CSC 322: Computer Organization Lab

Lecture 01: C for Java Programmers

Course Introduction

- Lab will be held on Thursdays from 11:00-12:15 pm, from January 16, 2018 until April 25, 2018
- Prerequisites
  - The ability to program
- What will we do in the lab?
  - Learn C programming
  - Learn Python Programming
  - Learn Verilog
  - Model hardware using the above languages
- We will be using LaTex in order to write the reports!

Grading and Class Policies

- Final Exam: 15%
- Labs: 70%
- Two Capstones
  - Software-based: 10%
  - Hardware-based: 15%
- Exam Details
  - Exams are closed book, closed notes
- All assignments must be your own original work.
  - Cheating/copying/partnering will not be tolerated

Lab Reports

- You need to submit a report at the conclusion of each lab
- The report should follow the LaTex template on `github`
  - https://github.com/harmanani/csc322/tree/master/Lab%20Report%20Template

Contact Information

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Lab Assignments

- All assignments and handouts will be communicated via piazza
  – Make sure you enable your account
- Use piazza for questions and inquiries
  – No questions will be answered via email
- All assignments must be submitted via github
  – git is a distributed version control system
  – Version control systems are better tools for sharing code than emailing files, using flash drives, or Dropbox
  – Make sure you get a private repo
    - Apply for a free account: https://education.github.com/discount_requests/new

On to C …

Why learn C (after Java)?

- Both high-level and low-level language
  - OS: user interface to kernel to device driver
- Better control of low-level mechanisms
  - Memory allocation, specific memory locations
- Performance better than Java
  - More predictable
- Java hides many details needed for writing OS code
- But you will have to worry about:
  - Memory management
  - Initialization and error detection
- More room for mistakes in C
- Philosophical considerations:
  - Being multi-lingual is good!
  - Should be able to trace program from UI to assembly (EEs: to electrons)

C history

- C
  - Dennis Ritchie in late 1960s and early 1970s
  - *systems* programming language
    - make OS portable across hardware platforms
    - not necessarily for real applications – could be written in Fortran or PL/I
- C++
  - Bjarne Stroustrup (Bell Labs), 1980s
  - object-oriented features
- Java
  - James Gosling in 1990s, originally for embedded systems
  - object-oriented, like C++
  - ideas and some syntax from C

C for Java programmers

- Java is mid-90s high-level OO language
- C is early-70s *procedural* language
- C advantages:
  - Direct access to OS primitives (system calls)
  - Fewer library issues – just execute
- (More) C disadvantages:
  - language is portable, APIs are not
  - memory and “handle” leaks
  - preprocessor can lead to obscure errors

C vs. Java

- Java program
  - collection of classes
  - class containing main method is starting class
  - running `java StartClass` invokes `StartClass.main` method
  - JVM loads other classes as required
- C Program
  - collection of functions
  - one function – `main()` – is starting function
  - running executable (default name a.out) starts main function
  - typically, single program with all user code linked in – but can be dynamic libraries (.dll, .so)

C vs. Java

```
public class hello
{
   public static void main (String args [])
 {
      System.out.println
      ("Hello world");
   }
}
```

```
#include <stdio.h>
int main(int argc, char *argv[])
{
  puts("Hello, World");
  return 0;
}
```

Simple Example

```
#include <stdio.h>

void main(void)
{
    printf(“Hello World. \n \t and you ! \n ”);
                 /* print out a message */
    return;
}
```

```
$ gcc hello.c
$  ./a.out
$ Hello World.
        and you !
$
```


Simple Example

```
#include <stdio.h>

void main(void)
{
    printf(“Hello World. \n \t and you ! \n ”);
                 /* print out a message */
    return;
}
```

```
$ gcc -o hello hello.c
$  ./hello
$ Hello World.
        and you !
$
```

Dissecting the example

- `#include <stdio.h>`
  - include header file `stdio.h`
  - # lines processed by *pre-processor*
  - No semicolon at end
  - Lower-case letters only – C is case-sensitive
- `void main(void){ … }` is the only code executed
- `printf(" /* message you want printed */ ");`
- `\n` = newline, `\t` = tab
- \ in front of other special characters within `printf`.
  - `printf("Have you heard of \"The Rock\" ? \n");`

Compiling and Executing a C Program

Executing the C program

- How can we pass parameters to a C program?
- Example
  - Assume we have a set of names in a file
  - I would like to pass the file as an argument so that these names are processed.
  - I do not wish to be prompted for a file name

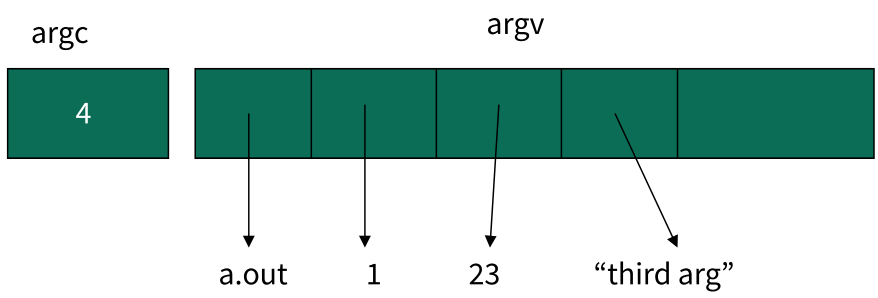
Executing the C program

```
int main(int argc, char argv[])
```

- argc is the argument count
- argv is the argument vector
  - array of strings with command-line arguments
- the `int` value is the return value
  - convention: 0 means success, > 0 some error
  - can also declare as void (no return value)

Executing a C program

- Name of executable + space-separated arguments
- $ a.out 1 23 ‘third arg’



Executing a C program

- If no arguments, simplify:

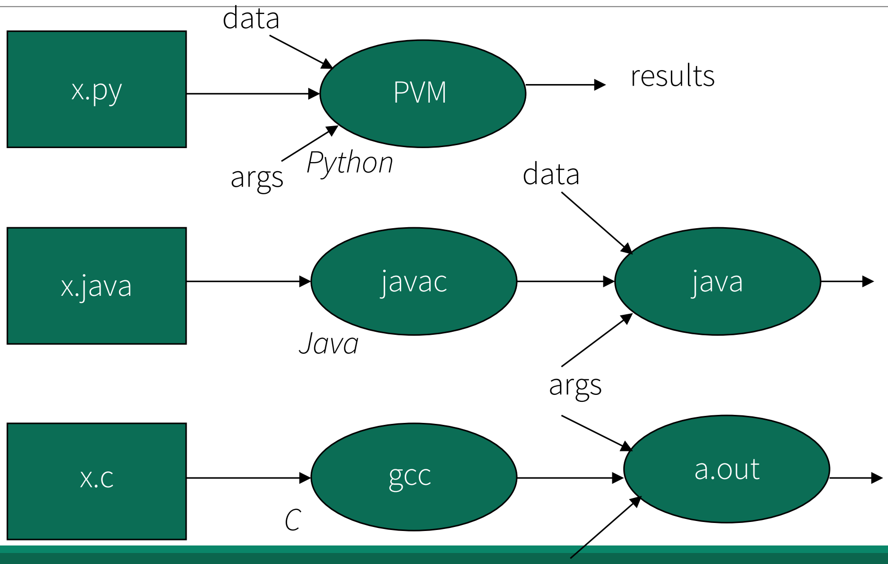
```
int main() {
  puts("Hello World");
  exit(0);
}
```

- Uses `exit()` instead of return – same thing.

Executing C programs

- Scripting languages are usually interpreted
  - perl (python, Tcl) reads script, and executes it
  - sometimes, just-in-time compilation – invisible to user
- Java programs semi-interpreted:
  - javac converts foo.java into foo.class
  - not machine-specific
  - byte codes are then interpreted by JVM
- C programs are normally compiled and linked:
  - gcc converts foo.c into a.out
  - a.out is executed by OS and hardware

Executing C programs



The C compiler gcc

- gcc invokes C compiler
- gcc translates C program into executable for some target
- default file name a.out
- also “cross-compilation”

```
$ gcc hello.c
$ a.out
Hello, World!
```


Using gcc

- Two-stage compilation
  - pre-process & compile: gcc –c hello.c
  - link: `gcc -o hello hello.o`
- Linking several modules:

  `gcc -c a.c` → a.o

  `gcc -c b.c` → b.o

  `gcc -o hello a.o b.o`
- Using math library
  - `gcc -o calc calc.c -lm`

Error reporting in gcc

- Multiple sources
  - preprocessor: missing include files
  - parser: syntax errors
  - assembler: rare
  - linker: missing libraries

Error reporting in gcc

- If `gcc` gets confused, hundreds of messages
  - fix first, and then retry – ignore the rest
- `gcc` will produce an executable with warnings
  - don’t ignore warnings – compiler choice is often not what you had in mind
- Does not flag common mindos
  - `if (x = 0)` vs. `if (x == 0)`

gcc errors

- Produces object code for each module
- Assumes references to external names will be resolved later
- Undefined names will be reported when linking:

```
undefined symbol   first referenced in file
 _print            program.o
ld fatal: Symbol referencing errors
No output written to file.
```

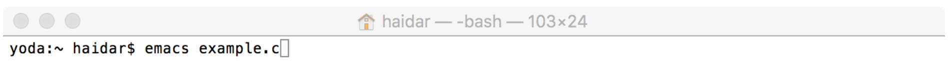

Let us try to compile something using gcc

Source Code

```
#include <stdio.h>

int main(void)
{
  int iNumberOfMoney = 0; /* Initialization, required */

  printf(“How much money do you have ?:”);
  scanf (“%d”, &iNumberOfMoney);  /* Read input */
  printf(“You have %d Lebanese Pounds.\n”, iNumberOfMoney);

  return 0;
}
```

$ How much money do you have ?: 200000 (enter)
You have 200000 Lebanese Pounds.

Using emacs, Linux, and gcc



Type The code

```
haidar — emacs example.c — 103×24
#include <stdio.h>

int main(void)
{
  int iNumberOfMoney = 0; /* Initialization, required */

  printf("How much money do you have ?:");
  scanf ("%d", &iNumberOfMoney);  /* Read input */
  printf("You have %d Lebanese Pounds.\n", iNumberOfMoney);

  return 0;
}

-uuu:---F1  example.c      All L11     (C/l Abbrev)------------------------------------------------------
```


Compile and Run

```
haidar — -bash — 103×24
yoda:~ haidar$ gcc -o example example.c
yoda:~ haidar$ ./example
How much money do you have ?:200000
You have 200000 Lebanese Pounds.
yoda:~ haidar$
```

gcc Options

- ***gcc –o example example.c –g -Wall***
  - '-o' option tells the compiler to name the executable '**example**'
  - '-g' option adds symbolic information to **example** for debugging
  - '–Wall' tells it to print out all warnings (very useful!!!)
  - Can also give '-O6' to turn on full optimization
  - -l to include libraries
  - -E for preprocessor output only
- To execute the program simply type: ***./example***
- ***gdb*** is the Linux debugger

gcc Options: Summary

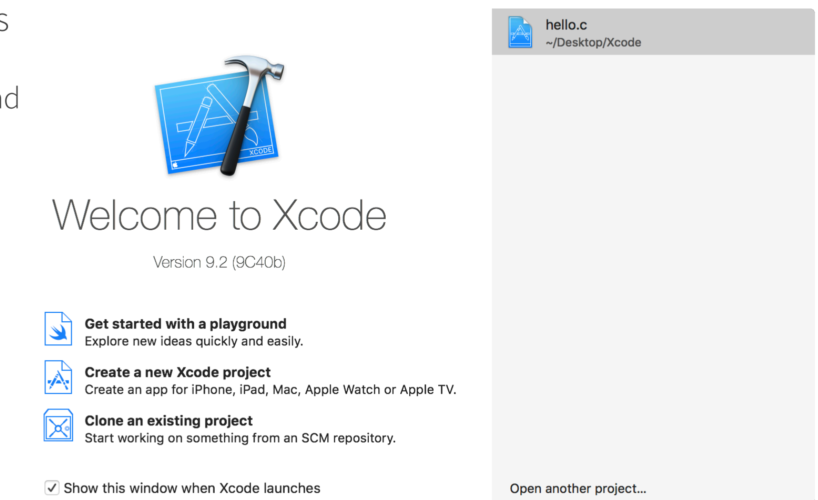
- Behavior controlled by command-line switches:

-o *file*	output file for object or executable
-Wall	all warnings – use always!
-c	compile single module (non-main)
-g	insert debugging code (gdb)
-p	insert profiling code
-l	library
-E	preprocessor output only

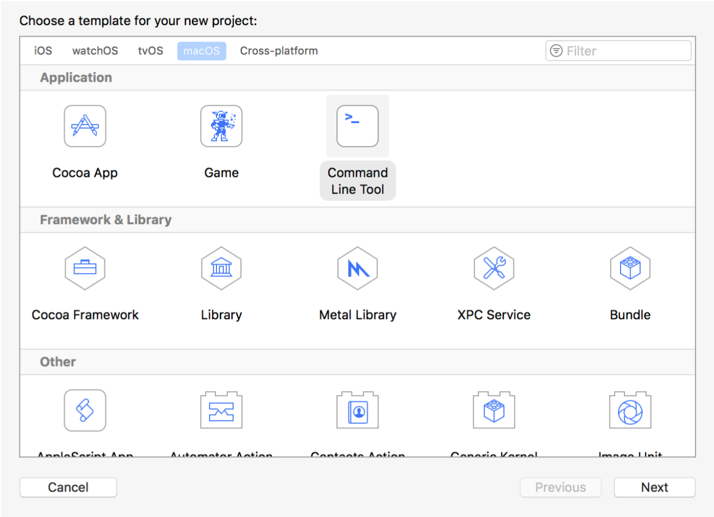
Let us redo the same example using Developer Studio or Xcode

Open Xcode:

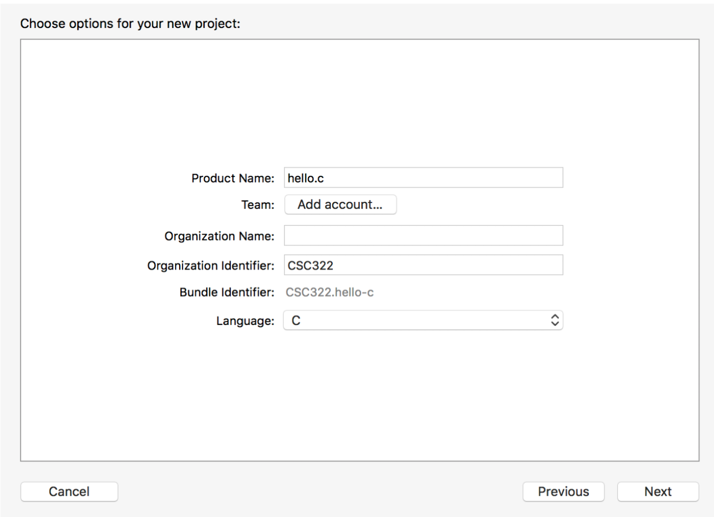
- Make sure that `Xcode` is already installed
  - Otherwise, freely download it from the `App Store`



Open Xcode and Create a Project Using the Command Line Tool

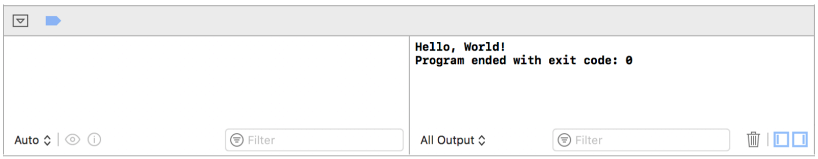


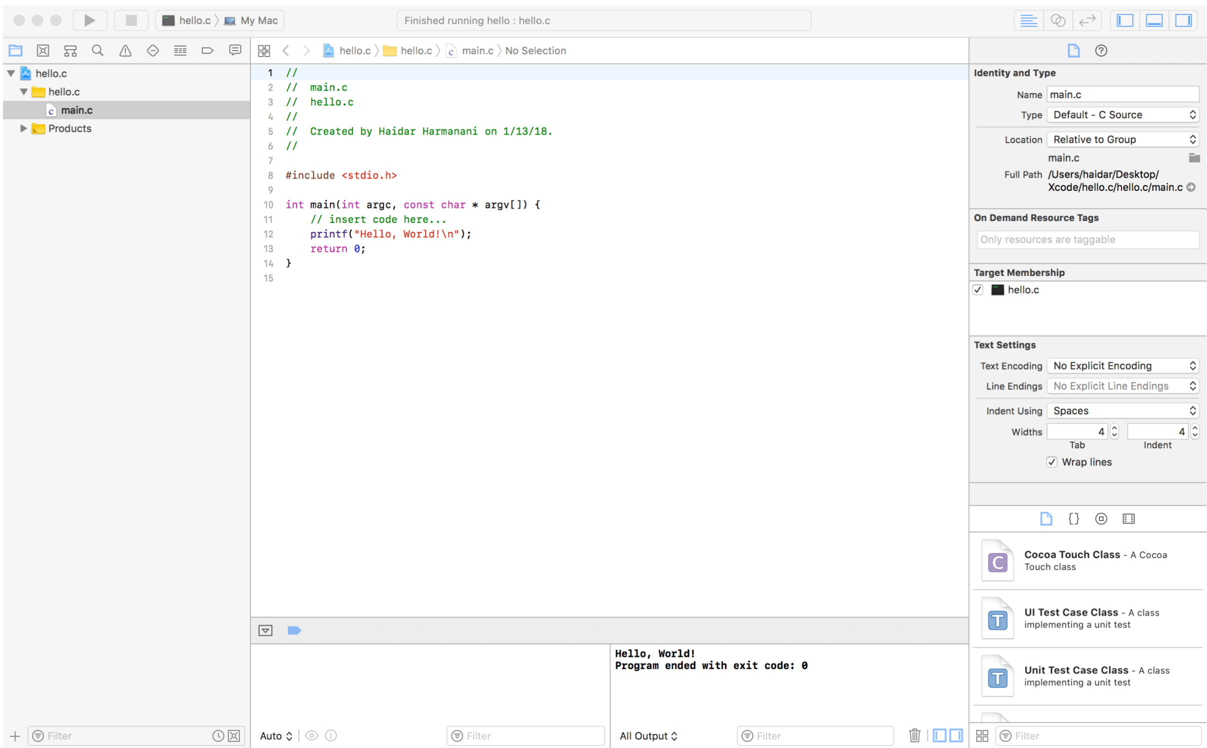
Name your project `hello.c` and Select any *organization identifier*



Edit and Compile

- Type your code in the built-in editor
- Compile by clicking on the arrow 
- Output will be appear in the bottom window





More C Programming

C preprocessor

- The C preprocessor (cpp) is a macro-processor which
  - manages a collection of macro definitions
  - reads a C program and transforms it
  - Example:

```
#define MAXVALUE 100
#define check(x) ((x) < MAXVALUE)
if (check(i) { …}
```

becomes

```
if ((i) < 100)  {…}
```

C preprocessor

- Preprocessor directives start with # at beginning of line:
  – define new macros
  – input files with C code (typically, definitions)
  – conditionally compile parts of file
- `gcc -E` shows output of preprocessor
- Can be used independently of compiler

C preprocessor

`#define` *name const-expression*

`#define` *name (param1,param2,…) expression*

`#undef` *`symbol`*

- replaces name with constant or expression
- textual substitution
- symbolic names for global constants
- *in-line* functions (avoid function call overhead)
  – mostly unnecessary for modern compilers
- type-independent code

C preprocessor

- Example: `#define MAXLEN 255`
- Lots of system .h files define macros
- invisible in debugger
- `getchar(), putchar()` in stdio library

```
#define valid(x) ((x) > 0 && (x) < 20)
if (valid(x++)) {…}
valid(x++) -> ((x++) > 0 && (x++) < 20)
```

Don’t treat macros like function calls

C preprocessor –file inclusion

```
#include "filename.h"
#include <filename.h>
```

- inserts contents of filename into file to be compiled
- “filename” relative to current directory
- <filename> relative to `/usr/include`
- `gcc -I` flag to re-define default
- import function prototypes (cf. Java import)
- Examples:

```
#include <stdio.h>
#include "mydefs.h"
#include "/home/alice/program/defs.h"
```

C preprocessor – conditional compilation

```
#if expression
code segment 1
#else
code segment 2
#endif
```

- preprocessor checks value of expression
- if true, outputs code segment 1, otherwise code segment 2
- machine or OS-dependent code
- can be used to comment out chunks of code – bad!

```
#define OS linux
…
#if OS == linux
  puts("Linux!");
#else
  puts("Something else");
#endif
```


C preprocessor - ifdef

- For boolean flags, easier:

```
#ifdef name
code segment 1
#else
code segment 2
#endif
```

- preprocessor checks if name has been defined
  - `#define USEDB`
- if so, use code segment 1, otherwise 2

Advice on preprocessor

- Limit use as much as possible
  - subtle errors
  - not visible in debugging
  - code hard to read
- much of it is historical baggage
- there are better alternatives for almost everything:
  - #define INT16 -> type definitions
  - #define MAXLEN -> const
  - #define max(a,b) -> regular functions
  - comment out code -> CVS, functions
- limit to .h files, to isolate OS & machine-specific code

C Comments and data types

Comments

- `/* any text until */`
- `//` C++-style comments – careful!
- no `/** */`, but doc++ has similar conventions
- Convention for longer comments:

```
/*
 * AverageGrade()
 * Given an array of grades, compute the average.
 */
```

- Avoid **** boxes – hard to edit, usually look ragged.

Numeric data types

type	bytes	range
char	1	-128 … 127
short	2	-65536…65535
int, long	4	-2,147,483,648 to 2,147,483,647
long long	8	2^{64}
float	4	3.4E+/-38 (7 digits)
double	8	1.7E+/-308 (15 digits)

Remarks on data types

- Range differs – `int` is "native" size, e.g., 64 bits on 64-bit machines, but sometimes `int` = 32 bits, `long` = 64 bits
- Also, `unsigned` versions of integer types
  – same bits, different interpretation
- `char` = 1 "character", but only true for ASCII and other Western char sets

Type conversion

```
#include <stdio.h>
void main(void)
{
  int i,j = 12;      /* i not initialized, only j */
  float f1,f2 = 1.2;

  i = (int) f2;      /* explicit: i <- 1, 0.2 lost */
  f1 = i;            /* implicit: f1 <- 1.0 */

  f1 = f2 + (int) j; /* explicit: f1 <- 1.2 + 12.0 */
  f1 = f2 + j;       /* implicit: f1 <- 1.2 + 12.0 */
}
```

Explicit and implicit conversions

- Implicit: e.g., `s = a (int) + b (char)`
- Promotion: `char` -> `short` -> `int` -> …
- If one operand is `double`, the other is made `double`
- If either is `float`, the other is made `float`, etc.
- Explicit: type casting – (*type*)
- Almost any conversion does something – but not necessarily what you intended

Type conversion

```
int x = 100000;
short s;

s = x;
printf("%d %d\n", x, s);
```

100000 -31072

C – no booleans

- C doesn't have booleans
- Emulate as int or char, with values 0 (false) and 1 or non-zero (true)
- Allowed by flow control statements:

```
if (n = 0) {
  printf("something wrong");
}
```

- Assignment returns zero -> false

User-defined types

- `typedef` gives names to types:

```
typedef short int smallNumber;
typedef unsigned char byte;
typedef char String[100];

smallNumber x;
byte b;
String name;
```

Defining your own boolean

```
typedef char boolean;
#define FALSE 0
#define TRUE 1
```

- Generally works, but beware:

```
check = x > 0;
if (check == TRUE) {…}
```

- If `x` is positive, check will be non-zero, but may not be `1`.

Enumerated types

- Define new integer-like types as enumerated types:

```
typedef enum {
  Red, Orange, Yellow, Green, Blue, Violet
} Color;
enum weather {rain, snow=2, sun=4};
```

- look like C identifiers (names)
- are listed (enumerated) in definition
- treated like integers
  - can add, subtract – even `color + weather`
  - can't print as symbol (unlike Pascal)
  - but debugger generally will

Enumerated types

- Just syntactic sugar for ordered collection of integer constants:

```
typedef enum {
   Red, Orange, Yellow
} Color;
```

is like

```
#define Red 0
#define Orange 1
#define Yellow 2
```

- `typedef enum {False, True} boolean;`

Bit fields

- On previous slides, labeled integers with size in bits (e.g., pt:7)
- Allows aligning struct with real memory data, e.g., in protocols or device drivers
- Order can differ between little/big-endian systems
- Alignment restrictions on modern processors – *natural* alignment
- Sometimes clearer than `(x & 0x8000) >> 31`

Control Structures

Control structures

- Same as Java
- sequencing: `;`
- grouping: `{...}`
- selection: `if`, `switch`
- iteration: `for`, `while`

Sequencing and grouping

- statement1 ; statement2; statement n;
  - executes each of the statements in turn
  - a semicolon after every statement
  - not required after a {...} block
- { statements} {declarations statements}
  - treat the sequence of statements as a single operation (block)
  - data objects may be defined at beginning of block

The `if` statement

- Same as Java

$\texttt{if (condition}_1\texttt{) \{statements}_1\texttt{\}}$
$\texttt{else if (condition }_2\texttt{) \{statements}_2\texttt{\}}$
$\texttt{else if (condition }_{n-1}\texttt{) \{statements }_{n-1}\texttt{\}|}$
$\texttt{else \{statements}_n\texttt{\}}$

- evaluates statements until find one with non-zero result
- executes corresponding statements

The `if` statement

- Can omit {}, but careful

```
if (x > 0)
   printf("x > 0!");
   if (y > 0)
     printf("x and y > 0!");
```


The `switch` statement

- Allows choice based on a single value

```
switch(expression) {
  case const1: statements1; break;
  case const2: statements2; break;
  default: statementsn;
}
```

- Effect: evaluates integer expression
- looks for case with matching value
- executes corresponding statements (or defaults)

The `switch` statement

```
Weather w;
switch(w) {
   case rain:
     printf("bring umbrella'');
   case snow:
     printf("wear jacket");
     break;
   case sun:
     printf("wear sunscreen");
     break;
   default:
     printf("strange weather");
}
```


Repetition

- C has several control structures for repetition

Statement	repeats an action…
while(c) {}	zero or more times, while condition is $\neq 0$
do {…} while(c)	one or more times, while condition is $\neq 0$
for (start; cond; upd)	zero or more times, with initialization and update

The `break` statement

- break allows early exit from one loop level

```
for (init; condition; next) {
  statements1;
  if (condition2) break;
  statements2;
}
```


The `continue` statement

- `continue` skips to next iteration, ignoring rest of loop body
- does execute `next` statement

```
for (init; condition1; next) {
   statement2;
   if (condition2) continue;
   statement2;
}
```

- often better written as `if` with block

C Objects (or lack thereof)

Objects (or lack thereof)

- C does not have objects (C++ does)
- Variables for C's primitive types are defined very similarly:

```
short int x;
char ch;
float pi = 3.1415;
float f, g;
```

- Variables defined in {} block are active only in block
- Variables defined outside a block are global (persist during program execution), but may not be globally visible (static)

C Variables

- Variable = container that can hold a value
  – in C, pretty much a CPU word or similar
- default value is (mostly) undefined – treat as random
  – compiler may warn you about uninitialized variables
- `ch = 'a'; x = x + 4;`
- Always pass by value, but can pass address to function:

```
scanf("%d%f", &x, &f);
```


C Variables

- Every data object in C has
  – a name and data type (specified in definition)
  – an address (its relative location in memory)
  – a size (number of bytes of memory it occupies)
  – visibility (which parts of program can refer to it)
  – lifetime (period during which it exists)
- Warning:

```
int *foo(char x) {
  return &x;
}
pt = foo(x);
*pt = 17;
```

C Variables

- Unlike scripting languages and Java, all C data objects have a fixed size over their lifetime
  - except dynamically created objects
- Size of object is determined when object is created:
  - global data objects at compile time (data)
  - local data objects at run-time (stack)
  - dynamic data objects by programmer (heap)

Dynamic Memory Allocation

```
int x;
int arr[20];
int main(int argc, char *argv[]) {
  int i = 20;
  {into x; x = i + 7;}
}
int f(int n)
{
  int a, *p;
  a = 1;
  p = (int *)malloc(sizeof int);
}
```

Dynamic Memory Allocation

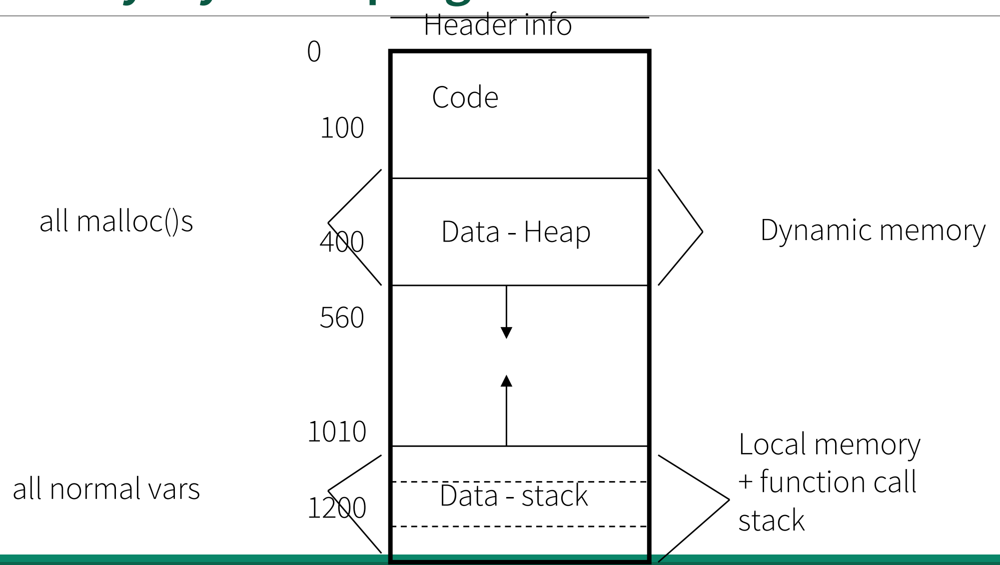
- `malloc()` allocates a block of memory
- Lifetime until memory is freed, with `free()`.
- Memory *leakage* – memory allocated is never freed:

```
char *combine(char *s, char *t) {
  u = (char *)malloc(strlen(s) + strlen(t) + 1);
  if (s != t) {
    strcpy(u, s); strcat(u, t);
    return u;
  } else {
    return 0;
  }
}
```


Dynamic Memory Allocation

- Note: `malloc()` does not initialize data
- `void *calloc(size_t n, size_t elsize)` does initialize (to zero)
- Can also change size of allocated memory blocks:
  `void *realloc(void *ptr, size_t size)`
  `ptr` points to existing block, `size` is new size
- New pointer may be different from old, but content is copied.

Memory layout of programs

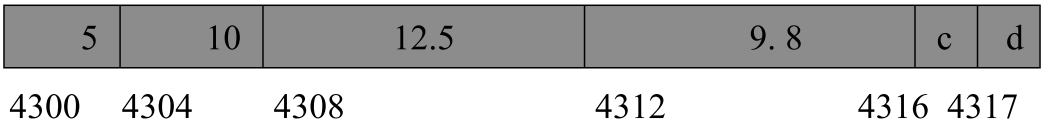


C Pointers

- The memory **address** of a data object, e.g., `int x`
  - can be obtained via `&x`
  - has a data type `int *` (in general, `type *`)
  - has a value which is a large (4/8 byte) unsigned integer
  - can have pointers to pointers: `int **`
- The **size** of a data object, e.g., `int x`
  - can be obtained via sizeof x or sizeof(x)
  - has data type `size_t`, but is often assigned to `int` (bad!)
  - has a value which is a small(ish) integer
  - is measured in bytes

C Pointers

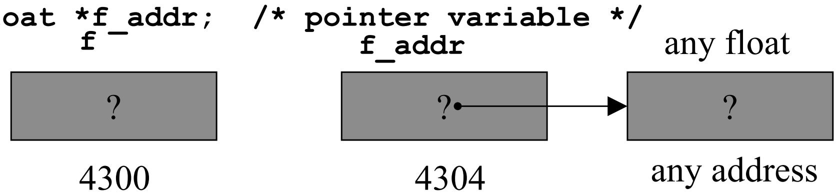
```
int x = 5, y = 10;
float f = 12.5, g = 9.8;
char c = 'c', d = 'd';
```



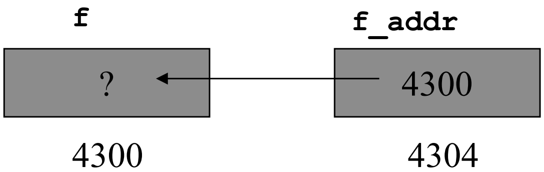
C Pointers

- *Pointer* = variable containing address of another variable

```
float f;          /* data variable */
float *f_addr;    /* pointer variable */
```

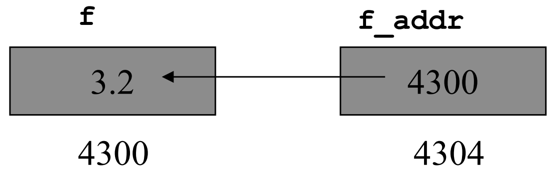



```
f_addr = &f; /* & = address operator */
```

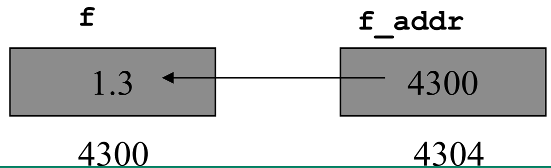


C Pointers

```
*f_addr = 3.2;    /* indirection operator */
```




```
float g=*f_addr; /* indirection:g is now 3.2 */
f = 1.3;
```

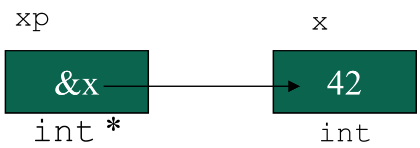


C Pointers

```
#include <stdio.h>

void main(void) {
        int j;
        int *ptr;

        ptr=&j;   /* initialize ptr before using it */
                  /* *ptr=4 does NOT initialize ptr */

        *ptr=4;   /* j <- 4 */

        j=*ptr;   /* j <- ??? */
}
```

C Pointers

- Every data type T in C/C++ has an associated pointer type T *
- A value of type * is the address of an object of type T
- If an object `int *xp` has value `&x`, the expression `*xp` dereferences the pointer and refers to `x`, thus has type `int`



C Pointers

- If p contains the address of a data object, then *p allows you to use that object
- *p is treated just like normal data object

```
int a, b, *c, *d;
*d = 17; /* BAD idea */
a = 2; b = 3; c = &a; d = &b;
if (*c == *d) puts("Same value");
*c = 3;
if (*c == *d) puts("Now same value");
c = d;
if (c == d) puts ("Now same address");
```

void pointers

- Generic pointer
- Unlike other pointers, can be assigned to any other pointer type:

```
void *v;
char *s = v;
```

- Acts like char * otherwise:

```
v++, sizeof(*v) = 1;
```


What does this C program do ?

```
#include <stdio.h>
struct list{int data; struct list *next};
struct list *start, *end;
void add(struct list *head, struct list *list, int data};
int delete(struct list *head, struct list *tail);

void main(void){
 start=end=NULL;
 add(start, end, 2);
 add(start, end, 3);
 printf("First element: %d", delete(start, end));
}

void add(struct list *head, struct list *tail, int data}{
 if(tail==NULL){
  head=tail=malloc(sizeof(struct list));
  head->data=data; head->next=NULL;
 }
 else{
  tail->next= malloc(sizeof(struct list));
  tail=tail->next; tail->data=data; tail->next=NULL;
 }
}
```

Terrified ? Come back to this at the end of the slide set and work through it.

What does this C program, do – cont'd?

```
void delete (struct list *head, struct list *tail){
 struct list *temp;
 if(head==tail){
  free(head); head=tail=NULL;
 }
 else{
  temp=head->next; free(head); head=temp;
 }
}
```


C Data Structures

Structured data objects

- Structured data objects are available as

object	property
array []	enumerated, numbered from 0
struct	names and types of fields
union	occupy same space (one of)

Arrays

- Arrays are defined by specifying an element type and number of elements
  - `int vec[100];`
  - `char str[30];`
  - `float m[10][10];`
- For array containing *N* elements, indexes are 0..*N*-1
- Stored as linear arrangement of elements
- Often similar to pointers

Arrays

- C does not remember how large arrays are (i.e., no length attribute)
- `int x[10]; x[10] = 5;` may work (for a while)
- In the block where array A is defined:
  - `sizeof A` gives the number of bytes in array
  - can compute length via `sizeof A /sizeof A[0]`
- When an array is passed as a parameter to a function
  - the size information is not available inside the function
  - array size is typically passed as an additional parameter
    - `PrintArray(A, VECSIZE);`
  - or as part of a `struct` (best, object-like)
  - or globally
    - `#define VECSIZE 10`

Arrays

- Array elements are accessed using the same syntax as in Java: array[index]
- Example (iteration over array):

```
int i, sum = 0;
...
for (i = 0; i < VECSIZE; i++)
  sum += vec[i];
```

- C does not check whether array index values are sensible (i.e., no bounds checking)
  - `vec[-1]` or `vec[10000]` will not generate a compiler warning!
  - if you're lucky, the program crashes with
    `Segmentation fault (core dumped)`

Arrays

- C references arrays by the address of their first element
- `array` is equivalent to &array[0]
- can iterate through arrays using pointers as well as indexes:

```
int *v, *last;
int sum = 0;
last = &vec[VECSIZE-1];
for (v = vec; v <= last; v++)
  sum += *v;
```


2-D arrays

- 2-dimensional array

`int weekends[52][2];`

- **`weekends[2][1]`** is same as **`*(weekends+2*2+1)`**
  - NOT **`*weekends+2*2+1`** :this is an int !

Arrays - example

```
#include <stdio.h>
void main(void) {
    int number[12]; /* 12 cells, one cell per student */
    int index, sum = 0;
                       /* Always initialize array before use */
    for (index = 0; index < 12; index++) {
           number[index] = index;
    }
    /* now, number[index]=index; will cause error:why ?*/

    for (index = 0; index < 12; index = index + 1) {
           sum += number[index];  /* sum array elements */
    }
    return;
}
```


Aside: void, void *

- Function that doesn't return anything declared as void
- No argument declared as void
- Special pointer *void can point to anything

```
#include <stdio.h>
extern void *f(void);
void *f(void) {
  printf("the big void\n");
  return NULL;
}
int main(void) {
  f();
}
```

Overriding functions – function pointers

- overriding: changing the implementation, leave prototype
- in C, can use function pointers

returnType (*ptrName)(arg1, arg2, ...);

- for example, int (*fp)(double x); is a pointer to a function that return an integer
- double * (*gp)(int) is a pointer to a function that returns a pointer to a double

structs

- Similar to fields in Java object/class definitions
- components can be any type (but not recursive)
- accessed using the same syntax struct.field
- Example:

```
struct {int x; char y; float z;} rec;
...
r.x = 3; r.y = 'a'; r.z= 3.1415;
```

structs

- Record types can be defined
  - using a tag associated with the struct definition
  - wrapping the struct definition inside a typedef
- Examples:

```
struct complex {double real; double imag;};
struct point {double x; double y;} corner;
typedef struct {double real; double imag;} Complex;
struct complex a, b;
Complex c,d;
```

- `a` and `b` have the same size, structure and type
- `a` and `c` have the same size and structure, but different types

structs

- Overall size is sum of elements, plus padding for alignment:

```
struct {
   char x;
   int y;
   char z;
} s1;   sizeof(s1) = ?
struct {
   char x, z;
   int y;
} s2;   sizeof(s2) = ?
```

structs - example

```
struct person {
  char name[41];
    int age;
    float height;
    struct {          /* embedded structure */
      int month;
      int day;
      int year;
    } birth;
};
struct person me;
me.birth.year=1977;
struct person class[60];
          /* array of info about everyone in class */
class[0].name="Gun"; class[0].birth.year=1971;……
```


structs

- Often used to model real memory layout, e.g.,

```
typedef struct {
  unsigned int version:2;
  unsigned int p:1;
  unsigned int cc:4;
  unsigned int m:1;
  unsigned int pt:7;
  u_int16 seq;
  u_int32 ts;
} rtp_hdr_t;
```

Dereferencing pointers to struct elements

- Pointers commonly to `struct`'s

```
(*sp).element = 42;
y = (*sp).element;
```

- Note: `*sp.element` doesn't work
- Abbreviated alternative:

```
sp->element = 42;
y = sp->element;
```


More pointers

```
int month[12]; /* month is a pointer to base address 430*/

month[3] = 7;  /* month address + 3 * int elements => int at address (430+3*4) is now 7 */

ptr = month + 2; /* ptr points to month[2], => ptr is now (430+2 * int elements)= 438 */
ptr[5] = 12;     /* ptr address + 5 int elements
              => int at address (434+5*4) is now 12.
                                Thus, month[7] is now 12 */

ptr++;         /* ptr <- 438 + 1 * size of int = 442 */
(ptr + 4)[2] = 12;   /* accessing ptr[6] i.e., array[9] */
```

- Now , **`month[6]`** , **`*(month+6)`** , **`(month+4)[2]`** , **`ptr[3]`** , **`*(ptr+3)`** are all the same integer variable.

C Functions

Functions

- Prototypes and functions (cf. Java interfaces)

```
– extern int putchar(int c);
– putchar('A');
– int putchar(int c) {
      do something interesting here
  }
```

- If defined before use in same file, no need for prototype
- Typically, prototype defined in .h file
- Good idea to include <.h> in actual definition

Functions

- static functions and variables hide them to those outside the same file:

```
static int x;
static int times2(int c) {
  return c*2;
}
```

- compare protected class members in Java.

Functions – const arguments

- Indicates that argument won't be changed.
- Only meaningful for pointer arguments and declarations:

```
int c(const char *s, const int x) {
  const int VALUE = 10;
  printf("x = %d\n", VALUE);
  return *s;
}
```

- Attempts to change `*s` will yield compiler warning.

Functions - extern

```
#include <stdio.h>

extern char user2line [20];    /* global variable defined
                    in another file */
char user1line[30];            /* global for this file */
void dummy(void);

void main(void) {
 char user1line[20];       /* different from earlier
                             user1line[30] */
 . . .                          /* restricted to this func */
}

void dummy(){
 extern char user1line[];  /* the global user1line[30] */
 . . .
}
```


Overloading functions – var. arg. list

- Java:
  `void product(double x, double y);`
  `void product(vector x, vector y);`
- C doesn't support this, but allows variable number of arguments:
  `debug("%d %f", x, f);`
  `debug("%c", c);`
- declared as `void debug(char *fmt, ...);`
- at least one known argument

Overloading functions

- must include <stdarg.h>:

```
#include <stdarg.h>
double product(int number, ...) {
  va_list list;
  double p;
  int i;
  va_start(list, number);
  for (i = 0, p = 1.0; i < number; i++) {
    p *= va_arg(list, double);
  }
  va_end(list);
}
```

- Danger
  - `product(2,3,4)` won't work, needs `product(2,3.0,4.0);`

Overloading functions

- Limitations:
  - cannot access arguments in middle
    - needs to copy to variables or local array
  - client and function need to know and adhere to type

Program with multiple files

```
#include <stdio.h>
#include "mypgm.h"

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

hw.c

```
#include <stdio.h>
#include "mypgm.h"

void myproc(void)
{
 mydata=2;
 . . . /* some code */
}
```

mypgm.c

Library headers
- Standard
- User-defined

```
void myproc(void);
int mydata;
```

mypgm.h

Data hiding in C

- C doesn't have classes or private members, but this can be approximated
- Implementation defines real data structure:

```
#define QUEUE_C
#include "queue.h"
typedef struct queue_t {
  struct queue_t *next;
  int data;
} *queue_t, queuestruct_t;
queue_t NewQueue(void) {
  return q;
}
```

- Header file defines public data:

```
#ifndef QUEUE_C
typedef struct queue_t *queue_t;
#endif
queue_t NewQueue(void);
```

Pointer to function

```
int func(); /*function returning integer*/
int *func(); /*function returning pointer to integer*/
int (*func)(); /*pointer to function returning integer*/
int *(*func)(); /*pointer to func returning ptr to int*/
```


Function pointers

```
int (*fp)(void);
double* (*gp)(int);
int f(void)
double *g(int);

fp=f;
gp=g;

int i = fp();
double *g = (*gp)(17);  /* alternative */
```

Pointer to function - example

```
#include <stdio.h>

void myproc (int d);
void mycaller(void (* f)(int), int param);

void main(void) {
          myproc(10);                   /* call myproc with parameter
10*/
          mycaller(myproc, 10); /* and do the same again ! */
}

void mycaller(void (* f)(int), int param){
          (*f)(param);          /* call function *f with param */
}

void myproc (int d){
          . . .               /* do something with d */
}
```


C Libraries

Libraries

- C provides a set of standard libraries for

numerical math functions	<math.h>	-lm
character strings	<string.h>	
character types	<ctype.h>	
I/O	<stdio.h>	

The math library

- `#include <math.h>`
  - careful: `sqrt(5)` without header file may give wrong result!
- `gcc -o` compute `main.o f.o -lm`
- Uses normal mathematical notation:

Math.sqrt(2)	sqrt(2)
Math.pow(x,5)	pow(x,5)
4*math.pow(x,3)	4*pow(x,3)

Characters

- The char type is an 8-bit byte containing ASCII code values (e.g., ‘A’ = 65, ‘B’ = 66, …)
- Often, char is treated like (and converted to) int
- `<ctype.h>` contains character classification functions:

isalnum(ch)	alphanumeric	[a-zA-Z0-9]
isalpha (ch)	alphabetic	[a-zA-Z]
isdigit(ch)	digit	[0-9]
ispunct(ch)	punctuation	[~!@#%^&…]
isspace(ch)	white space	[\t\n]
isupper(ch)	upper-case	[A-Z]
islower(ch)	lower-case	[a-z]

Strings

- In Java, strings are regular objects
- In C, strings are just **`char`** arrays with a **`NUL ('\0')`** terminator
- “a cat” =

a		c	a	t	\0

- A literal string (“a cat”)
  - is automatically allocated memory space to contain it and the terminating \0
  - has a value which is the address of the first character
  - can’t be changed by the program (common bug!)
- All other strings must have space allocated to them by the program

Strings

```
char *makeBig(char *s) {
  s[0] = toupper(s[0]);
  return s;
}
makeBig(“a cat”);
```


Strings

- We normally refer to a string via a pointer to its first character:

```
char *str = “my string”;
char *s;
s = &str[0]; s = str;
```

- C functions only know string ending by \0:

```
char *str = “my string”;
...
int i;
for (i = 0; str[i] != ‘\0’; i++) putchar(str[i]);
char *s;
for (s = str; *s; s++) putchar(*s);
```

Strings

- Can treat like arrays:

```
char c;
char line[100];
for (i = 0; i < 100 && line[c]; i++) {
  if (isalpha(line[c]) ...
}
```


Copying strings

- Copying content vs. copying pointer to content
- `s = t` copies pointer – `s` and `t` now refer to the same memory location
- strcpy(s, t); copies content of t to s

```
char mybuffer[100];
...
mybuffer = "a cat";
```

- is incorrect (but appears to work!)
- Use `strcpy(mybuffer, "a cat")` instead

Example string manipulation

```
#include <stdio.h>
#include <string.h>
int main(void) {
  char line[100];
  char *family, *given, *gap;
  printf("Enter your name:"); fgets(line,100,stdin);
  given = line;
  for (gap = line; *gap; gap++)
    if (isspace(*gap)) break;
  *gap = '\0';
  family = gap+1;
  printf("Your name: %s, %s\n", family, given);
  return 0;
}
```


string.h library

- Assumptions:
  - `#include <string.h>`
  - strings are `NUL`-terminated
  - all target arrays are large enough
- Operations:
  - `char *strcpy(char *dest, char *source)`
    - copies chars from source array into dest array up to NUL
  - `char *strncpy(char *dest, char *source, int num)`
    - copies chars; stops after num chars if no NUL before that; appends NUL

string.h library

- `int strlen(const char *source)`
  - returns number of chars, excluding NUL
- `char *strchr(const char *source, const char ch)`
  - returns pointer to first occurrence of ch in source; NUL if none
- `char *strstr(const char *source, const char *search)`
  - return pointer to first occurrence of search in source

Formatted strings

- String parsing and formatting (binary from/to text)
- `int sscanf(char *string, char *format, ...)`
  - parse the contents of string according to format
  - placed the parsed items into 3rd, 4th, 5th, ... argument
  - return the number of successful conversions
- `int sprintf(char *buffer, char *format, ...)`
  - produce a string formatted according to format
  - place this string into the buffer
  - the 3rd, 4th, 5th, ... arguments are formatted
  - return number of successful conversions

Formatted strings

- The format strings for `sscanf` and `sprintf` contain
  – plain text (matched on input or inserted into the output)
  – formatting codes (which must match the arguments)
- The `sprintf` format string gives template for result string
- The `sscanf` format string describes what input should look like

Formatted strings

- Formatting codes for `sscanf`

Code	meaning	variable
%c	matches a single character	char
%d	matches an integer in decimal	int
%f	matches a real number (ddd.dd)	float
%s	matches a string up to white space	char *
%[^c]	matches string up to next c char	char *

Formatted strings

- Formatting codes for sprintf
- Values normally right-justified; use negative field width to get left-justified

Code	meaning	variable
%nc	char in field of n spaces	char
%nd	integer in field of n spaces	int, long
%n.mf	real number in width n, m decimals	float, dou ble
%n.mg	real number in width n, m digits of precision	float, double
%n.ms	first m chars from string in width n	char *

Formatted strings - examples

```
char *msg = “Hello there”;
char *nums = “1 3 5 7 9”;
char s[10], t[10];
int a, b, c, n;

n = sscanf(msg, “%s %s”, s, t);
n = printf(“%10s %-10s”, t, s);
n = sscanf(nums, “%d %d %d”, &a, &b, &c);

printf(“%d flower%s”, n, n > 1 ? “s” : “ “);
printf(“a = %d, answer = %d\n”, a, b+c);
```

The stdio library

- Access stdio functions by
  - using `#include <stdio.h>` for prototypes
  - compiler links it automatically
- defines `FILE *` type and functions of that type
- data objects of type `FILE *`
  - can be connected to file system files for reading and writing
  - represent a buffered stream of chars (bytes) to be written or read
- always defines `stdin`, `stdout`, `stderr`

The stdio library: fopen(), fclose()

- Opening and closing FILE * streams:

```
FILE *fopen(const char *path, const char *mode)
```
  - open the file called path in the appropriate mode
  - modes: “r” (read), “w” (write), “a” (append), “r+” (read & write)
  - returns a new FILE * if successful, NULL otherwise

```
int fclose(FILE *stream)
```
  - close the stream FILE *
  - return 0 if successful, EOF if not

stdio – character I/O

`int getchar()`
– read the next character from `stdin`; returns **EOF** if none

`int fgetc(FILE *in)`
– read the next character from FILE *in*; returns **EOF** if none

`int putchar(int c)`
– write the character *c* onto stdout; returns *c* or **EOF**

`int fputc(int c, FILE *out)`
– write the character **c** onto out; returns **c** or **EOF**

stdio – line I/O

`char *fgets(char *buf, int size, FILE *in)`
– read the next line from `in` into buffer `buf`
– halts at `'\n'` or after size-1 characters have been read
– the '\n' is read, but not included in buf
– returns pointer to strbuf if ok, NULL otherwise
– do **not** use `gets(char *)` – buffer overflow

`int fputs(const char *str, FILE *out)`
– writes the string `str` to `out`, stopping at `'\0'`
– returns number of characters written or EOF

stdio – formatted I/O

`int fscanf(FILE *in, const char *format, ...)`
- read text from stream according to format

`int fprintf(FILE *out, const char *format, ...)`
- write the string to output file, according to format

`int printf(const char *format, ...)`
- equivalent to fprintf(stdout, format, ...)

- Warning:
  - do not use `fscanf(...);` use `fgets(str, ...); sscanf(str, ...);`

Before you go….

- Always initialize anything before using it (especially pointers)
- Don’t use pointers after freeing them
- Don’t return a function’s local variables by reference
- No exceptions – so check for errors everywhere
  - memory allocation
  - system calls
  - Murphy’s law, C version: anything that can’t fail, will fail
- An array is also a pointer, but its value is immutable.