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 Athena[1] servers

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

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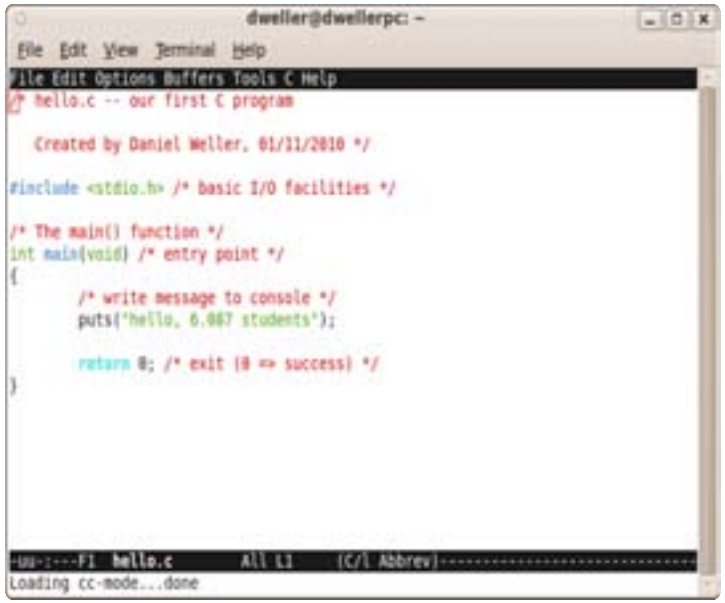
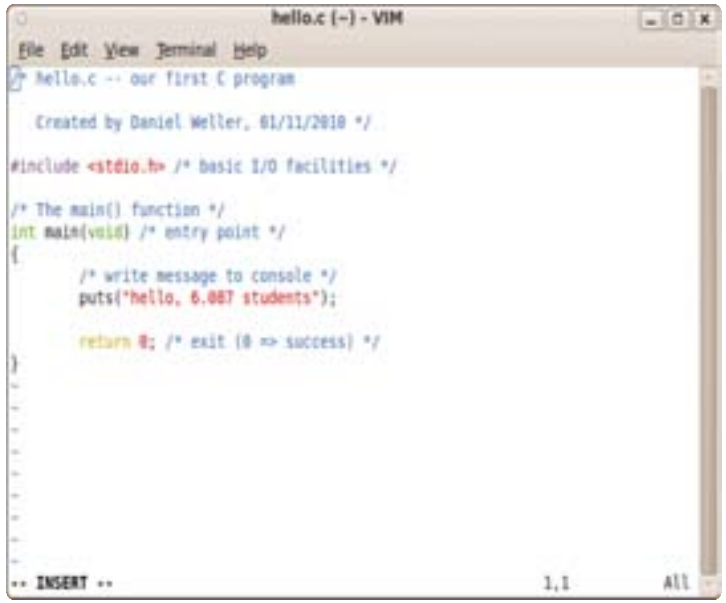
Editing C code

- `.c` extension
- Editable directly

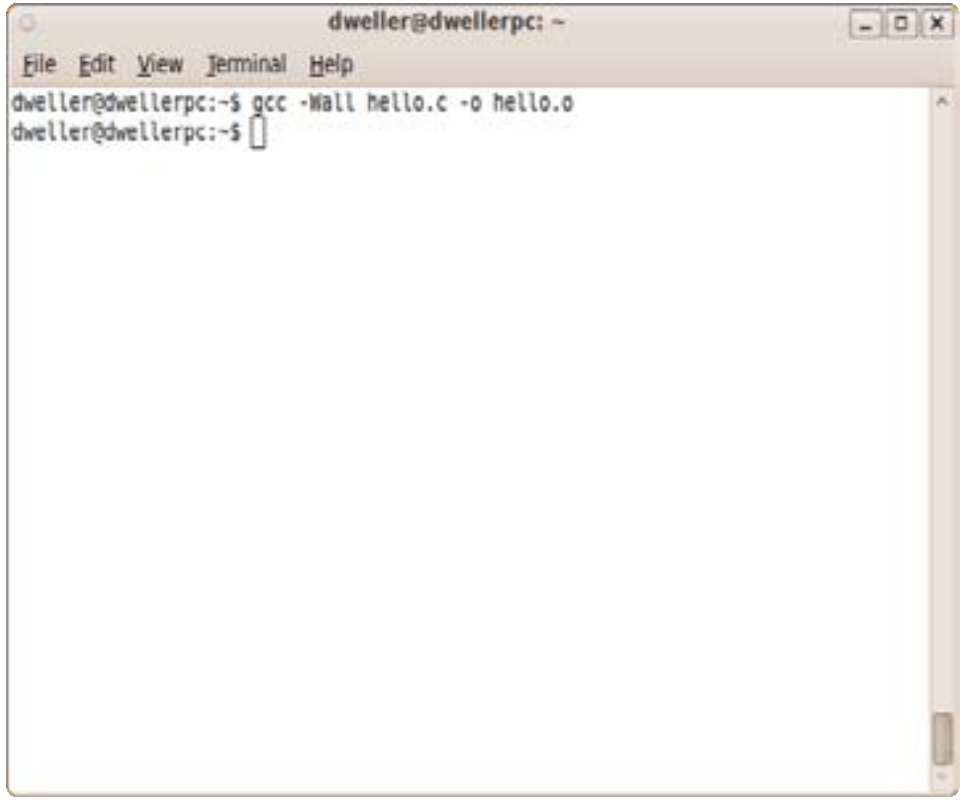




- More later. . .

Compiling a program

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



More about gcc

- Run `gcc`:

```
athena%[1] gcc -Wall infilename.c -o
outfilename.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 infilename.c -o
outfilename.o
```

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Debugging

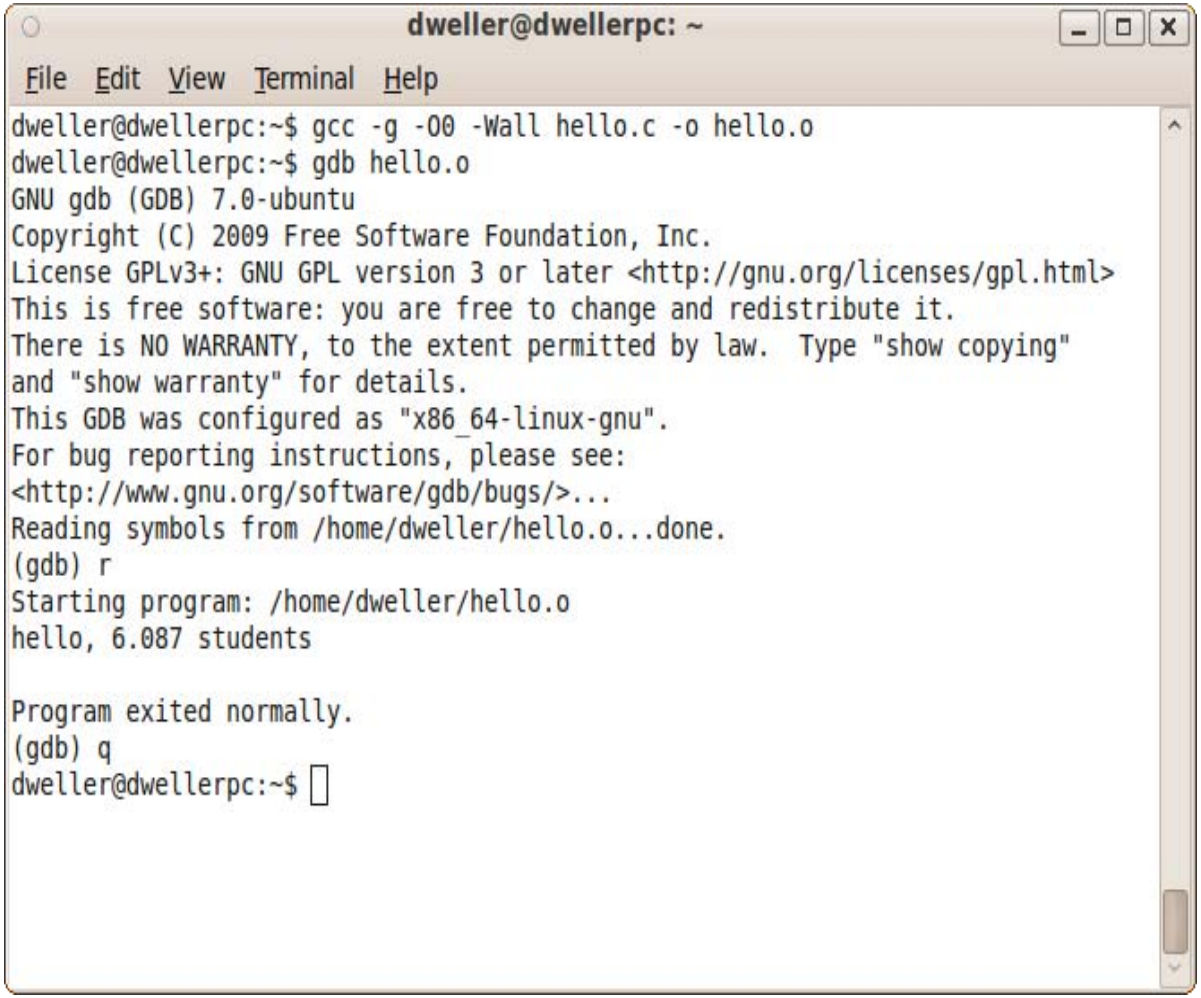


Figure: `gdb`: command-line debugger

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

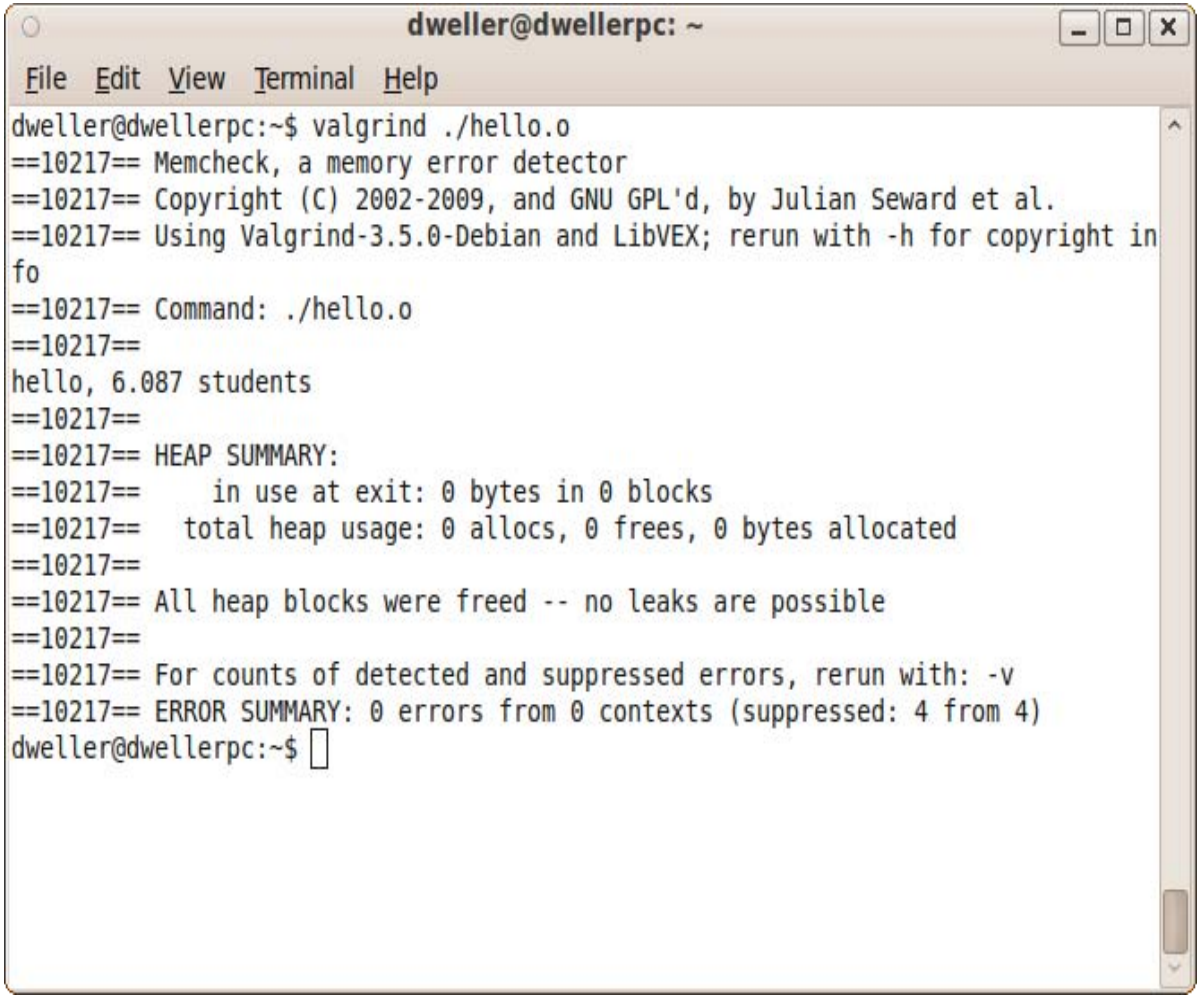
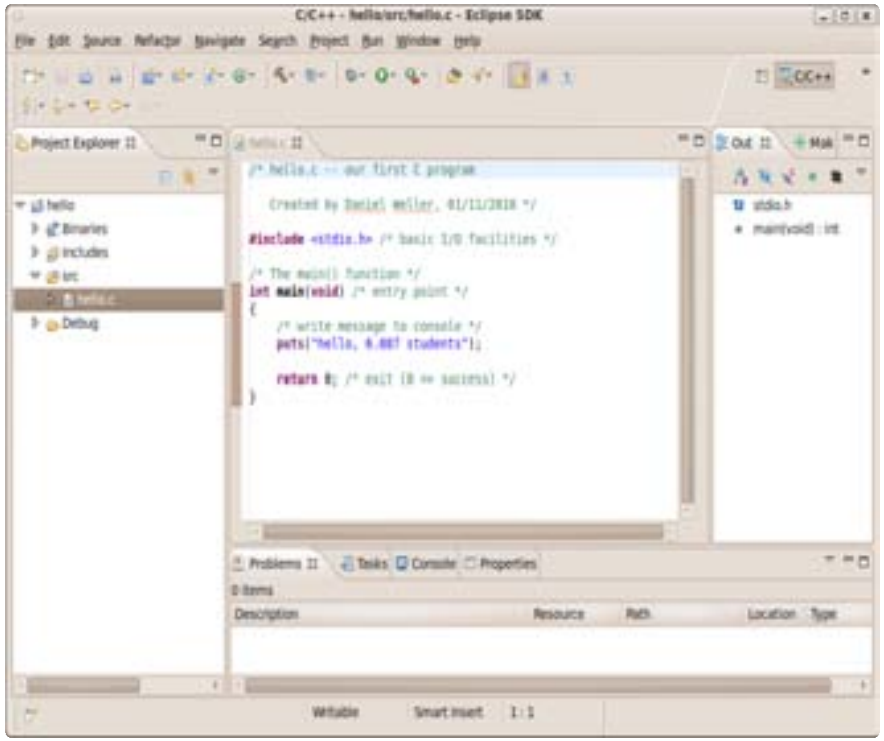


Figure: `valgrind`: diagnose memory-related problems

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



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

- Introduction to C
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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*
  - `-I`*`directory`* 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 $\mathrm{x} = 2.0$ and $\mathrm{y} = 6.0$. 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 $\mathrm{x} = 2.0$ and $\mathrm{y} = 6.0$. Evaluate the statement

float z = x+3∗x/(y−4);

1. Evaluate expression in parentheses

   float z = x+3∗x/(y−4); → **float** z = x+3∗x/2.0;

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

   float z = x+3∗x/2.0; → **float** z = x+6.0/2.0; → **float** z = x+3.0;

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   float z = x+3∗x/2.0; → **float** z = x+6.0/2.0; → **float** z = x+3.0;

3. Evaluate addition

   float z = x+3.0; → **float** z = 5.0;

Order of operations

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4. Perform initialization with assignment

   Now, $\mathrm{z} = 5.0$.

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4. Perform initialization with assignment

   Now, $\mathrm{z} = 5.0$.

How do I insert parentheses to get $\mathrm{z} = 4.0$?

Order of operations

Assume $\mathrm{x} = 2.0$ and $\mathrm{y} = 6.0$. Evaluate the statement

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   float z = x+3∗x/2.0; → **float** z = x+6.0/2.0; → **float** z = x+3.0;

3. Evaluate addition

   float z = x+3.0; → **float** z = 5.0;

4. Perform initialization with assignment

   Now, $\mathrm{z} = 5.0$.

How do I insert parentheses to get $\mathrm{z} = 4.0$?

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`*, `\x`*`hh`* – octal and hexadecimal ASCII character codes, *e.g.* `\x41` – `'A'`, `\060` – `'0'`

Console I/O

- 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 `-D`*`name`*`=`*`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.

[1] Athena 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%
```

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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

6.087 Practical Programming in C

IAP 2010