A Taste of C
Goals of this Lecture

Help you learn about:
  • The basics of C
  • Deterministic finite-state automata (DFA)
  • Expectations for programming assignments

Why?
  • Help you get started with Assignment 1
    • Required readings…
    • + coverage of programming environment in precepts…
    • + minimal coverage of C in this lecture…
    • = enough info to start Assignment 1
  • DFAs are useful in many contexts
    • E.g. Assignment 1, Assignment 7
Agenda

The charcount program
The upper program
The upper1 program
The “charcount” Program

Functionality:
• Read all chars from stdin (standard input stream)
• Write to stdout (standard output stream) the number of chars read
The “charcount” Program

The program:

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != EOF)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```
Building and Running "charcount"

```
$ gcc217 charcount.c -o charcount
$ ./charcount
Line 1
Line 2
^D
14
$
```

What is this? What is the effect?
Building and Running

```
$ cat somefile
Line 1
Line 2
$ ./charcount < somefile
14
$
```

What is this? What is the effect?
```
$ ./charcount > someotherfile
Line 1
Line 2
^D
$ cat someotherfile
14
```

What is this? What is the effect?
“charcount” Building and Running in Detail

Question:
• Exactly what happens when you issue the command
  gcc217 charcount.c –o charcount

Answer: Four steps
• Preprocess
• Compile
• Assemble
• Link
The starting point

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
  chars in stdin. Return 0. */
int main(void)
{
  int c;
  int charCount = 0;
  c = getchar();
  while (c != EOF)
  {
    charCount++;
    c = getchar();
  }
  printf("%d\n", charCount);
  return 0;
}
```

- C language
- Missing definitions of `getchar()` and `printf()`
Preprocessing “charcount”

Command to preprocess:

• gcc217 -E charcount.c > charcount.i

Preprocessor functionality

• Removes comments
• Handles preprocessor directives
# Preprocessing “charcount”

### charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != EOF)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```

Preprocessor replaces
#include <stdio.h>
with contents of
/usr/include/stdio.h

Preprocessor replaces
EOF with -1
```c
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != -1)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```

Preprocessor removes comment
The result

charcount.c

```c
...  
int getchar();  
int printf(char *fmt, ...);
...

int main(void)  
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != -1)
   {  charCount++;
       c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

Why int instead of char?

- C language
- Missing comments
- Missing preprocessor directives
- Contains code from stdio.h
  - **Declarations** of getchar() and printf()
- Missing **definitions** of getchar() and printf()
Compiling “charcount”

Command to compile:
  • gcc217 -S charcount.i

Compiler functionality
  • Translate from C to assembly language
  • Use function declarations to check calls of getchar() and printf()
Compiling “charcount”

charcount.i

```c
...  int getchar();  int printf(char *fmt, ...);
...  int main(void)
{    int c;
      int charCount = 0;
      c = getchar();
      while (c != -1)
        {    charCount++;
              c = getchar();
        }
      printf("%d\n", charCount);
      return 0;
  }
```

- Compiler sees function declarations
- So compiler has enough information to check subsequent calls of getchar() and printf()
Compiling “charcount”

charcount.i

...  
int getchar();  
int printf(char *fmt, ...);  
...  
int main(void)  
{  int c;  
    int charCount = 0;  
    c = getchar();  
    while (c != -1)  
    {  charCount++;  
        c = getchar();  
    }  
    printf("%d\n", charCount);  
    return 0;  
}  

- Definition of main() function
- Compiler checks calls of getchar() and printf() when encountered
- Compiler translates to assembly language
Compiling “charcount”

The result:  charcount.s

```assembly
.section "".rodata"
format:
  .string "%d\n"
.section ".text"
.globl main
.type main,@function
main:
  pushq %rbp
  movq %rsp, %rbp
  subq $4, %rsp
  call getchar
loop:
  cmpl $-1, %eax
  je endloop
  incl -4(%rbp)
  call getchar
  jmp loop
endloop:
  movq $format, %rdi
  movl -4(%rbp), %esi
  movl $0, %eax
  call printf
  movl $0, %eax
  movq %rbp, %rsp
  popq %rbp
  ret
```

- Assembly language
- Missing definitions of getchar() and printf()
Assembling “charcount”

Command to assemble:
• gcc217 –c charcount.s

Assembler functionality
• Translate from assembly language to machine language
Assembling “charcount”

The result:

`charcount.o`

- Machine language version of the program
- No longer human readable
- Machine language
- Missing definitions of `getchar()` and `printf()`
Linking “charcount”

Command to link:

• gcc217 charcount.o -o charcount

Linker functionality

• Resolve references
• Fetch machine language code from the standard C library (/usr/lib/libc.a) to make the program complete
The result:

charcount

- Machine language
- Contains definitions of getchar() and printf()

Complete! Executable!
Running “charcount”

Command to run:

• ./charcount < somefile
Running “charcount”

Run-time trace, referencing the original C code…

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != EOF)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```

Computer allocates space for `c` and `charCount` in the stack section of memory.

Why `int` instead of `char`?
Running “charcount”

Run-time trace, referencing the original C code...

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
chars in stdin. Return 0. */
int main(void)
{
  int c;
  int charCount = 0;
  c = getchar();
  while (c != EOF)
  {
    charCount++;
    c = getchar();
  }
  printf("%d\n", charCount);
  return 0;
}
```

- Computer calls getchar()
- getchar() tries to read char from stdin
  - Success ⇒ returns char (within an int)
  - Failure ⇒ returns EOF

EOF is a special non-char value that getchar()
returns to indicate failure
Running “charcount”

Run-time trace, referencing the original C code…

charcount.c

```c
#include <stdio.h>

/* Write to stdout the number of chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != EOF)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```

Assuming `c ≠ EOF`, computer increments `charCount`
Running “charcount”

Run-time trace, referencing the original C code…

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{
    int c;
    int charCount = 0;
    c = getchar();
    while (c != EOF)
    {
        charCount++;
        c = getchar();
    }
    printf("%d\n", charCount);
    return 0;
}
```

Computer calls getchar() again, and repeats
Running “charcount”

Run-time trace, referencing the original C code...

charcount.c

```c
#include <stdio.h>
/* Write to stdout the number of chars in stdin. Return 0. */
int main(void)
{  int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF)
   {  charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

- Eventually `getchar()` returns EOF
- Computer breaks out of loop
- Computer calls `printf()` to write `charCount`
Running “charcount”

Run-time trace, referencing the original C code...

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void)
{
  int c;
  int charCount = 0;
  c = getchar();
  while (c != EOF)
  {
    charCount++;
    c = getchar();
  }
  printf("%d\n", charCount);
  return 0;
}
```

- Computer executes return stmt
- Return from main() terminates program

Normal execution ⇒ return 0 or EXIT_SUCCESS
Abnormal execution ⇒ return EXIT_FAILURE
Other Ways to “charcount”

1. `for (c=getchar(); c!=EOF; c=getchar())
   charCount++;`

2. `while ((c=getchar())!=EOF)
   charCount++;`

3. `for (;;) {
   c = getchar();
   if (c == EOF)
      break;
   charCount++;`

4. `c = getchar();
   while (c!=EOF)
      { charCount++;
      c = getchar();
      }`

Which way is best?
Review of Example 1

Input/Output
- Including `stdio.h`
- Functions `getchar()` and `printf()`
- Representation of a character as an integer
- Predefined constant `EOF`

Program control flow
- The `for` and `while` statements
- The `break` statement
- The `return` statement

Operators
- Assignment: `=`
- Increment: `++`
- Relational: `==` `!=`
Agenda

The charcount program

The upper program

The upper1 program
Example 2: “upper”

Functionality
- Read all chars from stdin
- Convert each lower case alphabetic char to upper case
  - Leave other kinds of chars alone
- Write result to stdout

stdin
Does this work?
It seems to work.

upper

stdout
DOES THIS WORK?
IT SEEMS TO WORK.
```
$ gcc217 upper.c -o upper
$ cat somefile
Does this work?
It seems to work.
$ ./upper < somefile
DOES THIS WORK?
IT SEEMS TO WORK.
$
```
American Standard Code for Information Interchange

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Partial map

Note: Lower case and upper case letters are 32 apart
#include <stdio.h>
int main(void)
{
    int c;
    while ((c = getchar()) != EOF)
    {
        if ((c >= 97) && (c <= 122))
        {
            c -= 32;
            putchar(c);
        }
        return 0;
    }
}
### Extended Binary Coded Decimal Interchange Code

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</table>

**Note:** Lower case not contiguous; same for upper case.
## Character Literals

### Examples

<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
<th>ASCII Systems</th>
<th>EBCDIC Systems</th>
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<tbody>
<tr>
<td>'a'</td>
<td>the a character</td>
<td>97</td>
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<td>'''</td>
<td>single quote</td>
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<td>125</td>
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<tr>
<td>'\0'</td>
<td>the null character (alias NUL)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
```c
#include <stdio.h>
int main(void)
{
    int c;
    while ((c = getchar()) != EOF)
    {
        if ((c >= 'a') && (c <= 'z'))
        {
            c += 'A' - 'a';
            putchar(c);
        }
        putchar(c);
    }
    return 0;
}
```

What's wrong?

Arithmetic on chars?
NAME

isalnum, isalpha, isascii, isblank, iscntrl, isdigit, isgraph,
islower, isprint, ispunct, isspace, isupper, isxdigit –
character classification routines

SYNOPSIS

#include <ctype.h>
int isalnum(int c);
int isalpha(int c);
int isascii(int c);
int isblank(int c);
int iscntrl(int c);
int isdigit(int c);
int isgraph(int c);
int islower(int c); These functions
int isprint(int c);
int ispunct(int c);
int isspace(int c);
int isupper(int c); check whether c...
int isxdigit(int c); falls into a

These functions check whether c...

fall into a certain character class...
$ man toupper

NAME

toupper, tolower - convert letter to upper or lower case

SYNOPSIS

#include <ctype.h>
int toupper(int c);
int tolower(int c);

DESCRIPTION

toupper() converts the letter c to upper case, if possible.
tolower() converts the letter c to lower case, if possible.

If c is not an unsigned char value, or EOF, the behavior of these functions is undefined.

RETURN VALUE

The value returned is that of the converted letter, or c if the conversion was not possible.
```c
#include <stdio.h>
#include <ctype.h>
int main(void)
{
    int c;
    while ((c = getchar()) != EOF)
    {
        if (islower(c))
            c = toupper(c);
        putchar(c);
    }
    return 0;
}
```

Is the if statement really necessary?
Review of Example 2

Representing characters
• ASCII and EBCDIC character sets
• Character literals (e.g., ‘A’ or ‘a’)

Manipulating characters
• Arithmetic on characters
• Functions such as islower() and toupper()
Agenda

The charcount program
The upper program
The upper1 program
Example 3: “upper1”

Functionality
- Read all chars from stdin
- Capitalize the first letter of each word
  - “cos 217 rocks” ⇒ “Cos 217 Rocks”
- Write result to stdout

stdin

\[ \text{cos 217 rocks} \]
\[ \text{Does this work?} \]
\[ \text{It seems to work.} \]

upper1

stdout

\[ \text{Cos 217 Rocks} \]
\[ \text{Does This Work?} \]
\[ \text{It Seems To Work.} \]
$ gcc217 upper1.c -o upper1
$ cat somefile
cos 217 rocks
Does this work?
It seems to work.
$ ./upper1 < somefile
Cos 217 Rocks
Does This Work?
It Seems To Work.
$
“upper1” Challenge

Problem
• Must remember where you are
• Capitalize “c” in “cos”, but not “o” in “cos” or “c” in “rocks”

Solution
• Maintain some extra information
• “In a word” vs “not in a word”
Deterministic Finite Automaton

Deterministic Finite State Automaton (DFA)

- **States**, one of which is denoted the **start** state
- **Transitions** labeled by chars or char categories
- Optionally, **actions** on transitions
```c
#include <stdio.h>
#include <ctype.h>
int main(void)
{
    int c;
    int state = 0;
    while ((c = getchar()) != EOF)
    {
        switch (state)
        {
        case 0:
            if (isalpha(c))
            {
                putchar(toupper(c)); state = 1; }
            else
            {
                putchar(c); state = 0; } break;
        case 1:
            if (isalpha(c))
            {
                putchar(c); state = 1; }
            else
            {
                putchar(c); state = 0; } break;
        }
    }
    return 0;
}
```

That’s a B. What's wrong?
Problem:
- The program works, but…
- States should have names

Solution:
- Define your own named constants
  - `enum Statetype {NORMAL, INWORD};`
  - Define an enumeration type
- `enum Statetype state;`
  - Define a variable of that type
#include <stdio.h>
#include <ctype.h>
enum Statetype {NORMAL, INWORD};
int main(void)
{
    int c;
    enum Statetype state = NORMAL;
    while ((c = getchar()) != EOF)
    {
        switch (state)
        {
            case NORMAL:
                if (isalpha(c))
                {
                    putchar(toupper(c)); state = INWORD;
                }
                else
                {
                    putchar(c); state = NORMAL;
                }
                break;
            case INWORD:
                if (isalpha(c))
                {
                    putchar(c); state = INWORD;
                }
                else
                {
                    putchar(c); state = NORMAL;
                }
                break;
        }
    }
    return 0;
}
“upper1” Toward Version 3

Problem:
- The program works, but…
- Deeply nested statements
- No modularity

Solution:
- Handle each state in a separate function
```
#include <stdio.h>
#include <ctype.h>
enum Statetype {NORMAL, INWORD};

enum Statetype handleNormalState(int c)
{
    enum Statetype state;
    if (isalpha(c))
    {
        putchar(toupper(c));
        state = INWORD;
    }
    else
    {
        putchar(c);
        state = NORMAL;
    }
    return state;
}

enum Statetype handleInwordState(int c)
{
    enum Statetype state;
    if (!isalpha(c))
    {
        putchar(c);
        state = NORMAL;
    }
    else
    {
        putchar(c);
        state = INWORD;
    }
    return state;
}

int main(void)
{
    int c;
    enum Statetype state = NORMAL;
    while ((c = getchar()) != EOF)
    {
        switch (state)
        {
            case NORMAL:
            {
                state = handleNormalState(c);
                break;
            }
            case INWORD:
            {
                state = handleInwordState(c);
                break;
            }
        }
        return 0;
    }
}
```

That's an A-. What's wrong?
Problem:
  • The program works, but…
  • No comments

Solution:
  • Add (at least) function-level comments
Function Comments

Function comment should describe

*what the function does* (from the caller’s viewpoint)

- Input to the function
  - Parameters, input streams
- Output from the function
  - Return value, output streams, (call-by-reference parameters)

Function comment should not describe

*how the function works*
Function Comment Examples

**Bad main() function comment**

```
Read a character from stdin. Depending upon the current DFA state, pass the character to an appropriate state-handling function. The value returned by the state-handling function is the next DFA state. Repeat until end-of-file.
```

- Describes **how the function works**

**Good main() function comment**

```
Read text from stdin. Convert the first character of each "word" to uppercase, where a word is a sequence of letters. Write the result to stdout. Return 0.
```

- Describes **what the function does** from caller’s viewpoint
/*------------------------------------------------------------*/
/* upper1.c                                                   */
/* Author: Bob Dondero                                        */
/*------------------------------------------------------------*/

#include <stdio.h>
#include <ctype.h>

enum Statetype {NORMAL, INWORD};
/* Implement the NORMAL state of the DFA. c is the current DFA character. Write c or its uppercase equivalent to stdout, as specified by the DFA. Return the next state. */

enum Statetype handleNormalState(int c)
{
    enum Statetype state;
    if (isalpha(c))
    {
        putchar(toupper(c));
        state = INWORD;
    }
    else
    {
        putchar(c);
        state = NORMAL;
    }
    return state;
}
/* Implement the INWORD state of the DFA. c is the current DFA character. Write c to stdout, as specified by the DFA. Return the next state. */

enum Statetype handleInwordState(int c)
{
    enum Statetype state;
    if (!isalpha(c))
    {
        putchar(c);
        state = NORMAL;
    }
    else
    {
        putchar(c);
        state = INWORD;
    }
    return state;
}
int main(void)
{
  int c;
  /* Use a DFA approach. state indicates the DFA state. */
  enum Statetype state = NORMAL;
  while ((c = getchar()) != EOF)
  {
    switch (state)
    {
    case NORMAL:
    {
      state = handleNormalState(c);
      break;
    }
    case INWORD:
    {
      state = handleInwordState(c);
      break;
    }
    }

    return 0;
  }
}
Review of Example 3

Deterministic finite-state automaton

- Two or more states
- Transitions between states
  - Next state is a function of current state and current character
  - Actions can occur during transitions

Expectations for COS 217 assignments

- Readable
  - Meaningful names for variables and literals
  - Reasonable max nesting depth
- Modular
  - Multiple functions, each of which does one well-defined job
- Function-level comments
  - Should describe what function does
- See K&P book for style guidelines specification
Summary

The C programming language
- Overall program structure
- Control statements (if, while, for, and switch)
- Character I/O functions (getchar() and putchar())

Deterministic finite state automata (DFA)

Expectations for programming assignments
- Especially Assignment 1

Start Assignment 1 soon!
Appendix:
Additional DFA Examples
Another DFA Example

Does the string have “nano” in it?
- “banano” ⇒ yes
- “nnnnnnnanoff” ⇒ yes
- “banananonano” ⇒ yes
- “banananananashanana” ⇒ no

Double circle is accepting state
Single circle is rejecting state
Old Exam Question
Compose a DFA to identify whether or not a string is a floating-point literal

Valid literals
- “-34”
- “78.1”
- “+298.3”
- “-34.7e-1”
- “34.7E-1”
- “7.”
- “.7”
- “999.99e99”

Invalid literals
- “abc”
- “-e9”
- “1e”
- “+”
- “17.9A”
- “0.38+”
- “.”
- “38.38f9”