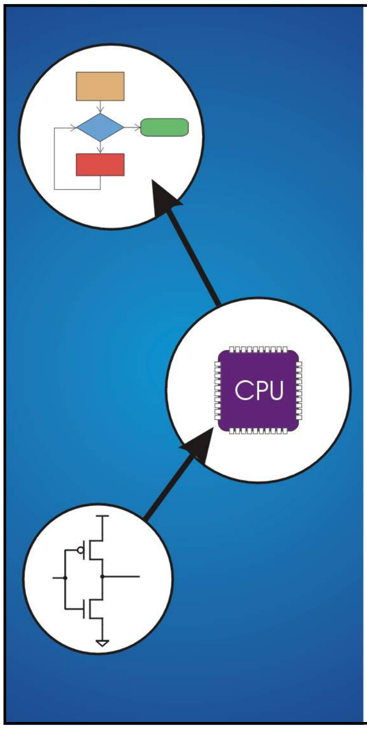


Chapter 11
Introduction to Programming in C

C: A High-Level Language

Gives symbolic names to values

- don’t need to know which register or memory location

Provides abstraction of underlying hardware

- operations do not depend on instruction set
- example: can write “a = b * c”, even though LC-3 doesn’t have a multiply instruction

Provides expressiveness

- use meaningful symbols that convey meaning
- simple expressions for common control patterns (if-then-else)

Enhances code readability

Safeguards against bugs

- can enforce rules or conditions at compile-time or run-time

Compilation vs. Interpretation

Different ways of translating high-level language

Interpretation

- interpreter = program that executes program statements
- generally one line/command at a time
- limited processing
- easy to debug, make changes, view intermediate results
- languages: BASIC, LISP, Perl, Java, Matlab, C-shell

Compilation

- translates statements into machine language
  - does not execute, but creates executable program
- performs optimization over multiple statements
- change requires recompilation
  - can be harder to debug, since executed code may be different
- languages: C, C++, Fortran, Pascal

Compilation vs. Interpretation

Consider the following algorithm:

```
• Get W from the keyboard.
• X = W + W
• Y = X + X
• Z = Y + Y
• Print Z to screen.
```

If interpreting, how many arithmetic operations occur?

If compiling, we can analyze the entire program and possibly reduce the number of operations. Can we simplify the above algorithm to use a single arithmetic operation?

Compiling a C Program

Entire mechanism is usually called the "compiler"

Preprocessor

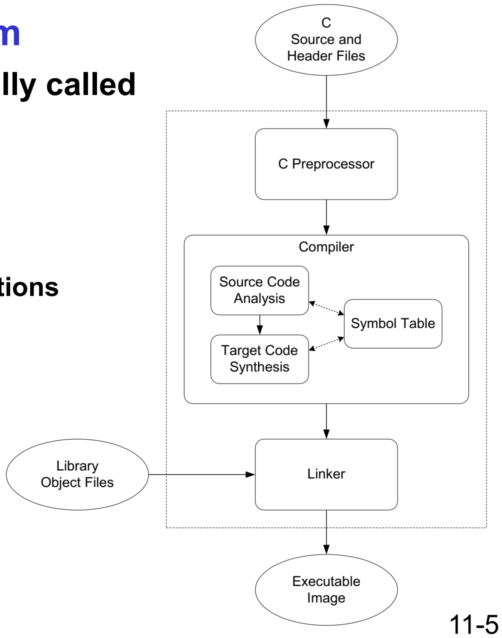
- macro substitution
- conditional compilation
- "source-level" transformations
  - ➢ output is still C

Compiler

- generates object file
  - ➢ machine instructions

Linker

- combine object files (including libraries) into executable image



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Compiler

Source Code Analysis

- "front end"
- parses programs to identify its pieces
  - ➢ variables, expressions, statements, functions, etc.
- depends on language (not on target machine)

Code Generation

- "back end"
- generates machine code from analyzed source
- may optimize machine code to make it run more efficiently
- very dependent on target machine

Symbol Table

- map between symbolic names and items
- like assembler, but more kinds of information

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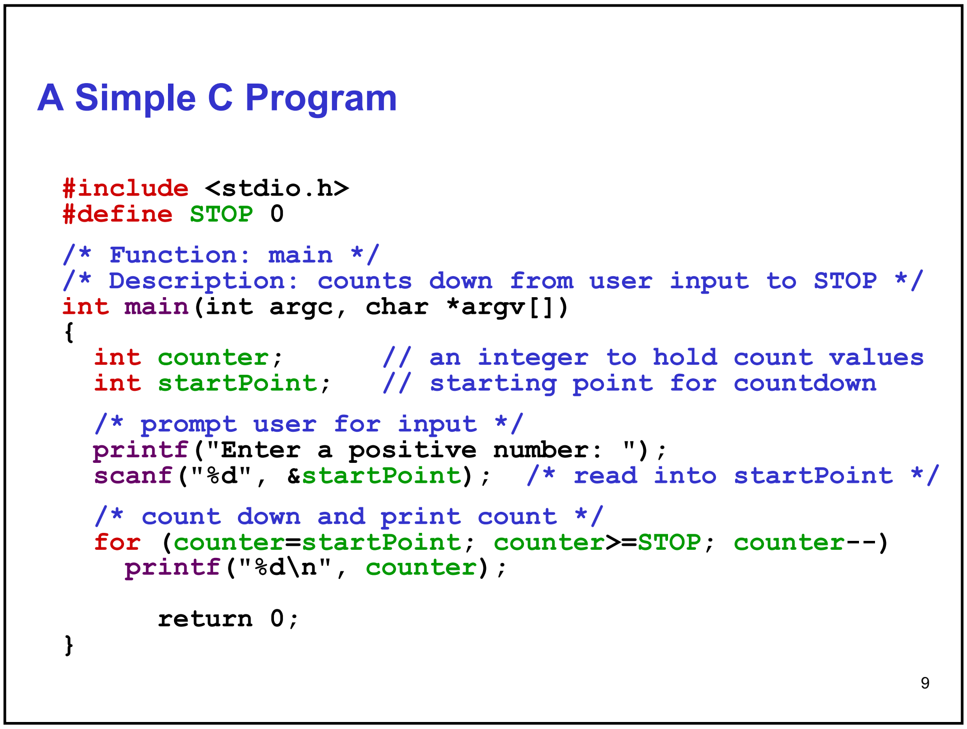
A Simple Java Program

```
import java.lang;
public class Simple {

  /* Function: main */
  /* Description: count down from user input to STOP */
  public static void main(String[] args)
  {
    /* variable declarations */
    static final int STOP = 0;
    int counter;  /* an integer to hold count values */
    int startPoint; /* starting point for countdown */

    /* prompt user for input, assumes scanner */
    System.out.printf("Enter a positive number: ");
    startPoint = in.nextInt();

    /* count down and print count */
    for (counter=startPoint; counter>=STOP; counter--)
      System.out.printf("%d\n", counter);
  }
}
```

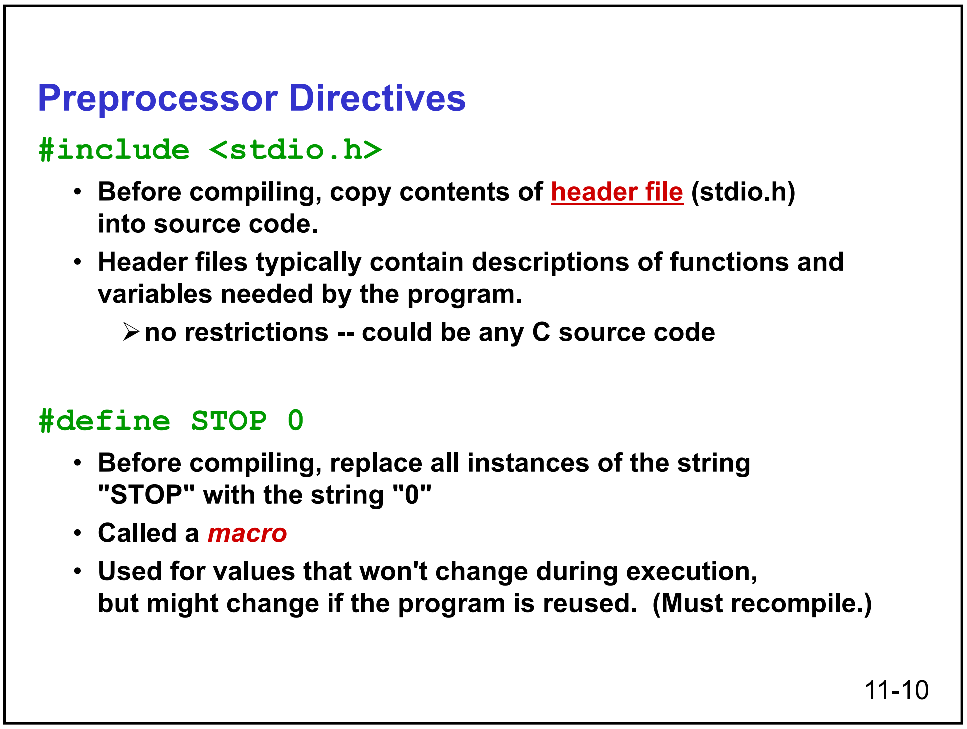
C vs. Java: some differences

Java	C
1990s	1970s
Object Oriented	Function oriented
Compilation: byte code	Compilation: machine code
No pointers	Pointers
Automatic allocation/deallocation	Dynamic memory allocation malloc/free
	Array’s don’t know their own size
…	…



A Simple C Program

```
#include <stdio.h>
#define STOP 0

/* Function: main */
/* Description: counts down from user input to STOP */
int main(int argc, char *argv[])
{
  int counter;       // an integer to hold count values
  int startPoint;    // starting point for countdown

  /* prompt user for input */
  printf("Enter a positive number: ");
  scanf("%d", &startPoint);  /* read into startPoint */

  /* count down and print count */
  for (counter=startPoint; counter>=STOP; counter--)
    printf("%d\n", counter);

      return 0;
}
```



Preprocessor Directives

`#include <stdio.h>`

- Before compiling, copy contents of header file (stdio.h) into source code.
- Header files typically contain descriptions of functions and variables needed by the program.
  - ➢ no restrictions -- could be any C source code

`#define STOP 0`

- Before compiling, replace all instances of the string "STOP" with the string "0"
- Called a *macro*
- Used for values that won't change during execution, but might change if the program is reused. (Must recompile.)

Comments

Begins with `/*` and ends with `*/`

Can span multiple lines

Cannot have a comment within a comment

Comments are not recognized within a string

- example: "my/*don't print this*/string"
  would be printed as: my/*don't print this*/string

As before, use comments to help reader, not to confuse or to restate the obvious

`main` Function

Every C program must have a `main()` function:

The main function contains the code that is executed when the program is run.

As with all functions, the code for main lives within brackets:

```
int main(int argc, char *argv[])
{
/* code goes here */
}
```

Java is similar, but C needs the size of array (argc) since C has no length member.

`main` Function

`main()` returns an `int`

- Really
- “I tried `void main()`, and it worked!”
- This is an example of undefined behavior, which cannot be refuted by experimentation.

Variable Declarations

Variables are used as names for data items.

Each variable has a ***type***,
which tells the compiler how the data is to be interpreted
(and how much space it needs, etc.).

```
int counter;
int startPoint;
```

`int` is a predefined integer type in C.

Input and Output

Variety of I/O functions in *C Standard Library*.
Must include `<stdio.h>` to use them.

```
printf("%d\n", counter);
```

- **String contains characters to print and formatting directions for variables.**
- **This call says to print the variable `counter` as a decimal integer, followed by a linefeed (`\n`).**

```
scanf("%d", &startPoint);
```

- **String contains formatting directions for looking at input.**
- **This call says to read a decimal integer and assign it to the variable `startPoint`. (Don't worry about the `&` yet.)**

More About Output

Can print arbitrary expressions, not just variables

```
     printf("%d\n", startPoint - counter);
```

Print multiple expressions with a single statement

```
     printf("%d %d\n", counter,
            startPoint - counter);
```

Different formatting options:

`%d`	**decimal integer**
`%x`	**hexadecimal integer**
`%c`	**ASCII character**
`%f`	**floating-point number**

Examples

This code:

```
printf("%d is a prime number.\n", 43);
printf("43 plus 59 in decimal is %d.\n", 43+59);
printf("43 plus 59 in hex is %x.\n", 43+59);
printf("43 plus 59 as a character is %c.\n", 43+59);
```

produces this output:

```
43 is a prime number.
43 + 59 in decimal is 102.
43 + 59 in hex is 66.
43 + 59 as a character is f.
```

Examples of Input

Many of the same formatting characters are available for user input.

```
scanf("%c", &nextChar);
```

- **reads a single character and stores it in nextChar**

```
scanf("%f", &radius);
```

- **reads a floating point number and stores it in radius**

```
scanf("%d %d", &length, &width);
```

- **reads two decimal integers (separated by whitespace), stores the first one in length and the second in width**

Must use ampersand (&) for variables being modified.
(Explained in Chapter 16.)

Compiling and Linking

- Various compilers available
  - gcc, c99, c11, clang
  - includes preprocessor, compiler, and linker
  - Warning: some features are implementation dependent!
- Lots and lots of options
  - level of optimization, debugging
  - preprocessor, linker options
  - usually controlled by makefile
  - intermediate files --
    object (.o), assembler (.s), preprocessor (.i), etc.

Remaining Chapters on C

A more detailed look at many C features.

- Variables and declarations
- Operators
- Control Structures
- Functions
- Data Structures
- I/O

Emphasis on how C is implemented by LC-3 assembly language.

Also see C Reference in Appendix D.