

6.087 Lecture 1 – January 11, 2010

- Introduction to C
- Writing C Programs
- Our First C Program

What is C?

- Dennis Ritchie – AT&T Bell Laboratories – 1972
 - 16-bit DEC PDP-11 computer (right)
- Widely used today
 - extends to newer system architectures
 - efficiency/performance
 - low-level access

Features of C

C features:

- Few keywords
- Structures, unions – compound data types
- Pointers – memory, arrays
- External standard library – I/O, other facilities
- Compiles to native code
- Macro preprocessor

Versions of C

Evolved over the years:

- 1972 – C invented
- 1978 – *The C Programming Language* published; first specification of language
- 1989 – C89 standard (known as ANSI C or Standard C)
- 1990 – ANSI C adopted by ISO, known as C90
- 1999 – C99 standard
 - mostly backward-compatible
 - not completely implemented in many compilers
- 2007 – work on new C standard C1X announced

In this course: ANSI/ISO C (C89/C90)

What is C used for?

Systems programming:

- OSes, like Linux
- microcontrollers: automobiles and airplanes
- embedded processors: phones, portable electronics, etc.
- DSP processors: digital audio and TV systems
- ...

C vs. related languages

- More recent derivatives: C++, Objective C, C#
- Influenced: Java, Perl, Python (quite different)
- C lacks:
 - exceptions
 - range-checking
 - garbage collection
 - object-oriented programming
 - polymorphism
 - ...
- Low-level language \Rightarrow faster code (usually)

Warning: low-level language!

Inherently unsafe:

- No range checking
- Limited type safety at compile time
- No type checking at runtime

Handle with care.

- Always run in a debugger like `gdb` (more later. . .)
- Never run as `root`
- Never test code on the Athena¹ servers

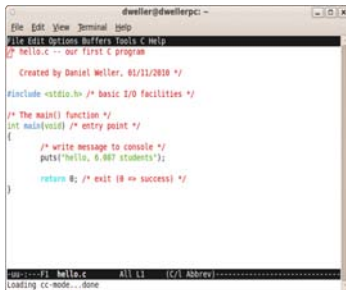
¹ Athena is MIT's UNIX-based computing environment. OCW does not provide access to it.

6.087 Lecture 1 – January 11, 2010

- Introduction to C
- Writing C Programs
- Our First C Program

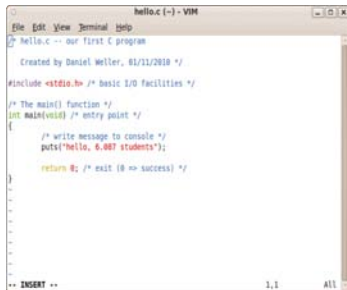
Editing C code

- .c extension
- Editable directly



```
dweiler@dweilerpc: -
File Edit View Terminal Help
hello.c -- our first C program
Created By Daniel Weller, 01/11/2010 */
#include <stdio.h> /* basic I/O facilities */
/* The main() function */
int main(void) /* entry point */
{
    /* write message to console */
    puts("hello, 6.087 students");
    return 0; /* exit (0 => success) */
}
```

su:~:--FI hello.c All 1,1 (C/I Abbrev)-----
Loading cc-mode...done




```
hello.c (-) - VIM
File Edit View Terminal Help
hello.c -- our first C program
Created By Daniel Weller, 01/11/2010 */
#include <stdio.h> /* basic I/O facilities */
/* The main() function */
int main(void) /* entry point */
{
    /* write message to console */
    puts("hello, 6.087 students");
    return 0; /* exit (0 => success) */
}
-- INSERT --
1,1 All
```

- More later...

Compiling a program

- `gcc` (included with most Linux distributions): compiler
- `.o` extension
 - omitted for common programs like `gcc`



```
dweller@dwellerpc: ~  
File Edit View Terminal Help  
dweller@dwellerpc:~$ gcc -Wall hello.c -o hello.o  
dweller@dwellerpc:~$
```

More about gcc

- Run gcc:

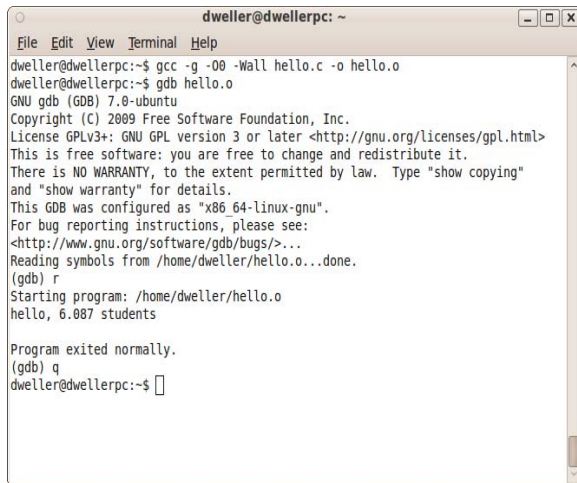
```
athena%1 gcc -Wall infile.c -o  
outfile.o
```

- `-Wall` enables most compiler warnings
- More complicated forms exist
 - multiple source files
 - auxiliary directories
 - optimization, linking
- Embed debugging info and disable optimization:

```
athena% gcc -g -O0 -Wall infile.c -o  
outfile.o
```

¹ Athena is MIT's UNIX-based computing environment. OCW does not provide access to it.

Debugging



```
dweller@dwellerpc: ~  
File Edit View Terminal Help  
dweller@dwellerpc:~$ gcc -g -O0 -Wall hello.c -o hello.o  
dweller@dwellerpc:~$ gdb hello.o  
GNU gdb (GDB) 7.0-ubuntu  
Copyright (C) 2009 Free Software Foundation, Inc.  
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>  
This is free software: you are free to change and redistribute it.  
There is NO WARRANTY, to the extent permitted by law. Type "show copying"  
and "show warranty" for details.  
This GDB was configured as "x86_64-linux-gnu".  
For bug reporting instructions, please see:  
<http://www.gnu.org/software/gdb/bugs/>...  
Reading symbols from /home/dweller/hello.o...done.  
(gdb) r  
Starting program: /home/dweller/hello.o  
hello, 6.087 students  
  
Program exited normally.  
(gdb) q  
dweller@dwellerpc:~$
```

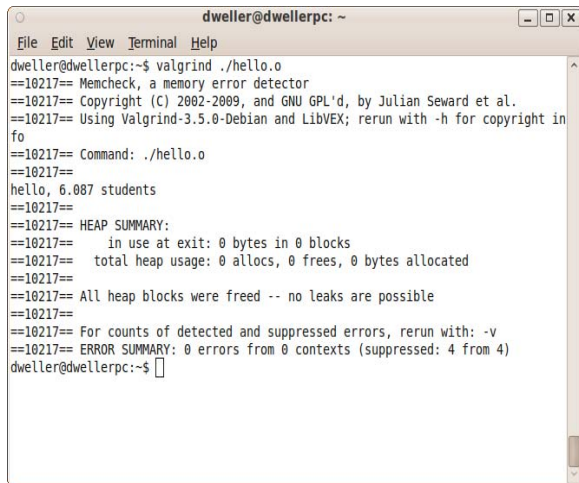
Figure: `gdb`: command-line debugger

Using gdb

Some useful commands:

- `break linenumber` – create breakpoint at specified line
- `break file:linenumber` – create breakpoint at line in file
- `run` – run program
- `c` – continue execution
- `next` – execute next line
- `step` – execute next line or step into function
- `quit` – quit gdb
- `print expression` – print current value of the specified expression
- `help command` – in-program help

Memory debugging

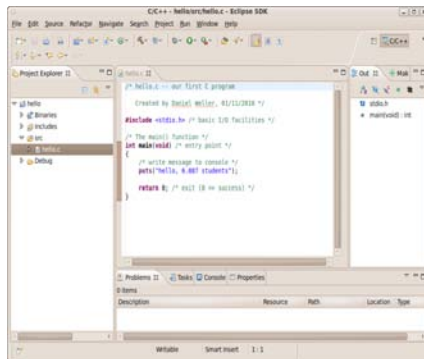


```
dweller@dwellerpc: ~  
File Edit View Terminal Help  
dweller@dwellerpc:~$ valgrind ./hello.o  
==10217== Memcheck, a memory error detector  
==10217== Copyright (C) 2002-2009, and GNU GPL'd, by Julian Seward et al.  
==10217== Using Valgrind-3.5.0-Debian and LibVEX; rerun with -h for copyright in  
fo  
==10217== Command: ./hello.o  
==10217==  
hello, 6.087 students  
==10217==  
==10217== HEAP SUMMARY:  
==10217==    in use at exit: 0 bytes in 0 blocks  
==10217==   total heap usage: 0 allocs, 0 frees, 0 bytes allocated  
==10217==  
==10217== All heap blocks were freed -- no leaks are possible  
==10217==  
==10217== For counts of detected and suppressed errors, rerun with: -v  
==10217== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 4 from 4)  
dweller@dwellerpc:~$
```

Figure: `valgrind`: diagnose memory-related problems

The IDE – all-in-one solution

- Popular IDEs: Eclipse (CDT), Microsoft Visual C++ (Express Edition), KDevelop, Xcode, . . .
- Integrated editor with compiler, debugger
- Very convenient for larger programs



Courtesy of The Eclipse Foundation. Used with permission.

Using Eclipse

- Need Eclipse CDT for C programs (see <http://www.eclipse.org/cdt/>)
- Use New > C Project
 - choose “Hello World ANSI C Project” for simple project
 - “Linux GCC toolchain” sets up `gcc` and `gdb` (must be installed separately)
- Recommended for final project

6.087 Lecture 1 – January 11, 2010

- Introduction to C
- Writing C Programs
- Our First C Program

Hello, 6.087 students

- In style of “Hello, world!”
- `.c` file structure
- Syntax: comments, macros, basic declarations
- The `main()` function and function structure
- Expressions, order-of-operations
- Basic console I/O (`puts()`, etc.)

Structure of a .c file

/ Begin with comments about file contents */*

Insert #include statements and preprocessor definitions

Function prototypes and variable declarations

Define main() function

```
{  
    Function body  
}
```

Define other function

```
{  
    Function body  
}  
:
```

Comments

- Comments: `/* this is a simple comment */`
- Can span multiple lines

```
/* This comment  
   spans  
   multiple lines */
```

- Completely ignored by compiler
- Can appear almost anywhere

```
/* hello.c — our first C program
```

```
   Created by Daniel Weller, 01/11/2010 */
```

The `#include` macro

- Header files: constants, functions, other declarations
- `#include` `<stdio.h>` – read the contents of the *header file* `stdio.h`
- `stdio.h`: standard I/O functions for console, files

```
/* hello.c — our first C program
```

```
    Created by Daniel Weller, 01/11/2010 */
```

```
#include <stdio.h> /* basic I/O facilities */
```

More about header files

- `stdio.h` – part of the C Standard Library
 - other important header files: `ctype.h`, `math.h`, `stdlib.h`, `string.h`, `time.h`
 - For the ugly details: visit http://www.unix.org/single_unix_specification/ (registration required)
- Included files must be on *include path*
 - `-Idirectory` with `gcc`: specify additional include directories
 - standard include directories assumed by default
- **#include** `"stdio.h"` – searches `./` for `stdio.h` first

Declaring variables

- Must declare variables before use
- Variable declaration:
 int n;
 float phi;
- `int` - integer data type
- `float` - floating-point data type
- Many other types (more next lecture...)

Initializing variables

- Uninitialized, variable assumes a default value
- Variables initialized via assignment operator:
`n = 3;`
- Can also initialize at declaration:
`float phi = 1.6180339887;`
- Can declare/initialize multiple variables at once:
`int a, b, c = 0, d = 4;`

Arithmetic expressions

Suppose x and y are variables

- $x+y$, $x-y$, $x*y$, x/y , $x\%y$: binary arithmetic
- A simple statement:
 $y = x+3*x/(y-4);$
- Numeric literals like 3 or 4 valid in expressions
- Semicolon ends statement (not newline)
- $x += y$, $x -= y$, $x *= y$, $x /= y$, $x \% = y$: arithmetic and assignment

Order of operations

- Order of operations:

Operator	Evaluation direction
$+, -$ (sign)	right-to-left
$*, /, \%$	left-to-right
$+, -$	left-to-right
$=, +=, -=, *=, /=, \%=$	right-to-left

- Use parentheses to override order of evaluation

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

2. Evaluate multiplies and divides, from left-to-right

float $z = x + 3 * x / 2.0; \rightarrow$ **float** $z = x + 6.0 / 2.0; \rightarrow$ **float** $z = x + 3.0;$

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

2. Evaluate multiplies and divides, from left-to-right

float $z = x + 3 * x / 2.0; \rightarrow$ **float** $z = x + 6.0 / 2.0; \rightarrow$ **float** $z = x + 3.0;$

3. Evaluate addition

float $z = x + 3.0; \rightarrow$ **float** $z = 5.0;$

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

2. Evaluate multiplies and divides, from left-to-right

float $z = x + 3 * x / 2.0; \rightarrow$ **float** $z = x + 6.0 / 2.0; \rightarrow$ **float** $z = x + 3.0;$

3. Evaluate addition

float $z = x + 3.0; \rightarrow$ **float** $z = 5.0;$

4. Perform initialization with assignment

Now, $z = 5.0$.

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

2. Evaluate multiplies and divides, from left-to-right

float $z = x + 3 * x / 2.0; \rightarrow$ **float** $z = x + 6.0 / 2.0; \rightarrow$ **float** $z = x + 3.0;$

3. Evaluate addition

float $z = x + 3.0; \rightarrow$ **float** $z = 5.0;$

4. Perform initialization with assignment

Now, $z = 5.0$.

How do I insert parentheses to get $z = 4.0$?

Order of operations

Assume $x = 2.0$ and $y = 6.0$. Evaluate the statement

float $z = x + 3 * x / (y - 4);$

1. Evaluate expression in parentheses

float $z = x + 3 * x / (y - 4); \rightarrow$ **float** $z = x + 3 * x / 2.0;$

2. Evaluate multiplies and divides, from left-to-right

float $z = x + 3 * x / 2.0; \rightarrow$ **float** $z = x + 6.0 / 2.0; \rightarrow$ **float** $z = x + 3.0;$

3. Evaluate addition

float $z = x + 3.0; \rightarrow$ **float** $z = 5.0;$

4. Perform initialization with assignment

Now, $z = 5.0$.

How do I insert parentheses to get $z = 4.0$?

float $z = (x + 3 * x) / (y - 4);$

Function prototypes

- Functions also must be declared before use
- Declaration called *function prototype*
- Function prototypes:
`int factorial (int);` or `int factorial (int n);`
- Prototypes for many common functions in header files for C Standard Library

Function prototypes

- General form:

return_type function_name(arg1, arg2, ...);

- Arguments: local variables, values passed from caller
- Return value: single value returned to caller when function exits
- `void` – signifies no return value/arguments
`int rand(void);`

The `main()` function

- `main()`: entry point for C program
- Simplest version: no inputs, outputs 0 when successful, and nonzero to signal some error

```
int main(void);
```

- Two-argument form of `main()`: access command-line arguments

```
int main(int argc, char **argv);
```

- More on the `char **argv` notation later this week...

Function definitions

```
Function declaration  
{  
  declare variables;  
  program statements;  
}
```

- Must match prototype (if there is one)
 - variable names don't have to match
 - no semicolon at end
- Curly braces define a *block* – region of code
 - Variables declared in a block exist only in that block
- Variable declarations before any other statements

Our `main()` function

```
/* The main() function */
int main(void) /* entry point */
{
    /* write message to console */
    puts("hello, 6.087 students");

    return 0; /* exit (0 => success) */
}
```

- `puts()`: output text to console window (stdout) and end the line
- String literal: written surrounded by double quotes
- `return 0;`
exits the function, returning value 0 to caller

Alternative `main()` function

- Alternatively, store the string in a variable first:

```
int main(void) /* entry point */
{
    const char msg[] = "hello, 6.087 students";

    /* write message to console */
    puts(msg);
}
```

- `const` keyword: qualifies variable as constant
- `char`: data type representing a single character; written in quotes: `'a'`, `'3'`, `'n'`
- `const char msg[]`: a constant array of characters

More about strings

- Strings stored as character array
- Null-terminated (last character in array is `'\0'` null)
 - Not written explicitly in string literals
- Special characters specified using `\` (escape character):
 - `\\` – backslash, `\'` – apostrophe, `\"` – quotation mark
 - `\b`, `\t`, `\r`, `\n` – backspace, tab, carriage return, linefeed
 - `\ooo`, `\xhh` – octal and hexadecimal ASCII character codes, *e.g.* `\x41` – `'A'`, `\060` – `'0'`

- `stdout`, `stdin`: console output and input streams
- `puts(string)`: print string to stdout
- `putchar(char)`: print character to stdout
- `char = getchar()`: return character from stdin
- `string = gets(string)`: read line from stdin into string
- Many others - later this week

Preprocessor macros

- Preprocessor macros begin with # character
`#include <stdio.h>`
- `#define` msg "hello, 6.087 students"
defines *msg* as "hello, 6.087 students" throughout source file
- many constants specified this way

Defining expression macros

- **#define** can take arguments and be treated like a function
#define add3(x,y,z) ((x)+(y)+(z))
- parentheses ensure order of operations
- compiler performs inline replacement; not suitable for recursion

Conditional preprocessor macros

- #if, #ifdef, #ifndef, #else, #elif, #endif
conditional preprocessor macros, can control which lines are compiled
 - evaluated before code itself is compiled, so conditions must be preprocessor defines or literals
 - the `gcc` option `-Dname=value` sets a preprocessor define that can be used
 - Used in header files to ensure declarations happen only once

Conditional preprocessor macros



- **#pragma**
preprocessor directive
- **#error**, **#warning**
trigger a custom compiler error/warning
- **#undef** msg
remove the definition of `msg` at compile time

Compiling our code

After we save our code, we run `gcc`:

```
athena%1 gcc -g -O0 -Wall hello.c -o  
hello.o
```

Assuming that we have made no errors, our compiling is complete.

¹Athena is MIT's UNIX-based computing environment. OCW does not provide access to it.

Running our code

Or, in gdb,

```
athena%1 gdb hello.o
:
Reading symbols from hello.o...done.
(gdb) run
Starting program:  hello.o
hello, 6.087 students

Program exited normally.
(gdb) quit
athena%
```

¹Athena is MIT's UNIX-based computing environment. OCW does not provide access to it.

Summary

Topics covered:

- How to edit, compile, and debug C programs
- C programming fundamentals:
 - comments
 - preprocessor macros, including `#include`
 - the `main()` function
 - declaring and initializing variables, scope
 - using `puts()` – calling a function and passing an argument
 - returning from a function

MIT OpenCourseWare

<http://ocw.mit.edu>

6.087 Practical Programming in C

IAP 2010

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.