C Language Basics

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A history of C in one slide

- **First developed in the early 1970s for Unix**
  - Originally by Dennis Richie, descended from BCPL and B
  - Made Unix one of the first OSes not written in assembly
  - Defined in a book by Kernighan and Richie (K&R)
- **Popularity grew with Unix, then for microcomputers**
- **Standardized by ANSI/ISO in 1989/1990**
- **Object-oriented variants appeared in the 1980s:**
  - Objective-C and C++
  - Java in turn derives largely from C++, in the 1990s
- **Further standards in 1999 (C99) and 2011 (C11)**

C as compared with C++ and Java

- **Unlike Java and C++, C does not have:**
  - Classes
  - Packages/namespaces
  - Templates/generics
  - Exceptions
  - Operator or function overloading
  - Anonymous functions/closures/lambdas
  - A rich standard data-structure library
- **Unlike Java, C allows potentially-unsafe operations:**
  - Uninitialized variables and memory
  - Out-of-bounds array accesses
  - Creating pointers from integers
  - Deallocating memory that is still in use

C programs are made up of functions

- **The primary unit of structure is a function**
  - AKA "procedure", "subroutine"

```
type name ( type arg , type arg )
{
    statements
}
```

```
int add(int arg1, int arg2)
{
   return arg1 + arg2;
}
```


Hello world in detail

standard library function declarations

```
#include <stdio.h>

int main(int argc, char **argv) {
    printf("Hello, world!\n");
    return 0;
}
```

standard library function to print a message

command-line arguments

Return values and prototypes

- **Functions can return a value with a `return` statement**
- **No return value, or no arguments, are signified by the keyword `void`**
- **To tell the compiler about a function without defining it, write a function prototype:**

```
int add(int arg1, int arg2);
```

- **In a single file program, prototypes mostly not needed if functions are defined lower-level first**
  - But, give stylistic freedom to change function order

Numeric types

- **Integer types:**

Type name	Common minimum size
`char`	8 bits
`short`	16 bits
`int`	32 bits
`long`	32 bits – for us, 64 bits
`long long`	64 bits

- **"`unsigned`" variants cannot be negative**
- **Common floating point types:**
  - **`float`: usually 32 bits**
  - **`double`: usually 64 bits**

Characters

- **`char`'s name comes from representing characters**
- **Actually three types:**
  - `signed char`, -128 to 127
  - `unsigned char`, 0 to 255
  - `char`, might be either signed or unsigned
- **On almost all systems, values 0-127 represent ASCII**
  - US-standardized code for roman alphabet, numbers, symbols, etc.
- **Wider variety of standards for meanings of 128-255**
  - Windows-1252, Latin-1: add accented letters and a few symbols
  - UTF-8: multiple bytes represent >100,000 Unicode characters
- **Escape sequences starting with \ for hard-to-type ones:**
  - E.g., `'\n'` for newline, `'\0'` for character zero

Declaration, initialization, assignment

- **A new variable is introduced with a *declaration*:**

```
int weight, height;
```

- **Optionally, give it a value by including an *initialization*:**

```
int score = 100;
```

- **An assignment statement changes the value of an already-declared variable:**

```
score = score - 5;
```


Type conversion and casts

- **Values are automatically converted between numeric types, sometimes with strange effects:**

```
long x = 1000000;
char c = x;
/* c is now 64 */
```

- **The act of converting can be written explicitly as a cast operation:**

```
long x = 1000000;
char c = (char)x;
/* c is now 64 */
```


Local, global, and `static`

- **A variable defined inside a function (local) is usually:**
  - Created once per call to the function
  - Visible only inside the function
- **Variable can be declared outside any function, global:**
  - Exists during the whole program
  - Visible in any (later) function
- **If a local variable is declared with keyword static:**
  - One version for the whole execution
  - Still visible only inside the function
  - E.g., useful for counter function

Arithmetic operators

- **C has the standard math operators:**
  - `+`, `-` (both unary and binary)
  - `*`, multiplication
  - `/`, integer or floating-point division
  - `%`, integer division remainder
- **Precedence rules define the default grouping**
  - E.g., `1 + 2 * 3` is `1 + (2 * 3)` i.e. 7, not 9
- **When in doubt, use parentheses**
  - Rules are mostly, but not always, what you'd expect

Assignment abbreviations

- Unary ++ and -- add or subtract 1, respectively
  - E.g., `c++` is short for `c = c + 1`
  - Also called increment and decrement
- Putting a = after an operator makes an update operator
  - E.g., `c += 10` is short for `c = c + 10`
- You can string together multiple assignment left-hand sides
  - `assignment_grade = course_grade = 0;`

Comparisons and logic

- Numbers can be compared with the usual operators:
  - `<`, `>`
  - `<=`, `>=` mean ≤, ≥
  - `==`, `!=` mean =, ≠; note double equals
- Integers used for logic (no separate Boolean type):
  - 0 represents false
  - any non-zero interpreted as true, produced as 1
  - (C99 defines `<stdbool.h>`, hasn't caught on)
- Logic operators:
  - `&&` for and, `||` for or, `!` for not
  - `(d != 0) && (n / d < 10)` is safe ("short-circuiting")

Arrays in C

- Arrays are the key building block for large data structures
- C arrays have limited features, allowing for simple compilation strategies
  - Local and global arrays can only have fixed size
  - At runtime, no way to ask how long an array is
  - No bounds checking
  - First index is always 0
- Implementation is just a sequence of adjacent values
- C arrays are closely related with C's pointers

Array syntax

- Syntax is based on square brackets `[]` as a suffix
- On a type, inside brackets is the size
- On a value, inside brackets is the index
  - Can appear on left or right side of assignment
  - Note, 0-based means index always less than size

```
double point[3] = {1.0, 1.0, 0.0};
point[0] = -2.0;
double dist =
 sqrt(point[0]*point[0] +
      point[1]*point[1] +
      point[2]*point[2]);
```


Multidimensional arrays

- Repeat sets of brackets for tables with more numeric indexes
- E.g., chess board:

```
char board[8][8];
board[0][0] = 'r';
```

- Note, not commas
- Again, only usable when the dimensions are fixed

Pointer basics

- A pointer is a value that stores the location of another value
  - As we'll later see in detail, it's implemented as a memory address
- The type of a pointer variable keeps track of the type of what it can point to
  - E.g., pointer-to-char, pointer-to-int
- Type declaration syntax puts a * before the variable name:

```
int num, *num_ptr;
```

Basic pointer operations

- `&` creates a pointer
  - If `x` is an int variable, `&x` is an int pointer, pointing at x
- `*` gets what the pointer points to
  - If `ip` is an int pointer, `*ip` is the int it points at
  - Also called "following" or "dereferencing"
- Multiple levels are possible

```
int i = 5;
int *ip = &i;
int **ipp = &ip;
(**ipp)++;
/* i and **ipp are now 6 */
```

"Declaration resembles use"

Pointer arithmetic

- Adding an integer to a pointer advances it by that number of objects
- If `p` is an `int *`, `p + 1` is a pointer to the int next to it
  - Type indicates how much to move
  - Programmer's responsibility to know there is an `int` there
- p[i] is equivalent to *(p + i)
- Thus, a pointer is roughly equivalent to an array of unknown size
- Array converted into pointer in most places it appears
  - E.g. in function argument type, `int x[]` and `int *x` are equivalent

Strings are arrays of characters

- String length is unknown at compile time
  - Thus, type is `char *`
- Length of string indicated by `\0` character after contents
  - "Null termination"
  - Many C programs don't cope well with `\0` characters in their input

```
void caesar_string(char *s, int amt) {
    int i;
    for (i = 0; s[i] != '\0'; i++) {
        s[i] = rotate(s[i], amt);
    }
}
```


String constants

- Put text inside double quote marks: `"string"`
  - Can also include escape sequences
  - Usually put `\n` at end of lines to be printed
- Normally string constants are read-only
  - Type is `const char *`
- Can be used to initialize a modifiable character array

```
char a[] = "hi!";
/* size 4, including \0 */

char a[3] = "hi!";
/* size 3, no \0 */
```


Basics of `printf`

- Standard library function for formatted output
- First argument, format string, may contain format specifiers starting with `%`
  - Generally, each corresponds to a later argument
- Most basic format specifiers:
  - `%d`: signed `int`, printed in decimal
  - `%g`: `double`, in scientific notation if needed
  - `%s`: `char *`, interpreted as string

```
printf("One %s one is %d\n",
       "plus", 1 + 1);
/* One plus one is 2 */
```


`if` and `if-else` statements

- Basic way to make decisions. `if` does either something, or nothing:

```
if (x % 2 == 0)
    printf("x is even\n");
```

- `if-else` does one thing if true, other if false

```
if (x % 2 == 0)
    printf("x is even\n");
else
    printf("x is odd\n");
```

Blocks and indentation

- **Use curly braces to group multiple statements, e.g. inside an `if` statement**
  - Without braces, only one statement inside `if`
- **Can declare variables inside a block, not visible outside**
- **Safer to use braces than not: they make grouping clear, like parentheses**
  - Example "dangling else" ambiguity: `else` after nested `if`s
- **It is conventional to use indentation to show nesting level**
  - But compiler completely ignores whitespace
  - Many opinions and arguments about where to put braces relative to indentation

`while` and `for` loops

- **A `while` loop repeats a statement/block as many times as a condition is true (can be 0 times)**

```
while (x > 0) {
    x--;
} /* x is now 0 or negative */
```

- **A `for` loop groups a `while` with two other statements, commonly assignment and update of the same variable**

```
for (A; B; C) D;
   /* is equivalent to: */
A;
while (B) { D; C }
```

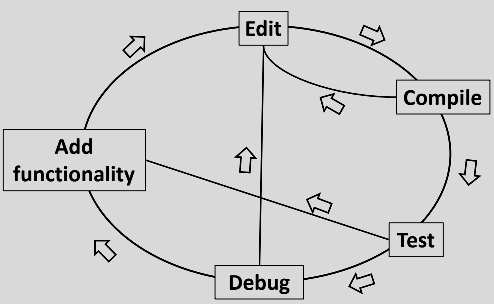

Leaving in the middle of a loop

- **A `break` statement jumps to the end of the innermost enclosing loop**
- **A `continue` statement jumps to the next iteration of a loop**
  - For a `for` loop, the increment part *is* executed
- **A `return` statement ends the entire function**
- **There is also a `goto` statement, but don't use it**
  - One arguable application: jumping out of an outer loop

Debugging and debuggers

- **You have probably already had the experience of making a mistake in a program**
- **Speaking roughly, "debugging" is the process:**
  - After you know *that* your code is wrong
  - But before you know *how* it is wrong
- **Some kinds of debugging that don't need much tool support:**
  - Code review
  - Rubber duck debugging
  - Printf debugging

Debugging in the development cycle



What is a debugger for?

- **Not to fix your bugs for you, alas**
  - Computers aren't that smart yet
- **Instead, helps you examine your program's execution in more detail**
  - See what is happening if something is obviously wrong
  - Walk through normal execution, to compare with your expectations
- **Standard practice is source-level debugging**
  - I.e., the debugger shows your program in terms of its source code
  - For binaries, made possible by debugging information (enabled with compiler option `-g`)

The GNU debugger GDB

- Standard command-line, source and binary-level debugger on Linux
- Start up with `gdb ./my_program`
- Supply program arguments to the GDB `run` command
  - Abbreviated just `r`
- Or, use `gdb --args ./my_program arg1 arg2`
  - This mode doesn't work for redirection (shell <, >)
- Today: using GDB as a source-level debugger

`break`, `step`, `next`, `continue`

- Normally, GDB will execute your program normally
- To get it to stop to let you look around, turn on a breakpoint with the command `break` (`b`)
  - Argument can be function name, file and line number, others
- When the breakpoint is reached, your program will stop and you can give GDB commands
- Run the program for one line with `step` (`s`)
  - Variant `next` (`n`) does not go into other functions
- To go back to full-speed execution, use `continue` (`c`)

`print`

- The most important command for examining program state is `print` (`p`)
  - The argument is a source-level (i.e., C) expression
- Some features to know about
  - Can do arithmetic
  - Can refer to any variable in scope
  - Can call functions
  - Can do assignments
  - `p/x` prints in hexadecimal (other formats also available)

Crashes, interrupts, and `backtrace`

- GDB will automatically stop if the program runs into a crash like a segfault (technically: a Unix signal)
- To stop in the middle of execution, type Ctrl-C
  - Good for debugging infinite loops
- The command `backtrace` (`bt`) summarizes all the currently executing functions
  - Similar to what Java and Python print for an unhandled exception

Watchpoints

- A watchpoint is sort of like a breakpoint, but based on data
- The command `watch` takes an argument like print
- A watchpoint stops execution when that value changes
- Useful for tracking down problems caused to pointers
- If you use a source-level expression, you'll usually get a software watchpoint, which is slow
  - Later, we'll see hardware watchpoints

Pass by value

- The parameters to a C function are always just copies of values from the caller
  - Called "pass by value"
- I.e., they are local variables; changing them has no effect outside the function

```
int global;
void f(int a, int b) {
    a++; /* does not change global */
    b--; /* does not change 2 + 2 */
}
void g(void) { f(global, 2 + 2); }
```

Recursion

- A function can call itself, directly or indirectly
- Each instance has its own copy of local variables
  - Used to implement algorithms like quicksort, parsing
- Can also be used as an alternative form of loop
  - Not as common in C as in functional languages
- Each instance usually uses some memory
  - Deep recursion is not too common in C

Simulating pass by reference

- What if you want a function to modify caller's variables?
  - Called "pass by reference"
- Simulated in C by passing explicit pointers

```
void increment_by(int *ip, int amt) {
    *ip += amt;
}
void f(void) {
    int x;
    increment_by(&x, 5);
}
```

- Commonly used instead of multiple return values
  - Pointer parameters classified as "in", "out", "in/out"

Structures

- Data type that groups multiple named values

```
struct student {
    char *name;
    int grade;
};
```

- Fields accessed with the . operator

```
struct student jane;
jane.name = "Jane";
jane.grade = 100;
```

- Compared to OO languages, like objects but without methods, inheritance, or visibility restrictions

Pointers to structures

- In more complex situations, you often want to refer to `struct`s with pointers
- sp->f is short for (*sp).f

```
void mark_off(struct student *sp) {
    sp->grade += 10;
}
```

- Note for Java users: Java object (references) are like structure *pointers*
  - Even though pointer aspect is not explicit in syntax
  - E.g., two variables can refer to the same object
  - Despite the symbol, Java's `.` is like C's `->`

Allocating structures

- If structs are like objects, what's the equivalent of `new`?

```
struct student *sp =
   malloc(sizeof(struct student));
```

- Malloc is a basic routine for dynamically allocating memory
  - Argument is size in bytes
  - Return value has type `void *`, automatically converted
  - Contents can be anything, you must initialize
- For now, learn as an idiom; we'll see more details later
  - Use with arrays
  - Changing size with `realloc`
  - Returning memory with `free` (don't need to do this in Proj 1)

Null pointers

- Pointers have a special value that means not pointing at anything
  - Often used to represent endpoints or empty data structures
- Integer 0 converted to pointer, also `NULL` macro
  - On most systems, internal representation is 0
- A null pointer counts as false, any other pointer is true
- Dereferencing a null pointer usually causes a segfault
  - So you need to check first

Pointer and sharing pitfalls

- **Passing a pointer to data is usually faster than copying it**
  - Only one copy of data exists; it is *shared* by different users
- **But, sharing can also lead to unexpected behavior**
  - E.g., data changing when you do not expect it to
- **Pointer to a local variable is valid only until its function finishes**
  - Attempts to access later may cause a crash
- **Sometimes you do want to make a copy of data**
  - Allocate a new struct/array and copy contents over
  - `strdup` is a convenience function for duplicating a null-terminated string

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Example: linked list length

- **Can iterate over a singly-linked list with a `for` loop:**

```
struct list_node {
   struct list_node *next;
   int value;
};

int length(struct list_node *root) {
    struct list_node *p; int i = 0;
    for (p = root; p; p = p->next)
        i++;
    return i;
}
```

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A few more fun operators

- **The "ternary" operator `? :` is like an if-then-else**

```
printf("Found %d object%s\n", n,
       ((n == 1) ? "" : "s"));
```

- **The comma `,` evaluates two expressions and returns the right-hand one**
  - Useful for putting multiple assignments in a `for` loop header
- **++ and -- can also be prefixes, and return a value**
  - Prefix versions like ++x first update, then return new value, "pre-increment"
  - Postfix versions like x++ update, but return old value, "post-increment"
- **Overusing these operators can make code hard to read**

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typedef

- **Used to create a type name that is a synonym for another type**
  - Syntax is like that of a variable declaration

```
typedef char zipcode[5];
zipcode umn = "55455";
```

- **Commonly used to save typing "`struct`":**

```
typedef struct list_node node;
node table[100];
```

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switch statement

- **Used for making a choice based on several integer values**

```
switch ('a' + (letter % 26)) {
    case 'a': case 'e': case 'i':
    case 'o': case 'u':
        printf("Vowel\n");
        break;
    case 'y':
        printf("Maybe y\n");
        break;
    default:
        printf("Consonant\n")
        break;
}
```

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The C standard library

- **Every C implementation implements a large number of common routines**
  - Load the declarations with an appropriate `#include`
  - `stdio.h`: `printf`, `scanf`, `fopen`, `fclose`, `fread`, `fwrite`
  - `stdlib.h`: `malloc`, `exit`, `NULL`, `atoi`, `qsort`
  - `math.h`: `sqrt`, `sin`, `pow`
  - `string.h`: `strlen`, `strcpy`, `memcpy`
  - `assert.h`: `assert`
  - `ctype.h`: `isalpha`, `isspace`
- **Still limited compared to Java, C++, or Python**
  - Some interfaces have old/poor designs (e.g., `gets`)
  - Lacking general-purpose data structures
  - Other stuff also in a typical OS-specific C library / C runtime

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The C preprocessor

- **The first step of compiling C code is text-level processing**
  - Also available as a separate tool, `cpp` on Unix
- **Preprocessor directives are lines that start with #**
- **`#include` reads in another file**
  - Typically a header (`.h`) file that contains declarations
  - `<>` for system headers, `""` for program headers
- **`#define` creates a macro**
  - Synonym for a value that is substituted in later
  - Simple uses similar to `typedef` or `const` variable

```
#define TABLE_SIZE 1000
int table[TABLE_SIZE];
```

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Conditional compilation

- **Use macros and simple arithmetic to decide what code to use**

```
#ifdef __i386__
typedef long long int64;
#elif defined(__amd64__)
typedef long int64;
#else
#error "No known 64-bit type"
#endif
```

- **`#if 0` / `#endif` can “comment-out” code containing comments**

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Function-like macros

- **Macros can also define simple computations**
  - Implemented by textual substitution

```
#define MAX(x, y) \
    ((x) > (y) ? (x) : (y))
```

- **A number of pitfalls to be aware of:**
  - Should have parentheses around outside, and each argument
  - Multiple lines need `\` continuation
  - Variables can cause name clashes
  - Multiple side-effects possible with `,`
  - Statement needs `do { … } while (0)`
- **Often better to use a real function, compiler can inline**

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