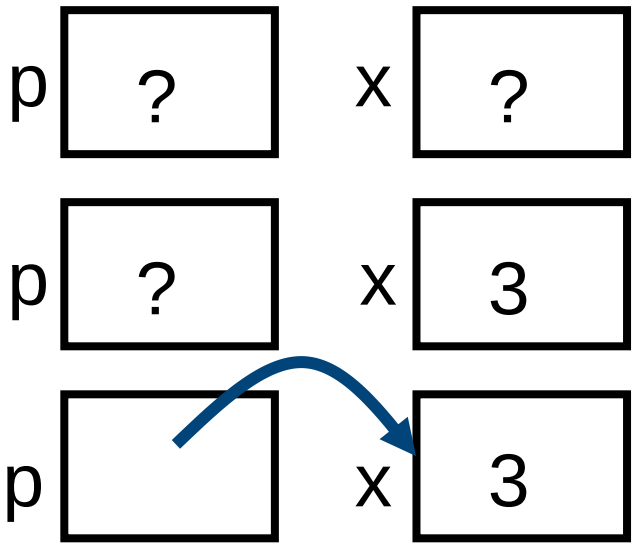
- An address refers to a particular memory location. In other words, it points to a memory location.
- Pointer: A variable that contains the address of a variable.



Pointers

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

```
int *p, x;

x = 3;

p =&x;
```



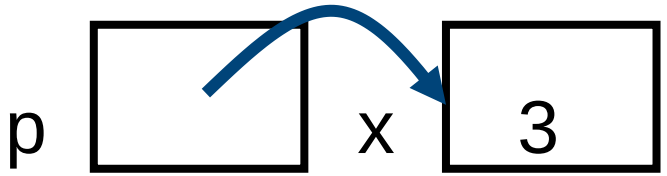
Note the "*" gets used 2 different ways in this example. In the declaration to indicate that `p` is going to be a pointer, and in the `printf` to get the value pointed to by `p`.

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

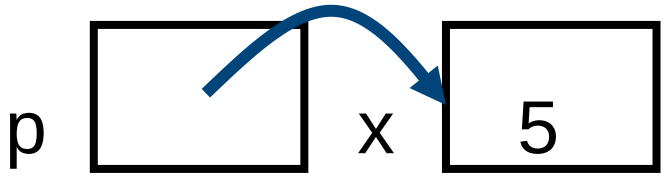
```
printf("p points to %d\n",*p);
```

Pointers

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




```
*p = 5;
```



Pointers and Parameter Passing

- 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

- How to get a function to change a value?

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

addOne(&y);
```

Passing the reference of y

`y` is now = 4

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!

Pointers & Allocation (1/2)

- After declaring a pointer:

  `int *ptr;`

  `ptr` doesn't actually point to anything yet (it actually points somewhere - but we don't know where!).
- We can either:
  - make it point to something that already exists, or
  - allocate room in memory for something new that it will point to… (we will talk about it later)

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. (unsigned vs signed)
- The second declaration is valid C but is almost certainly wrong
  - Is it ever correct?

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate anything 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;
}
```

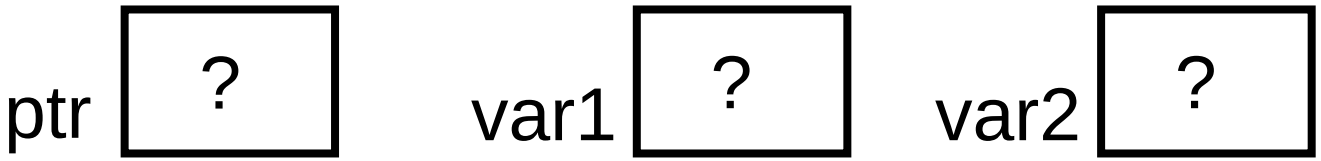
Where does it store the “5”?

Pointers & Allocation (2/2)

- Pointing to something that already exists:

```
int *ptr, var1, var2;
```

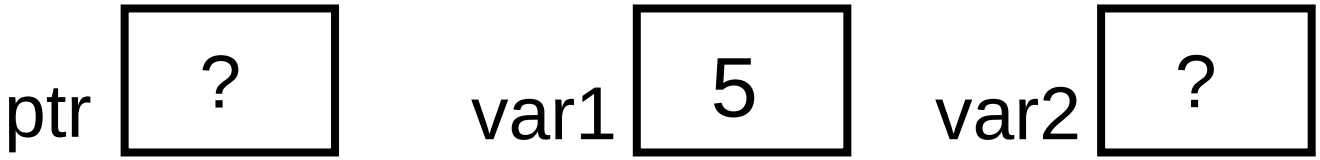
- `var1` and `var2` have room implicitly allocated for them.



Pointers & Allocation (2/2)

- Pointing to something that already exists:

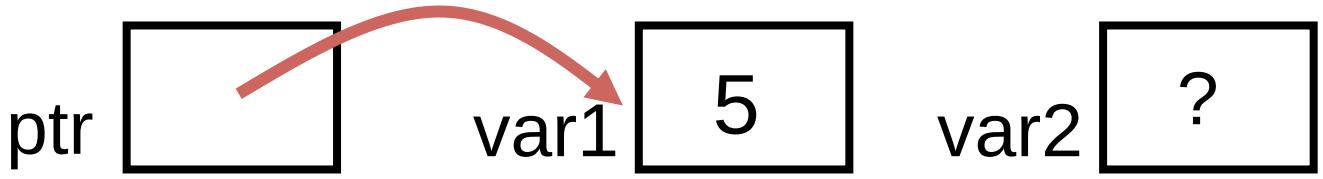
```
int *ptr, var1, var2;
var1 = 5;
```



Pointers & Allocation (2/2)

- Pointing to something that already exists:

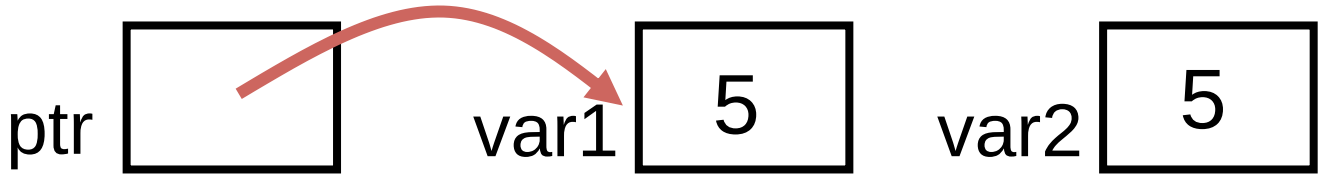
```
int *ptr, var1, var2;
var1 = 5;
ptr  = &var1;
```



Pointers & Allocation (2/2)

- Pointing to something that already exists:

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



Arrays (1/5)

- Declaration:

  `int ar[2];`

  declares a 2-element integer array. An array is really just a block of memory.

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

  declares and fills a 2-element integer array.

- Accessing elements:

  `ar[num]`

  returns the (`num+1`)th 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…)

Segmentation Fault vs Bus Error?

- 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.

- Bus Error
  - A fatal failure in the execution of a machine language instruction resulting from the processor detecting an anomalous condition on its bus (communicating connection between hardware) . 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.

Arrays (one element past array must be valid)

- 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 vs. Pointers

- An array name is a read-only pointer to the 1st element of the array.
- An array parameter can be declared as an array or 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])
```

Pointer Arithmetic (1/3)

- 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 element
- `*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 size of the array element.

Pointer Arithmetic (2/3)

- 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 (3/3)

- What is 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 to Copy Memory

- 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++;
     }
}
```

- Note we had to pass size (`n`) to `copy`

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!

Pointers (1/4)

- 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 (2/4)

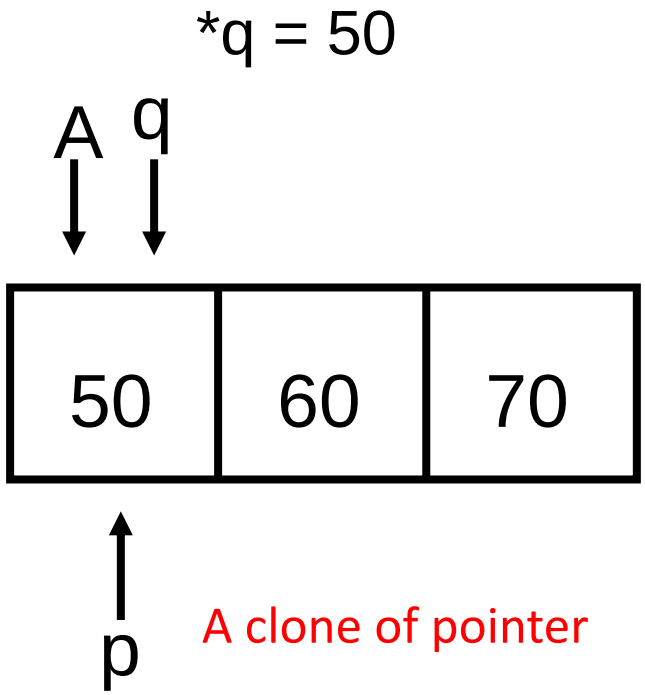
- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```
void AddOne(int *p)                    y = 6
{     *p = *p + 1;    }

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

Pointers (3/4)

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

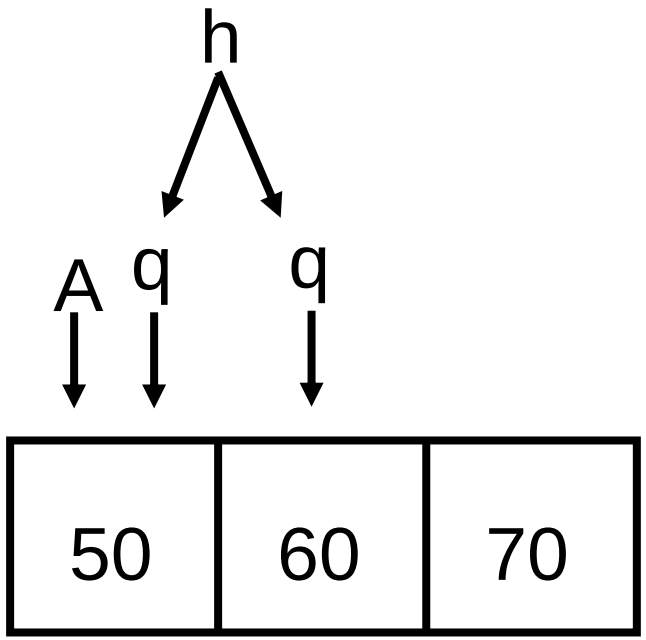
```
void IncrementPtr(int  *p)
{    p =  p + 1;   }

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



Pointers (4/4)

- Solution! 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);
```



*q = 60

Quiz:

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
a) 1
b) 2
c) 3
d) 4
e) 5

Quiz:

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#invalid
a) 1
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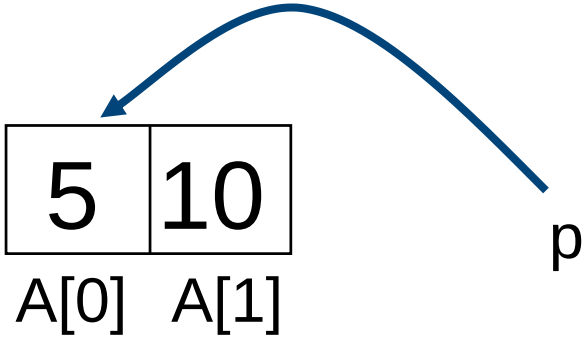
d) 4
e) 5

Quiz:

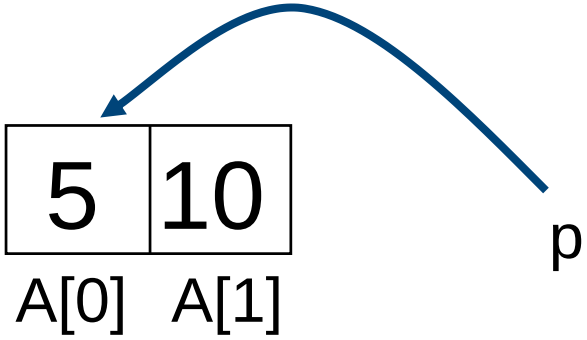


- int main(void){
  int A[] = {5,10};
  int *p = A;

  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  p = p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  *p = *p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  }
- If the first printf outputs 100 5 5 10, what will the other two printf output?

- a) 101 10 5 10 then 101 11 5 11
  b) 104 10 5 10 then 104 11 5 11
  c) 101 <other> 5 10 then 101 <3-others>
  d) 104 <other> 5 10 then 104 <3-others>
  e) One of the two printfs causes an ERROR

Quiz:



- int main(void){
  int A[] = {5,10};
  int *p = A;

  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  p = p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  *p = *p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
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- a) 101 10 5 10 then 101 11 5 11
  b) 104 10 5 10 then 104 11 5 11
  c) 101 <other> 5 10 then 101 <3-others>
  d) 104 <other> 5 10 then 104 <3-others>
  e) One of the two printfs causes an ERROR

Pointers in C

- Why use pointers?
  - If we want to pass a huge struct or array, it's easier / faster 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)
- Make sure you know what you are doing!

Summary

- Pointers and arrays are virtually the 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!”