CPS104
Computer Organization and Programming
Lecture 2 : C and C++

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Slides available on:
http://www.cs.duke.edu/~raw/cps104/Lectures

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Overview of Today's Lecture:

- C philosophy
  - Debugging
  - Good Programs
- C arrays and strings
- C procedures
- C Input Output

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C++ vs C: Philosophy

- C++ emphasizes reuse of code, ENCAPSULATION of data types
- The OO philosopy:
  - Define (real-world) objects, each with variables that indicate their "state", and each changeable ONLY by their own member functions
  - Insulate the programmer from machine level
    - Impossible to apply an inappropriate operation
    - Hard to reference memory that isn't holding an object
  - Overloading of operators simplifies program appearance --- more easily read

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C Philosophy

- C REVEALS machine level details
  - DESIRABLE for this course!!!
- Excellent language for explaining how computer really works
- Procedure-oriented, not object oriented
  - Any procedure may be applied to any item
  - BE CAREFUL
- Has fewer concepts than C++:
  - No inheritance hierarchy
- Uses global arrays, and explicitly allocated arrays, NOT “new”
- Each “executed” mention of a C name corresponds to ONE machine language instruction (unit time)

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C Philosophy (cont’d)

- C allows programmers to write very machine-efficient code
- Does not require use of “access functions” to reference a global array or collection of objects
  - Offers no “protection” against incorrect operations on them, either
- Does NO “array bounds checking”
  - Programmer is responsible for using legal subscript values

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Form of a C Program

- List of GLOBAL variable and procedure DECLARATIONS
- The “main” procedure must exist, and is executed on start
- Procedures may contain LOCAL declarations of variables
  - Declarations are written before any code
- Arrays are declared by following a variable name with [*constant expression*]:
  - int xyz[49];
    - Declares xyz to be an array of 49 integers, xyz[0]…xyz[48]
    - Reserves space in memory to hold all 49 of them
    - Reference an array element by xyz[*expression*].
- GLOBAL arrays elements initially hold 0. LOCAL hold garbage.

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Designing C Programs

- First concern is the METHOD to be used for the solution
  - Do I need to record input data for later processing? Or process input as it is read?
  - What computation is needed?
  - If a record is made, what form should it take?
    - Parallel arrays: int A[100], B[100]; A[i] and B[i] (same i) describe the i-th "object"
    - Objects can be "connected" logically: C[i] can hold the index of an object related in some way to (A[i], B[i])
  - Speed is increased if direct indexing can be used, rather than searching
- Later, decide how to read input, and write output

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Debugging

- C (and Assembly Language) programs are seldom correct as first written
- You must develop DETECTIVE skills, to find places where what you THOUGHT you told computer to do differs from what IT does
  - printf statements on procedure entry and exit
  - use of "gdb" (breakpoints; examine variables)
- Fixing the problems is usually easy
- Finding a problem is hard, because computer may run a long time, after the REAL error

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Testing

- Your program must work for ANY "valid" input
- You CANNOT assume that the test cases given adequately test your program
- You must design your own:
  - "Stress test" it -- by designing test cases that exercise the parts of the program that YOU find most confusing and difficult
  - Add test cases that check the "special cases"
- Design your program to avoid duplication of code to handle special cases -- if designed well, so each part of the program performs some "general" operation, one or two tests suffice to test each such part

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Positive Attributes of Programs

- Correct: Meets the specifications.
- Understandable to the reader
  - Clear, precise documentation of each subroutine
    - Mention each argument and result
    - Use "mathematical English"
  - Avoid error-prone C constructs
- Highest possible execution speed
  - Each programmer name or constant costs one unit of time each time it is "executed" (approximately)
- Fewest possible C tokens in the source text
  - Tokens are: Names, Numbers, Strings, Operators
  - Use parentheses and comments freely

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C Language Material

- The following on-line source seems to be a good reference :
  C Language Course
  www.strath.ac.uk/CC/Courses/NewCcourse/ccourse.html
- Another source on the Web is:
  www.cm.cf.ac.uk/Dave/C/CE.html
- The material on integer arithmetic, characters, and pointers will be important, along with simple I/O: getchar() putchar(), printf() and scanf(). You should learn how to use ***for*** and ***while*** loops, ***if*** statements and subroutines, as well.

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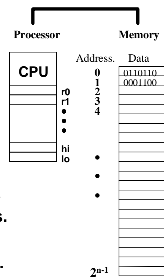
Computer Memory



- Memory is a large linear array of 8 bit bytes.
  - Each byte has a unique address (location)
- Bytes are grouped into longer sequences, some of which can be addressed as one unit. Their addresses must be multiples of their byte lengths.
  - Byte (1 byte) -- characters (char)
  - Word (4 bytes) -- integers (int), floats.
  - Double (8 bytes)

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Pointers

- A "pointer" is an integer intended to be used as an address for some object in memory
- In C, the type of the object pointed to must be declared, along with the pointer:
  - int *P; Declares P to hold a pointer to an integer
  - char *C; Declares C to point to a character
- A pointer to any variable or array element can be built by the "address of" operator "&": &X[i] is an integer, giving the address of X[i].
- An array reference A[I] is equivalent to *(&A+I), where "*" "de-references" its argument -- obtains the contents of the memory location the argument points to
- Addition of pointers and integers "scales" the integer to the size (in bytes) of the pointers reference type, so P+1 computes an address 4 bytes more than that held in P because each int occupies 4 bytes of memory.

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C Arrays

- The array is a primitive (built-in) structure in C
  - int A[100]; Sets aside a sequence of 400 bytes of memory whose first byte is at &A.
  - Indices start at 0: A[0] is first integer, A[99] the last.
  - Later A[I] generates a reference to location &A + I*4

Address	Contents
&A: 4044	A[0]
&A+99*4: 4440	A[99]
	NOT IN A

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C Strings

- C strings are represented as arrays of characters:
  - char c[10]; Declares space for a 9-character string
  - Why 9? Because a C string is terminated with a special "sentinel" character \0. The C string constant "A STRING" is a pointer to the first of a sequence of bytes, whose contents are 'A', ' ', 'S', 'T', 'R', 'I', 'N', 'G', and '\0'.
- There are NO C "operators" on strings. All string operations are handled by programs

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C Memory Allocation

- C has no "new" operator
- When a new object is needed, space for its state variables must be reserved, or "allocated"
- This could be done from a programmer-declared array, OR by use of the library function "malloc"
- I recommend declaring "large enough" arrays (whose size must be fixed before compilation).
  - Choose size based on statistics about input data
    - Ask problem poser
- The library function "(void *) malloc(int n)" can be used to reserve n bytes of memory, and return a pointer to the first byte of that area of memory.

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C Procedures and Naming

- All C procedures are accessible (callable) anywhere in the file after their declaration (header or signature) has appeared
- Declarations appearing outside procedures are ALSO accessible anywhere later in the file -- including global variables
- The procedure "main" must be defined
  int main(int argc, char ** argv);
- Names declared inside procedures (including parameters) are local to those procedures
- Procedures may not be declared inside procedures

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C Input / Output (a small subset)

- #include <stdio.h> // Include signatures and constant defs
- char getchar(void); // Return next character from stdin
  - stdin is UNIX default input stream; opened automatically when program is started
- int printf(char *, ...);
  - formatted output, to stdout
    - default output stream
- int scanf(char *, ...);
  - formatted input, from stdin
- Definitions of what these and other functions do can be found by running "man -s<section> <name of subroutine>" where <section> is 3s or 3c.

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Connection to UNIX

- UNIX command line:
  - *prog arglist* [<*in*] [>*out*]
    - Runs *prog* connecting its "stdin" to *in*, "stdout" to *out*
    - *in* and *out* are files on disk (so is *prog*)
    - If either <*in* or >*out* is absent, that file is the console
  - UNIX loads *prog* into memory, calls its main(argc, argv)
    - argc is set to the number of arguments in arglist
    - argv[i] is set to the i-th argument (a string)
    - argv[0] is set to the name of the program
  - xyz 35 abc <in.1
    - calls xyz.main(2, {"xyz", "35", "abc"})
    - stdin is file "in.1", stdout is the screen

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C Input / Output: printf

- Returns EOF if error occurs, otherwise != EOF
- Variable number of arguments, no types specified
- First argument is a format string, telling how each subsequent argument is to be converted (this string specifies the type of each argument, and how many columns it occupies on the output page)
- printf sends a stream of characters to stdout
- The formatting string includes:
  - text to be output as is
  - Characters to control the printer, like \n (new line) and \t (tab)
  - Conversion specifiers

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C Input / Output: printf Conversion Specifiers

- Each specifier begins with % and ends with a field type character. Between may be some characters which give minimum field width, and precision to use
- Examples:
  - %s :- Print a string. Field width is string's length
  - %7s :- Print 7 chars of a string, pad with space
  - %d :- Print an integer
  - %12d :- Print an integer in a field of at least 12 chars, pad with space
  - %012d :- Print an integer in a field of at least 12 chars, pad with 0
  - %10.2f :- Print a float, in a field of 10 chars, show 2 digits right of the decimal point

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Example 1

```
#include <stdio.h>
main() {
    int a = 23;
    char * s = “Have a happy one!”;
    float f = 12.678;

    printf(“print: Ival=%d, Fval=%f, String=%s\n”,
           a, f, s);
    }
Result:
print: Ival=23, Fval=12.678, String=Have a happy one!
```


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Example 2

```
#include <stdio.h>
main() {
    int a = 23;
    char * s = “Have a happy one!”;
    float f = 12.678;

    printf(“print: Ival=%5d, Fval=%7.2f, String=%10s\n”,
           a, f, s);
    }
Result:
print: Ival=   23, Fval=  12.68, String=Have a hap
```


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Programming with Ingenuity

Problem: Report the number of words which begin with each possible letter.

Word == Seq of one or more letters, surrounded by non-letters

Method: At start of word, increment the count for its first letter

- Linear search for the letter?
- Hash table search for the first letter?
- Better method?
- How detect that it IS a letter? How detect start of word?

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Ingenuity (cont'd)

- Linear search? 52 letters, so ~ 26 loop iterations @ 10 ops per iteration = 260 ops per letter read
- Hash table lookup? About 2 "probes" per letter @ 10 ops per probe = 20 ops per letter
- Better method: Use ASCII code as index into table!!
  - Ct[c]++; // 2 ops per letter
  - if (let[c]) … // Pre-initialize let[i]==0 if i does NOT // code a letter, 1 if i DOES code one
- Design "heart" of program -- part that will be executed most -- FIRST, fit rest of program around it, so heart does not have to change, to get the details correct

Ingenuity (3)

```
// Assume file holds N characters, Q of them non-letters
#include <stdio.h>
Int c, PrevIsLet=0, let[256], Ct[256];
Hrt1() {
        while ((c=getchar())!= EOF) {        // 3 ops, 13 toks
                if ( ! PrevIsLet )           // 1 op, 5 tokens
                        Ct[c]++;             //  2 ops, 6 toks
                PrevIsLet = let[c];          // 3 ops, 7 toks
                }                            // 0 ops, 1 tok
        }       // loop above:  7N+2Q ops, 33 tokens
```

Note: Ct[c]++ increments non-letter elements, which output routine ignores; Output routine combines UC and LC counts.

Ingenuity (4)

Is faster possible? Principle: "skip over" letters inside words.

```
Hrt2() {
        while ((c=getchar())!=EOF) {    // 3 ops, 13 toks
                if ( let[c] ) {         // 2 ops,   8 toks
                        Ct[c]++;        // 2 ops,   6 toks
                        while (((c=getchar()!=EOF) && let[c] ) ;
                                        // 5 ops, 19 toks
                        }
                }
        }       // 5N+2W ops, where W words in file;  46 toks
```

Ingenuity (5): Comparison

Guess that text file contains 5 letters per word, and each word is followed by an average of 1.5 non-letters. W=N/5, Q=1.5*N/5

Guess the rest of program contains 100 tokens.

	Toks	Speed	Eleg	Speed
Hrt1	133	7N + 2*0.3*N = 7.6N	10	7.1
Hrt2	146	5N + 2*N/5 = 5.4N	10*133/146 = 9.1	10

Conclude: Hrt2 should earn more total points than Hrt1.

(assumes Hrt1 is most elegant, Hrt2 is fastest program)

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Programming Example

```
#include <stdio.h>
int White[256];       // Sets White[0..255]=0;  0 acts as “false in tests.
main(){               // Parameters not needed
    char c, s[256], *p;       // s will hold the string
    White[‘ ‘]=White[‘\t’]=White[‘\n’]=1;   // non-zero acts as “true” in tests
    p = s;            // Set pointer p to the address of s[0]
    while ( (c=getchar() ) != EOF ) {   // skip white space
          if ( ! White[c] ) break;
          }
    *p++ = c;         // Increment p, after storing c “through” p’s old value
     while ( (c=getchar() ) != EOF ) { /* Copy non-white space into s */
          if (White[c] ) break;
          *p++ = c;
          }
    *p = ‘\0’;        // Null terminate the string
    printf(“%s\n”,s);         // Print first word of input.
    }
```

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Programming Example Using scanf

```
#include <stdio.h>
main(){          // Parameters not needed
    char s[256]; // s will hold the string
    int J, K;
    scanf(“%d %d %s”, &J, &K, s);
          /* scanf’s arguments are POINTERS.  Even  “s” is
          changed by the compiler into a pointer, because this
          array name has no subscript here.  */
    // This reads two white-space separated integers, and one
    // string, consisting of non-white-space  characters.
    }
```

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Summary

- C programs are procedure oriented, not OO
- They reflect actual features of machine hardware
  - A>>2, A&1 // Each performs one machine instruction
- Allow programmer control over sequence of instructions generated, primarily for efficiency at run-time
  - while (t[k] = s[k]) k++; // TRICKY. Copies until S[k]==0
- Naming conventions are primitive
- No run-time array bounds or pointer checking
- Very useful for describing what machine hardware is supposed to do

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