C Survival Guide

Announcements

- Homework 1 posted
  - Due 11am, August 31
  - Submit via svn
- Piazza access code: ________
- Discussion sections will be held this week

Good news: Writing C code is easy!

```
void* myfunction() {
    char *p;
    *p = 0;
    return (void*) &p;
}
```

Bad news: Writing BAD C code is easy!

```
void* myfunction() {
    char *p;
    *p = 0;
    return (void*) &p;
}
```

What is wrong with this code?

How do I write good C programs?

- Fluency in C syntax
- Stack (static) vs. Heap (dynamic) memory allocation
- Key skill: read code for bugs
  - Do not rely solely on compiler warnings, if any, and testing
- Key skill: debugging
  - Learn to use a debugger. Don't only rely on **`printf`**s!

Why C instead of Java?

- C helps you learn how to write large-scale programs
  - C is lower-level
    - C provides more opportunities to create abstractions
  - C has some flaws
    - C's flaws motivate discussions of software engineering principles
- C helps you get "under the hood"
  - C facilitates language levels tour
    - C is closely related to assembly language
  - C facilitates services tour
    - Many existing servers/systems written in C

C vs. Java: Design Goals

- Java design goals
  - Support object-oriented programming
  - Allow same program to run on multiple operating systems
  - Support using computer networks
  - Execute code from remote sources securely
  - Adopt the good parts of other languages
- Implications for Java
  - Good for application-level programming
  - High-level (insulates from assembly language, hardware)
  - Portability over efficiency
  - Security over efficiency

C vs. Java: Design Goals

- C design goals
  - Support structured programming
  - Support development of the Unix OS and Unix tools
    - As Unix became popular, so did C
- Implications for C
  - Good for systems-level programming
  - Low-level
  - Efficiency over portability
  - Efficiency over security
- Anything you can do in Java you can do in C – it just might look ugly in C!

C vs. C++

- C++ is “C with Classes”
  - C enhanced with objects
- C has some shortcomings compared to C++
  - C++ has objects, a bigger standard library (e.g., STL), parameterized types, etc.
  - C++ is a little bit more strongly typed
- Programming Challenge
  - All syntax you use in this class is valid for C++
  - Not all C++ syntax you’ve used, however, is valid for C

A Few Differences between C and C++

- Input/Output
  - C does not have “iostreams”
  - C++: cout<<"hello world“<<endl;
  - C: printf("hello world\n“);
- Heap memory allocation
  - C++: new/delete
    - int *x = new int[8]; delete(x);
  - C: malloc()/free()
    - int *x = malloc(8 * sizeof(int));   free(x);

Compiler

- gcc
  - Preprocessor
  - Compiler
  - Linker
  - See manual “man” for options: man gcc
- "Ansi-C" standards C89 versus C99
  - C99: Mix variable declarations and code (for int i=…)
  - C++ inline comments //a comment
- make – a utility to build executables

Programming in C

- C = Variables + Instructions

Programming in C

- C = Variables + Instructions
  - `char`
  - `int`
  - `float`
  - `pointer`
  - `array`
  - `string`

  ...

Programming in C

- C = Variables + Instructions

Variables	Instructions
char	assignment
int	printf/scanf
float	if
pointer	for
array	while
string	switch
…	…

What we'll show you

- You already know a lot of C from C++:

```
int my_fav_function(int x) {
   return x+1; }
```

- Key concepts for this lecture:
  - Pointers
  - Memory allocation
  - Arrays
  - Strings

Theme:
how memory
really works

Instant C in 3 slides: Pointers

- Data type that "points to" a value in memory, using its address
- Reference operator: &
  - address-of
- Dereference operator: *
  - contents-of
- Automatic variables
  - Temporary and stored in the stack
- Character pointers: char* p;
  - *p =0;
  - contents-of p set to 0. (Kaboom!)
- Initialization
  - Initialize a pointer to something before using it. (Doh!)

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```
int x=4;
int *y = &x;
```

Question: What is the value of y?

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  - contents-of p set to 0. (Kaboom!)
- Initialization
  - Initialize a pointer to something before using it. (Doh!)

```
int x=4;
int *y = &x;
int a = *y;
int b = y;
```

Question: What are the values of **a** and **b**?

Instant C in 3 slides: Pointers

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  - *p =0;
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- Initialization
  - Initialize a pointer to something befo

```
void main() {
     func();
}

void* func() {
     int x=3;
}
```

Question: What happens to x after func() returns?

Instant C in 3 slides: Pointers

- Data type that "points to" a value in memory, using its address
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  - *p =0;
  - contents-of p set to 0. (Kaboom!)
- Initialization
  - Initialize a pointer to something before using it. (Doh!)

```
void* func() {
     int* w;
     *w = 0
}
```

Question: What does this code output?

Instant C #2: Strings

- Unlike C++ and Java, C does not have a native string type
  - Instead, use arrays of characters terminated with a null byte
- Functions
  - strcpy("hello", "world") will crash
  - strcmp(s1,s2) returns 0 if s1==s2
- Arguments
  - argv[0] is the name of the executable
  - argv[argc] is a null pointer

Instant C #3: Dynamic Memory Allocation

- Allocation
  - malloc(bytes) to reserve memory
- Clean up
  - free(ptr) to free up memory
- Dynamically allocated memory is stored on the "heap"
  - Static variables are stored on the "stack"
  - You often use static variables (pointers) to refer to and manipulate heap memory
  - e.g., `char* c = malloc(sizeof(char))`

Common Causes of 'Death'

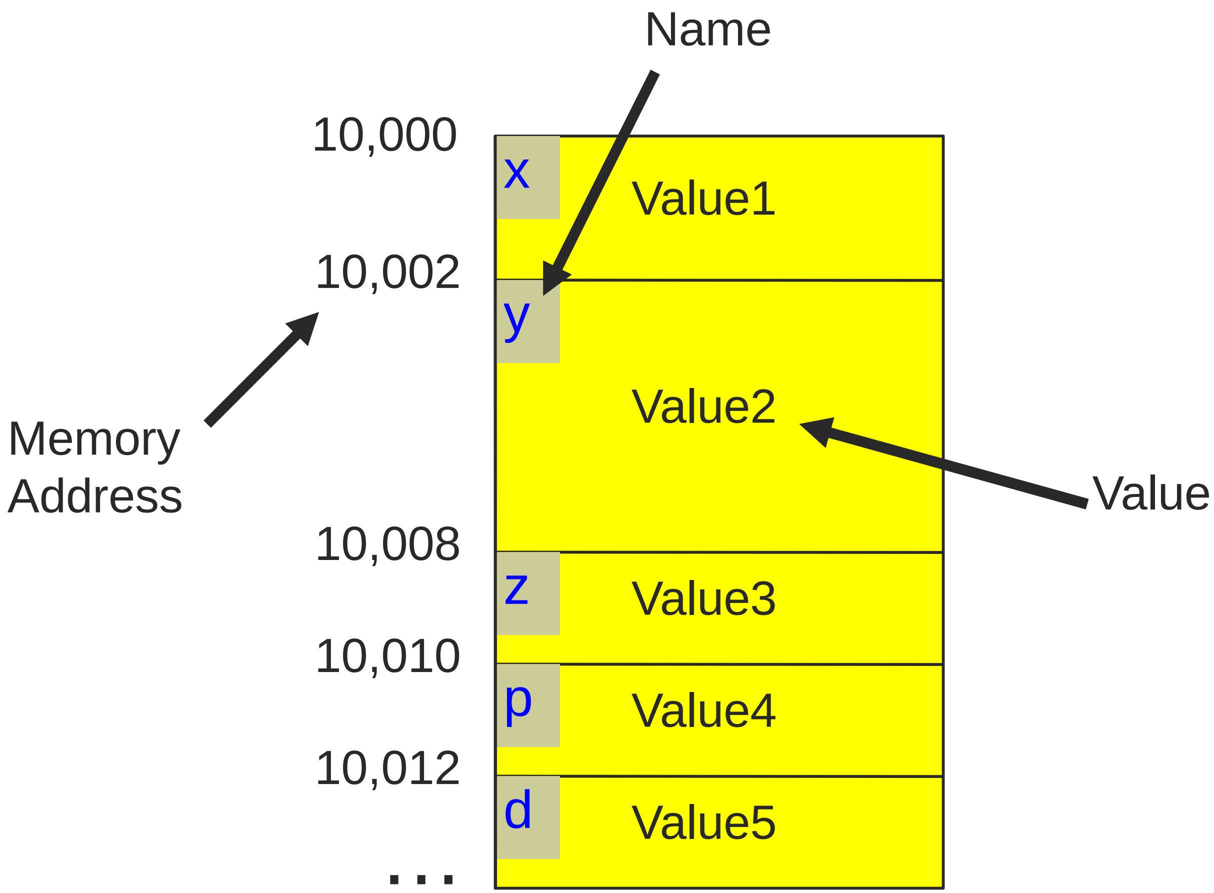
1. Uninitialized pointers

```
char *dest;
strcpy(dest,"hello");
```

2. C Strings need a null byte at the end
3. Buffer overflow
4. Un-initialized memory
5. Too confident: not checking return values
6. Misuse of static vs. stack variables.

Pointers

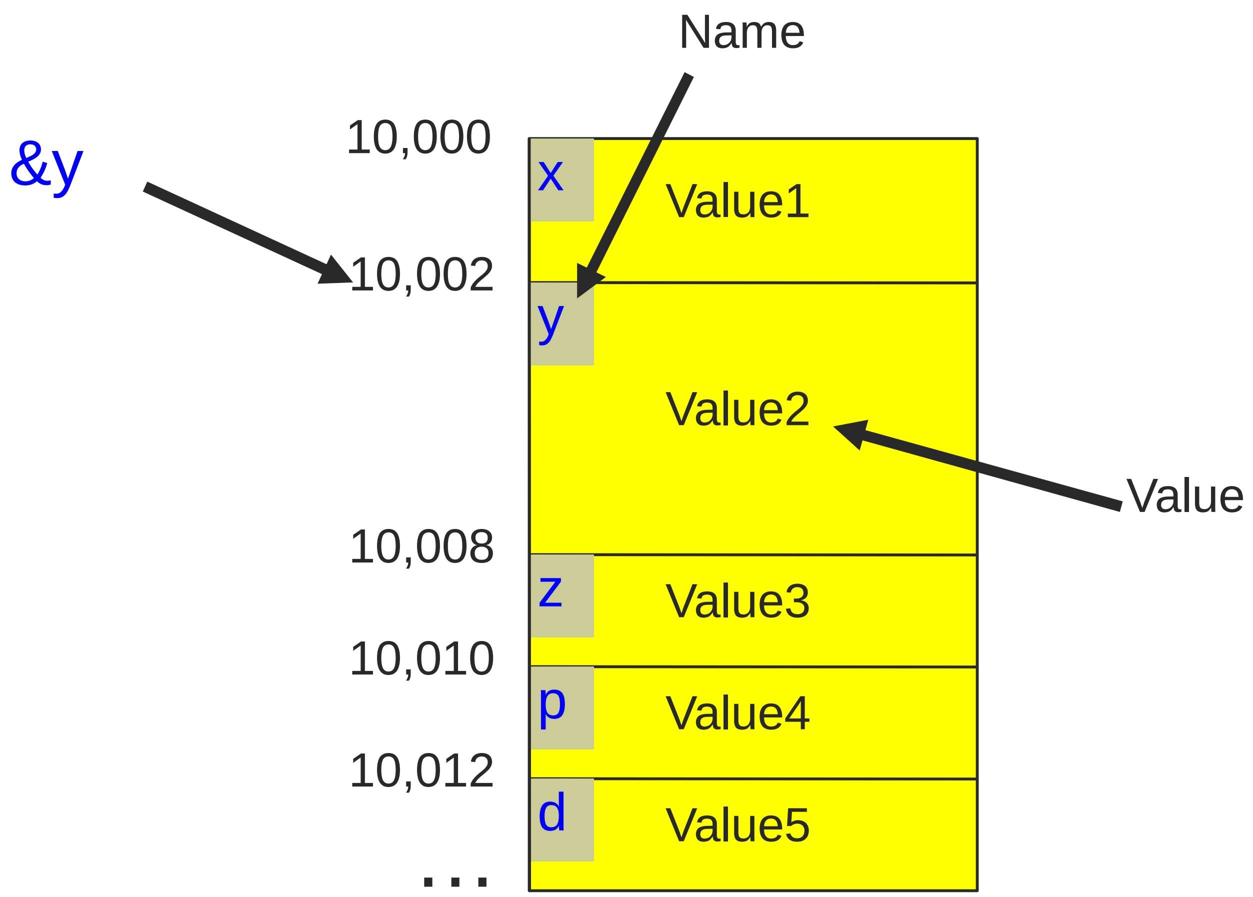
Variables



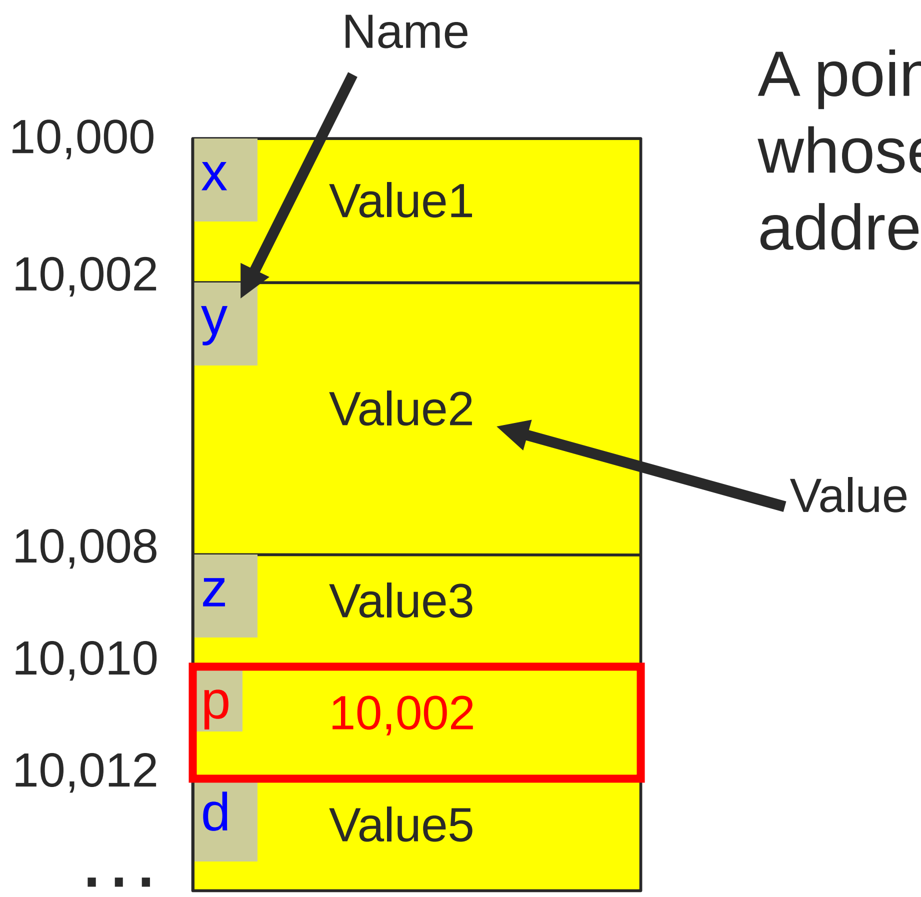
Type of each variable
(also determines size)

```
int      x;
double   y;
float    z;
double*  p;
int      d;
```

The “&” Operator: Reads “Address of”

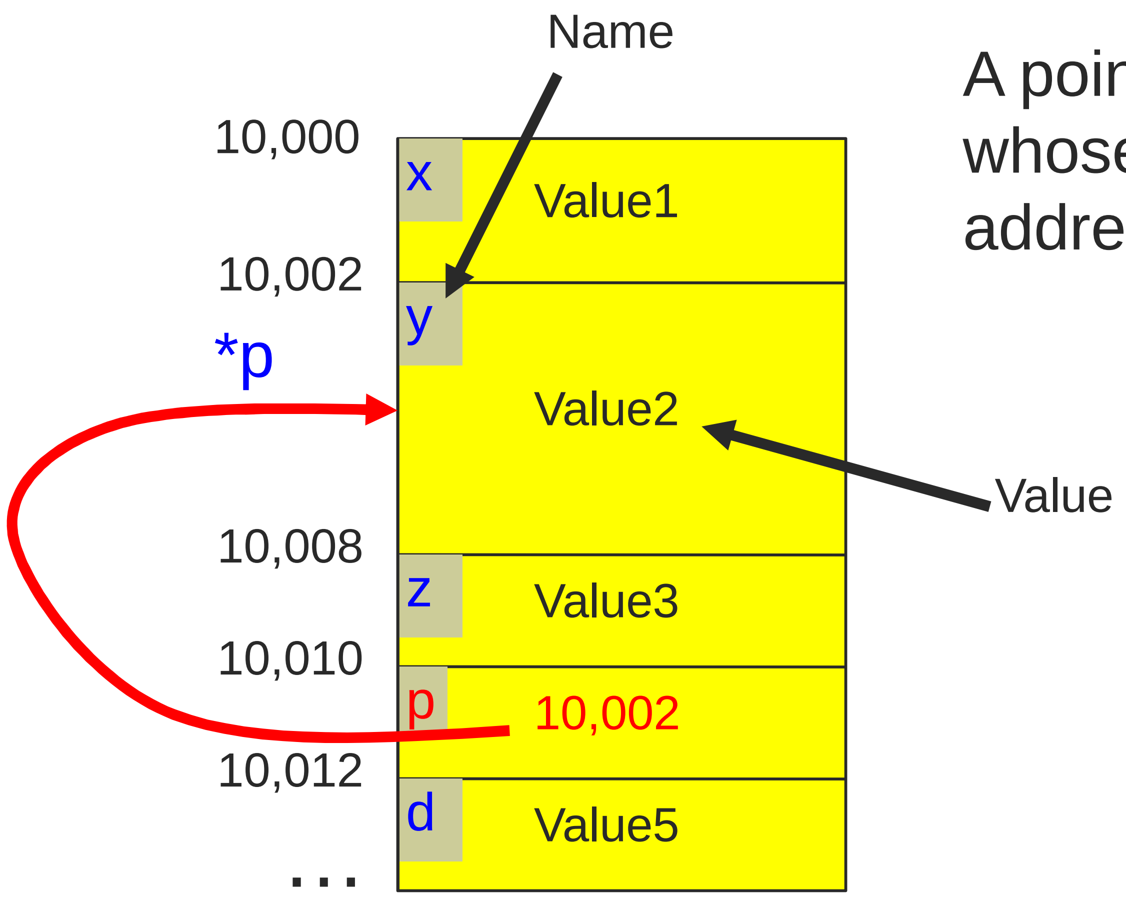


Pointers



A pointer is a variable whose value is the address of another

The "*" Operator
Reads "Variable pointed to by"



A pointer is a variable whose value is the address of another

What is the Output?

```
main() {
    int *p, q, x;
    x=10;
    p=&x;
    *p=x+1;
    q=x;
    printf (“Q = %d\n“, q);
}
```

What is the Output?

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main() {
    int *p, q, x;
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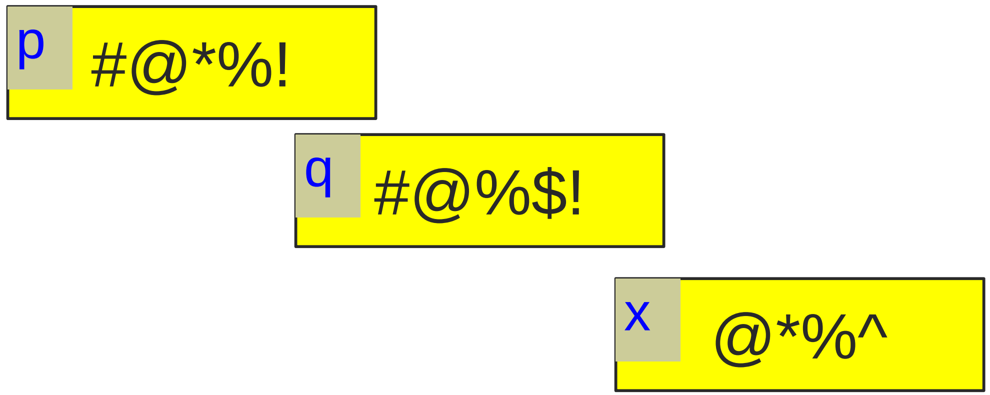

What is the Output?

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    int *p, q, x;
    x=10;
    p=&x;
    *p=x+1;
    q=x;
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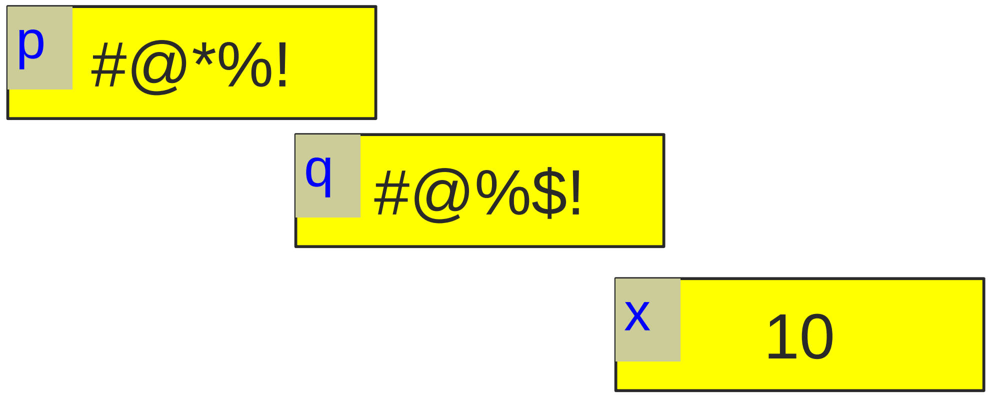
}
```



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    int *p, q, x;
    x=10;
    p=&x;
    *p=x+1;
    q=x;
    printf ("Q = %d\n", q);
}
```

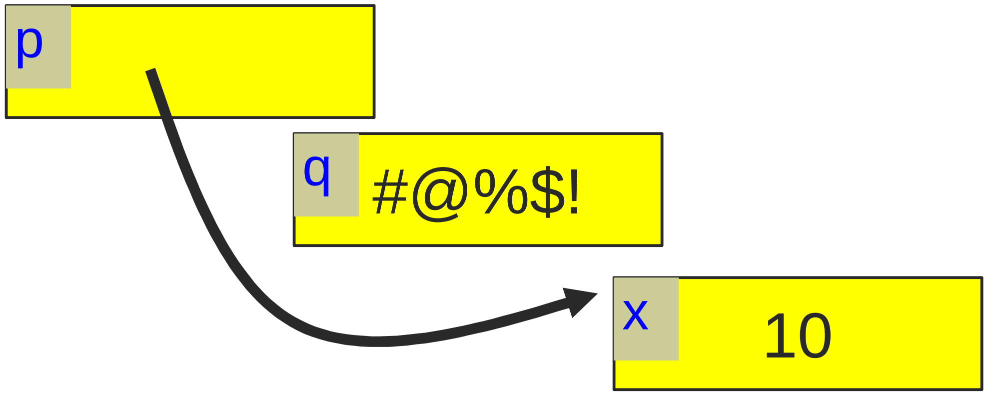

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    x=10;
    p=&x;
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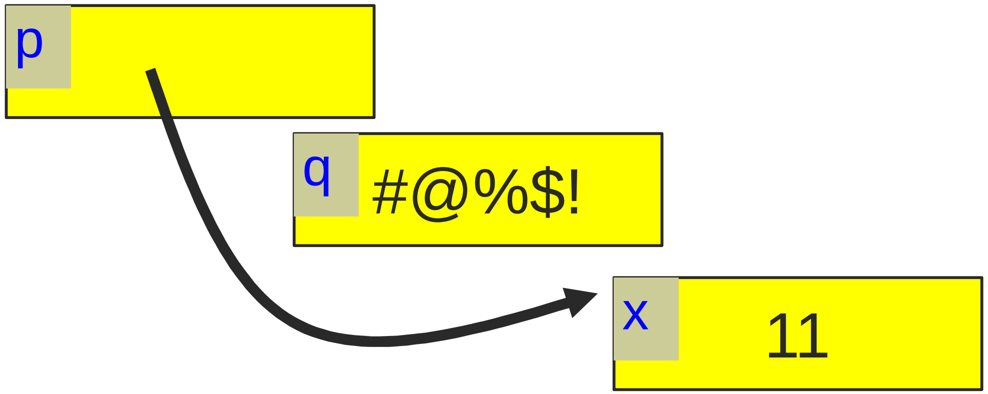

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    p=&x;
    *p=x+1;
    q=x;
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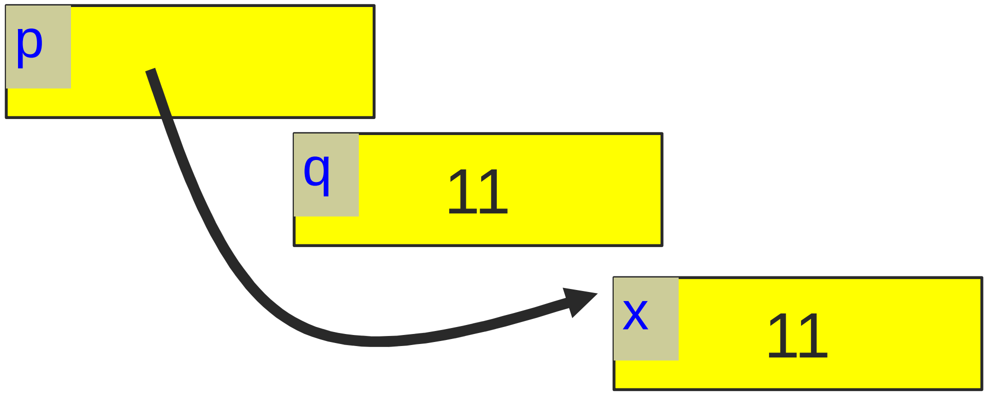
}
```



Cardinal Rule: Must Initialize Pointers before Using them

```
int *p;
*p = 10;
```

← GOOD or BAD?

Cardinal Rule: Must Initialize Pointers before Using them

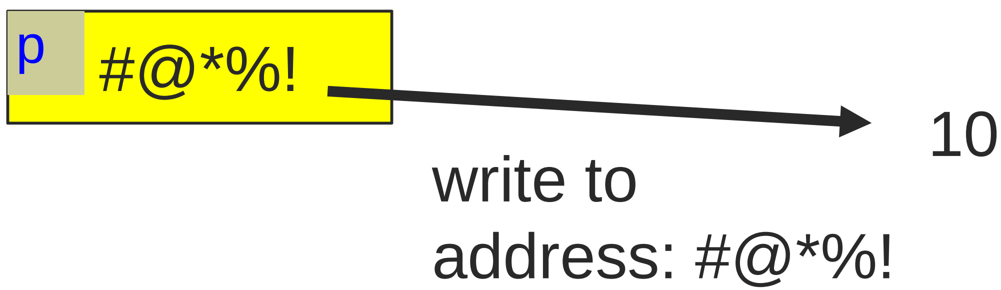
```
int *p;
*p = 10;
```

BAD!

Pointing somewhere random

Cardinal Rule: Must Initialize Pointers before Using them

```
int *p;
*p = 10;
```



Memory allocation

Memory allocation

- Two ways to dynamically allocate memory
- Stack
  - Named variables in functions
    - Allocated for you when you call a function
    - Deallocated for you when function returns
- Heap
  - Memory on demand
    - You are responsible for all allocation and deallocation

Allocating and deallocating heap memory

- Dynamically *allocating* memory
  - Programmer explicitly requests space in memory
  - Space is allocated dynamically on the heap
  - E.g., using “malloc” in C, “new” in Java
- Dynamically *deallocating* memory
  - Must reclaim or recycle memory that is never used again
  - To avoid (eventually) running out of memory
- “Garbage”
  - Allocated blocks in heap that will not be used again
  - Can be reclaimed for later use by the program

Option #1: Garbage Collection

- Run-time system does garbage collection (Java)
  - Automatically determines which objects can't be accessed
  - And then reclaims the resources used by these objects

```
Object x = new Foo() ;
Object y = new Bar() ;
x = new Quux() ;

if (x.check_something()) {
     x.do_something(y) ;
}

System.exit(0) ;
```

Object Foo() is never used again!

Challenges of Garbage Collection

- Detecting the garbage is not always easy
  - `long char z = x ;`
  - `x = new Quux();`
  - Run-time system cannot collect *all* the garbage
- Detecting the garbage introduces overhead
  - Keeping track of references to object (e.g., counters)
  - Scanning through accessible objects to identify garbage
  - Sometimes walking through a large amount of memory
- Cleaning the garbage leads to bursty delays
  - E.g., periodic scans of the objects to hunt for garbage
  - Leads to unpredictable “freezes” of the running program
  - Very problematic for real-time applications
    - … though good run-time systems avoid long freezes

Option #2: Manual Deallocation

- *Programmer* deallocates the memory (C and C++)
  - Manually determines which objects can't be accessed
  - And then explicitly returns those resources to the heap
  - E.g., using "free" in C or "delete" in C++
- Advantages
  - Lower overhead
  - No unexpected "pauses"
  - More efficient use of memory
- Disadvantages
  - More complex for the programmer
  - Subtle memory-related bugs
  - Can lead to security vulnerabilities in code

Manual deallocation can lead to bugs

- Dangling pointers
  - Programmer frees a region of memory
  - … but still has a pointer to it
  - Dereferencing pointer reads or writes nonsense values

```
int main(void) {
     char *p;
     p = malloc(10);
     …
     free(p);
     …
     printf("%c\n",*p);
}
```

May print nonsense character

Manual deallocation can lead to bugs

- Memory leak
  - Programmer neglects to free unused region of memory
  - So, the space can never be allocated again
  - Eventually may consume all of the available memory

```
void f(void) {
     char *s;
     s = malloc(50);
}

int main(void) {
     while (1) f();
}
```

Eventually, malloc() returns NULL

Manual deallocation can lead to bugs

- Double free
  - Programmer mistakenly frees a region more than once
  - Leading to corruption of the heap data structure
  - … or premature destruction of a different object

```
int main(void) {
      char *p, *q;
      p = malloc(10);
      …
      free(p)
      q = malloc(10);
      free(p)
}
```

Might free space allocated by **q**!

Heap memory allocation

- C++:
  - new and delete allocate memory for a whole object

- C:
  - malloc and free deal with unstructured blocks of bytes

```
void* malloc(size_t size);
void free(void* ptr);
```

Example

```
int* p;

p = (int*) malloc(sizeof(int));

*p = 5;

free(p);
```

How many bytes do you want?

Cast to the right type

I’m hungry. More bytes plz.

```
int* p = (int*) malloc(10 * sizeof(int));
```

- Now I have space for 10 integers, laid out contiguously in memory. What would be a good name for that...?

Arrays

- Contiguous block of memory
  - Fits one or more elements of some type
- Two ways to allocate
  - named variable

```
int x[10];
```

  - dynamic

```
int* x = (int*) malloc(10*sizeof(int));
```

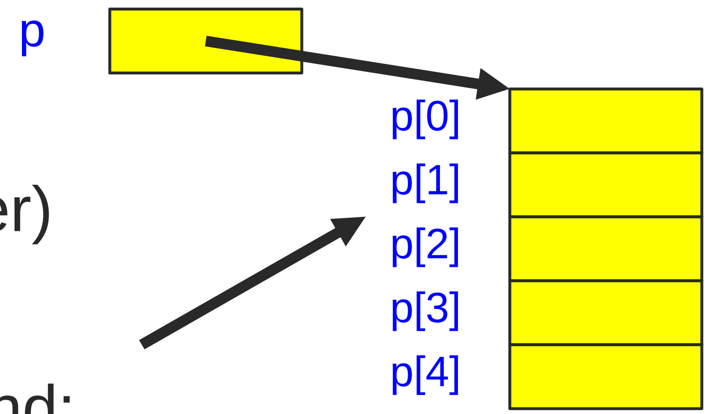
Is there a difference?

One is on the stack, one is on the heap

Arrays

int p[5];

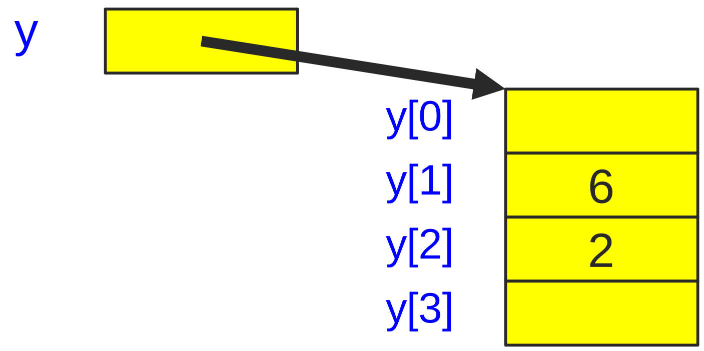
Name of array (is a pointer)



Shorthand:
*(p+1) is called p[1]
*(p+2) is called p[2]
etc..

Example

```
int y[4];
y[1]=6;
y[2]=2;
```



Array Name as Pointer

- What's the difference between the examples?

- Example 1:

```
int z[8];
int *q;
q=z;
```

- Example 2:

```
int z[8];
int *q;
q=&z[0];
```

Array Name as Pointer

- What's the difference between the examples?

- Example 1:

```
int z[8];
int *q;
q=z;
```

- Example 2:

```
int z[8];
int *q;
q=&z[0];
```

NOTHING!!

z (the array name) is a pointer to the beginning of the array, which is &z[0]

Questions

- What's the difference between

```
int* q;
int q[5];
```

- What's wrong with

```
int ptr[2];
ptr[1] = 1;
ptr[2] = 2;
```

Questions

- What is the value of b[2] at the end?

```
int b[3];
int* q;

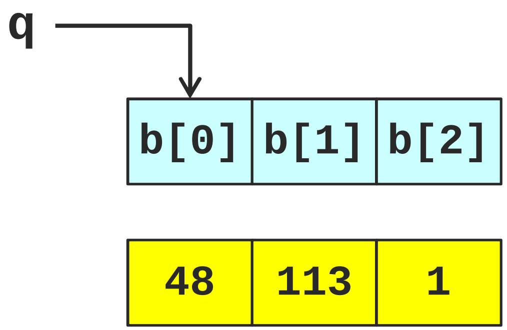
b[0]=48; b[1]=113; b[2]=1;

q=b;

*(q+1)=2;

b[2]=*b;

b[2]=b[2]+b[1];
```



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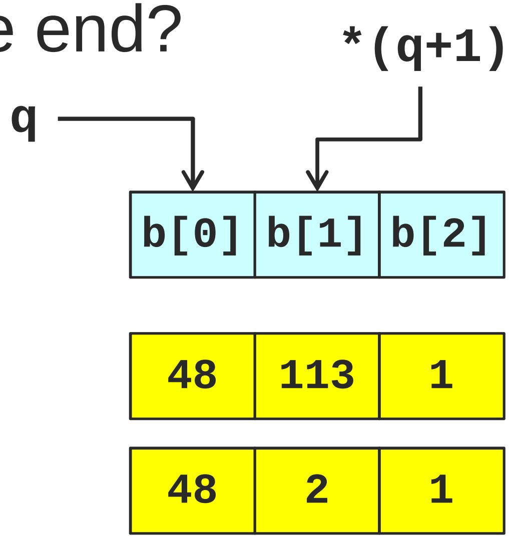

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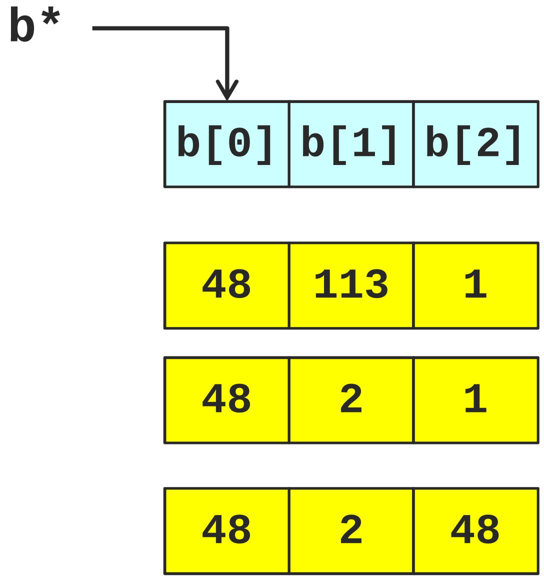

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b[0]=48; b[1]=113; b[2]=1;
q=b;
*(q+1)=2;
b[2]=*b;
b[2]=b[2]+b[1];
```

b[0]	b[1]	b[2]
48	113	1
48	2	1
48	2	48
48	2	50

Questions

- What is the value of b[2] at the end?

```
int b[3];
int* q;

b[0]=48; b[1]=113; b[2]=1;

q=b;

*(q+1)=2;

b[2]=*b;

b[2]=b[2]+b[1];
```

48	113	1

48	2	1

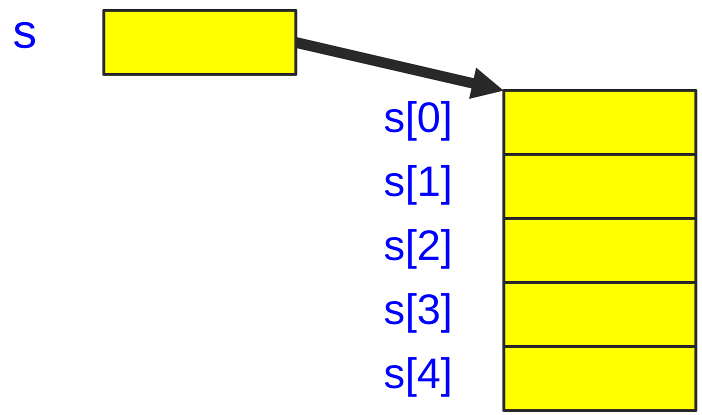
48	2	48

48	2	50

Strings

Strings (Null-terminated Arrays of Char)

- Strings are arrays that contain the string characters followed by a “Null” character ‘\0’ to indicate end of string.
  - Do not forget to leave room for the null character
- Example
  - char s[5];



Conventions

- Strings
  - “string”
  - “c”
- Characters
  - ‘c’
  - ‘X’

String Operations

- strcpy
- strlen
- strcat
- strcmp

strcpy, strlen

- strcpy(ptr1, ptr2);
  - ptr1 and ptr2 are pointers to char
- value = strlen(ptr);
  - value is an integer
  - ptr is a pointer to char

```
int len;
char str[15];
strcpy (str, "Hello, world!");
len = strlen(str);
```

strcpy, strlen

- What's wrong with

```
char str[5];
strcpy (str, "Hello");
```

strncpy

- strncpy(ptr1, ptr2, num);
  - ptr1 and ptr2 are pointers to char
  - num is the number of characters to be copied

```
int len;
char str1[15], str2[15];
strcpy (str1, "Hello,
    world!");
strncpy (str2, str1, 5);
```

strncpy

- strncpy(ptr1, ptr2, num);
  - ptr1 and ptr2 are pointers to char
  - num is the number of characters to be copied

```
int len;
char str1[15], str2[15];
strcpy (str1, "Hello,
    world!");
strncpy (str2, str1, 5);
```

Caution: strncpy blindly copies the characters. It does not voluntarily append the string-terminating null character.

strcat

- strcat(ptr1, ptr2);
  - ptr1 and ptr2 are pointers to char

- Concatenates the two null terminated strings yielding one string (pointed to by ptr1).

```
char S[25] = "world!";
char D[25] = "Hello, ";
strcat(D, S);
```

strcat

- strcat(ptr1, ptr2);
  - ptr1 and ptr2 are pointers to char
- Concatenates the two null terminated strings yielding one string (pointed to by ptr1).
  - Find the end of the destination string
  - Append the source string to the end of the destination string
  - Add a NULL to new destination string

strcat Example

- What's wrong with

```
char S[25] = "world!";
strcat("Hello, ", S);
```

strcat Example

- What’s wrong with

```
char *s = malloc(11 * sizeof(char));
        /* Allocate enough memory for an
           array of 11 characters, enough
           to store a 10-char long string. */
strcat(s, "Hello");
strcat(s, "World");
```

strcat

- strcat(ptr1, ptr2);
  - ptr1 and ptr2 are pointers to char
- Compare to Java and C++
  - string s = s + " World!";
- What would you get in C?
  - If you did char* ptr0 = ptr1+ptr2;
  - You would get the sum of two memory locations!

strcmp

- diff = strcmp(ptr1, ptr2);
  - diff is an integer
  - ptr1 and ptr2 are pointers to char
- Returns
  - zero if strings are identical
  - < 0 if ptr1 is less than ptr2 (earlier in a dictionary)
  - > 0 if ptr1 is greater than ptr2 (later in a dictionary)

```
int diff;
char s1[25] = "pat";
char s2[25] = "pet";
diff = strcmp(s1, s2);
```

Can we make this work?!

```
int x;

printf("This class is %s.\n", &x);
```

Can we make this work?!

```
int x;




printf("This class is %s.\n",   );
```

Can we make this work?!

```
int x;

(char*)&x

printf("This class is %s.\n", &x);
```

Can we make this work?!

```
int x;

((char*)&x)[0] = 'f';

printf("This class is %s.\n", &x);
```

Can we make this work?!

```
int x;

((char*)&x)[0] = 'f';
((char*)&x)[1] = 'u';
((char*)&x)[2] = 'n';

printf("This class is %s.\n", &x);
```

Can we make this work?!

```
int x;

((char*)&x)[0] = 'f';
((char*)&x)[1] = 'u';
((char*)&x)[2] = 'n';
((char*)&x)[3] = '\0';

printf("This class is %s.\n", &x);
```

Perfectly legal and perfectly horrible!

Can we make this work?!

```
int x;

char* s = &x;
strcpy(s, “fun”);
```

Perfectly legal and perfectly horrible!

```
printf("This class is %s.\n", &x);
```

Other operations

Increment & decrement

- x++: yield old value, add one
- ++x: add one, yield new value

```
int x = 10;
x++;
int y = x++;        11

int z = ++x;        13
```

- --x and x-- are similar (subtract one)

Math: Increment and Decrement Operators

- Example 1:

```
int x, y, z, w;
y=10; w=2;
x=++y;
z=--w;
```

- Example 2:

```
int x, y, z, w;
y=10; w=2;
x=y++;
z=w--;
```

What are **x** and **y** at the end of each example?

Math: Increment and Decrement Operators

- Example 1:

```
int x, y, z, w;
y=10; w=2;
x=++y;
z=--w;
```

- First increment/ decrement, then assign result
- x is 11, z is 1

- Example 2:

```
int x, y, z, w;
y=10; w=2;
x=y++;
z=w--;
```

- First assign result, then increment/ decrement
- x is 10, z is 2

Math: Increment and Decrement Operators on Pointers

- Example 1:

```
int a[2];
int number1, number2, *p;
a[0]=1; a[1]=10;
p=a;
number1 = *p++;
number2 = *p;
```

- What will number1 and number2 be at the end?

Math: Increment and Decrement Operators on Pointers

- Example

```
int a[2];
int number1, number2, *p;
a[0]=1; a[1]=10;
p=a;
number1 = *p++;
number2 = *p;
```

Hint: ++ increments pointer p not variable *p

- What will number1 and number2 be at the end?

Logic: Relational (Condition) Operators

==	equal to
!=	not equal to
>	greater than
<	less than
>=	greater than or equal to
<=	less than or equal to

Logic Example

```
if (a == b)
    printf ("Equal.");
else
    printf ("Not Equal.");
```

- Question: what will happen if I replaced the above with:

```
if (a = b)
    printf ("Equal.");
else
    printf ("Not Equal.");
```

Perfectly LEGAL C statement!
(syntactically speaking)
It copies the value in b into a. The statement will be interpreted as TRUE if b is non-zero.

Review

Review

- int p1;
  What does &p1 mean?

Review

- How much is y at the end?

```
int y, x, *p;

x = 20;
*p = 10;
y = x + *p;
```

Review

- How much is y at the end?

```
int y, x, *p;

x = 20;
*p = 10;
y = x + *p;
```

BAD!!
Dereferencing an uninitialized pointer will likely segfault or overwrite something!

Segfault = unauthorized memory access

Review

- What are the differences between x and y?

```
char* f() {
  char *x;
  static char*y;
  return y;
}
```

Review: Debugging

```
if(strcmp("a","a"))
   printf("same!");
```

Review: Debugging

```
int i = 4;
int *iptr;
iptr = &i;
*iptr = 5;//now i=5
```

Review: Debugging

```
char *p;
p=(char*)malloc(99);
strcpy("Hello",p);
printf("%s World",p);
free(p);
```

Review: Debugging

```
char msg[5];
strcpy (msg,"Hello");
```

<table>
<tr><th>Operator</th><th>Description</th><th>Associativity</th></tr>
<tr><td>()
[]
.
->
++ --</td><td>Parentheses (function call)
Brackets (array subscript)
Member selection via object name
Member selection via pointer
Postfix increment/decrement</td><td>left-to-right</td></tr>
<tr><td>++ --
+ -
! ~
(type)
*
&
sizeof</td><td>Prefix increment/decrement
Unary plus/minus
Logical negation/bitwise complement
Cast (change type)
Dereference
Address
Determine size in bytes</td><td>right-to-left</td></tr>
<tr><td>* / %</td><td>Multiplication/division/modulus</td><td>left-to-right</td></tr>
<tr><td>+ -</td><td>Addition/subtraction</td><td>left-to-right</td></tr>
<tr><td><< >></td><td>Bitwise shift left, Bitwise shift right</td><td>left-to-right</td></tr>
<tr><td>< <=
> >=</td><td>Relational less than/less than or equal to
Relational greater than/greater than or equal to</td><td>left-to-right</td></tr>
<tr><td>== !=</td><td>Relational is equal to/is not equal to</td><td>left-to-right</td></tr>
<tr><td>&</td><td>Bitwise AND</td><td>left-to-right</td></tr>
<tr><td>^</td><td>Bitwise exclusive OR</td><td>left-to-right</td></tr>
<tr><td>|</td><td>Bitwise inclusive OR</td><td>left-to-right</td></tr>
<tr><td>&&</td><td>Logical AND</td><td>left-to-right</td></tr>
<tr><td>||</td><td>Logical OR</td><td>left-to-right</td></tr>
<tr><td>?:</td><td>Ternary conditional</td><td>right-to-left</td></tr>
<tr><td>=
+= -=
*= /=
%= &=
^= |=
<<= >>=</td><td>Assignment
Addition/subtraction assignment
Multiplication/division assignment
Modulus/bitwise AND assignment
Bitwise exclusive/inclusive OR assignment
Bitwise shift left/right assignment</td><td>right-to-left</td></tr>
<tr><td>,</td><td>Comma (separate expressions)</td><td>left-to-right</td></tr>
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