



## 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

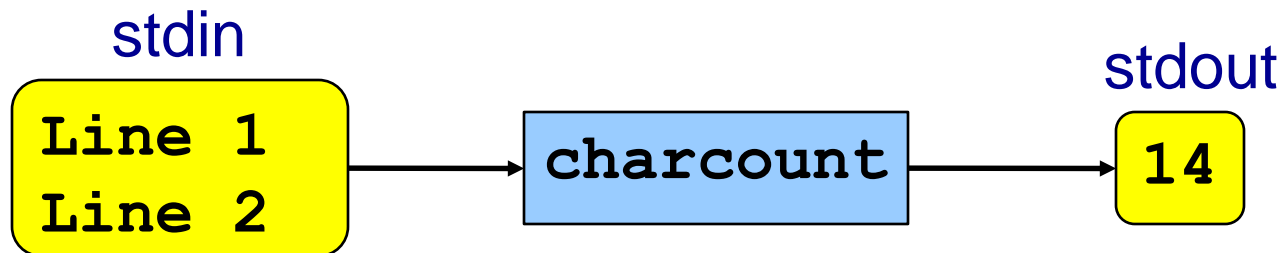
The upper1 program

# 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

```
#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;
}
```

# “charcount” Building and Running



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

What is this?  
What is the effect?

# “charcount” Building and Running



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

What is this?  
What is the effect?

# “charcount” Building and Running



```
$ ./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

# “charcount” Building and Running in Detail



## The starting point

### charcount.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

```
#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

# Preprocessing “charcount”



## charcount.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

# Preprocessing “charcount”



## The result

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;
}
```

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

```
...
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

```
.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

# Linking “charcount”



The result:

charcount

**Machine language  
version of the  
program**

**No longer human  
readable**

- 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

```
#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

```
#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  $\Rightarrow$  returns char (within an int)
  - Failure  $\Rightarrow$  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

```
#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  $c \neq \text{EOF}$ ,  
computer increments  
charCount

# Running “charcount”



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

## charcount.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

```
#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...

## charcount.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 executes return stmt
- Return from main() terminates program

Normal execution  $\Rightarrow$  return 0 or **EXIT\_SUCCESS**  
Abnormal execution  $\Rightarrow$  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();
}`



# 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

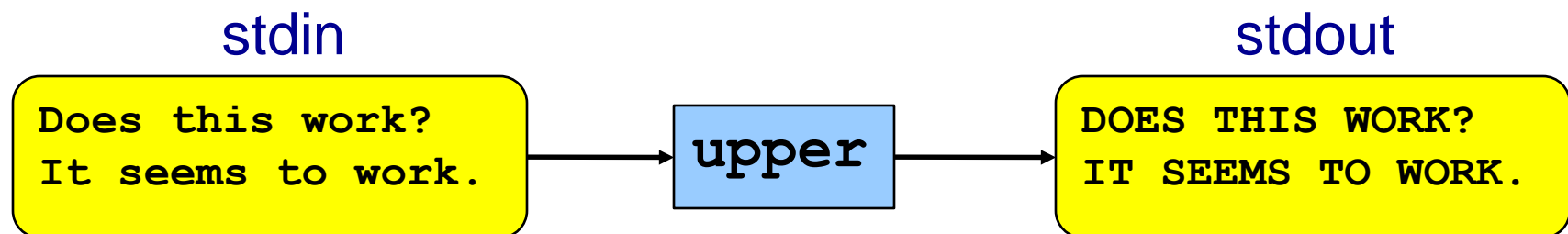




# Example 2: “upper”

## 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



# “upper” Building and Running



```
$ gcc217 upper.c -o upper
```

```
$ cat somefile
```

Does this work?

It seems to work.

```
$ ./upper < somefile
```

DOES THIS WORK?

IT SEEMS TO WORK.

```
$
```

# ASCII



## American Standard Code for Information Interchange

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL								HT	LF						
16																
32	SP	!	"	#	\$	%	&	'	(	)	*	+	,	-	.	/
48	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
64	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
80	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
96	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
112	p	q	r	s	t	u	v	w	x	y	z	{		}	~	

Partial map

Note: Lower case and upper case letters are 32 apart

# “upper” Version 1



```
#include <stdio.h>
int main(void)
{  int c;
   while ((c = getchar()) != EOF)
   {  if ((c >= 97) && (c <= 122))
      c -= 32;
      putchar(c);
   }
   return 0;
}
```

What's wrong?

# EBCDIC



## Extended Binary Coded Decimal Interchange Code

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL					HT										
16																
32						LF										
48																
64	SP											.	<	(	+	
80	&										!	\$	*	)	;	
96	-	/										,	%	_	>	?
112										`	:	#	@	'	=	"
128		a	b	c	d	e	f	g	h	i		{				
144		j	k	l	m	n	o	p	q	r		}				
160		~	s	t	u	v	w	x	y	z						
176																
192		A	B	C	D	E	F	G	H	I						
208		J	K	L	M	N	O	P	Q	R						
224	\		S	T	U	V	W	X	Y	Z						
240	0	1	2	3	4	5	6	7	8	9						

Partial map

Note: Lower case not contiguous; same for upper case

# Character Literals



## Examples

<code>'a'</code>	the a character 97 on ASCII systems 129 on EBCDIC systems
<code>'\n'</code>	newline 10 on ASCII systems 37 on EBCDIC systems
<code>'\t'</code>	horizontal tab 9 on ASCII systems 5 on EBCDIC systems
<code>'\\'</code>	backslash 92 on ASCII systems 224 on EBCDIC systems
<code>'\''</code>	single quote 39 on ASCII systems 125 on EBCDIC systems
<code>'\0'</code>	the null character (alias NUL) 0 on all systems

# “upper” Version 2



```
#include <stdio.h>
int main(void)
{  int c;
   while ((c = getchar()) != EOF)
   {  if ((c >= 'a') && (c <= 'z'))
       c += 'A' - 'a';
       putchar(c);
   }
   return 0;
}
```

Arithmetic  
on chars?

What's wrong?

# ctype.h Functions



```
$ man islower
```

## 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);
int isprint(int c);
int ispunct(int c);
int isspace(int c);
int isupper(int c);
int isxdigit(int c);
```

These functions check whether `c...` falls into a certain character class...



# ctype.h Functions



```
$ 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.

# “upper” Final Version



```
#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



# “upper1” Building and Running



```
$ 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”

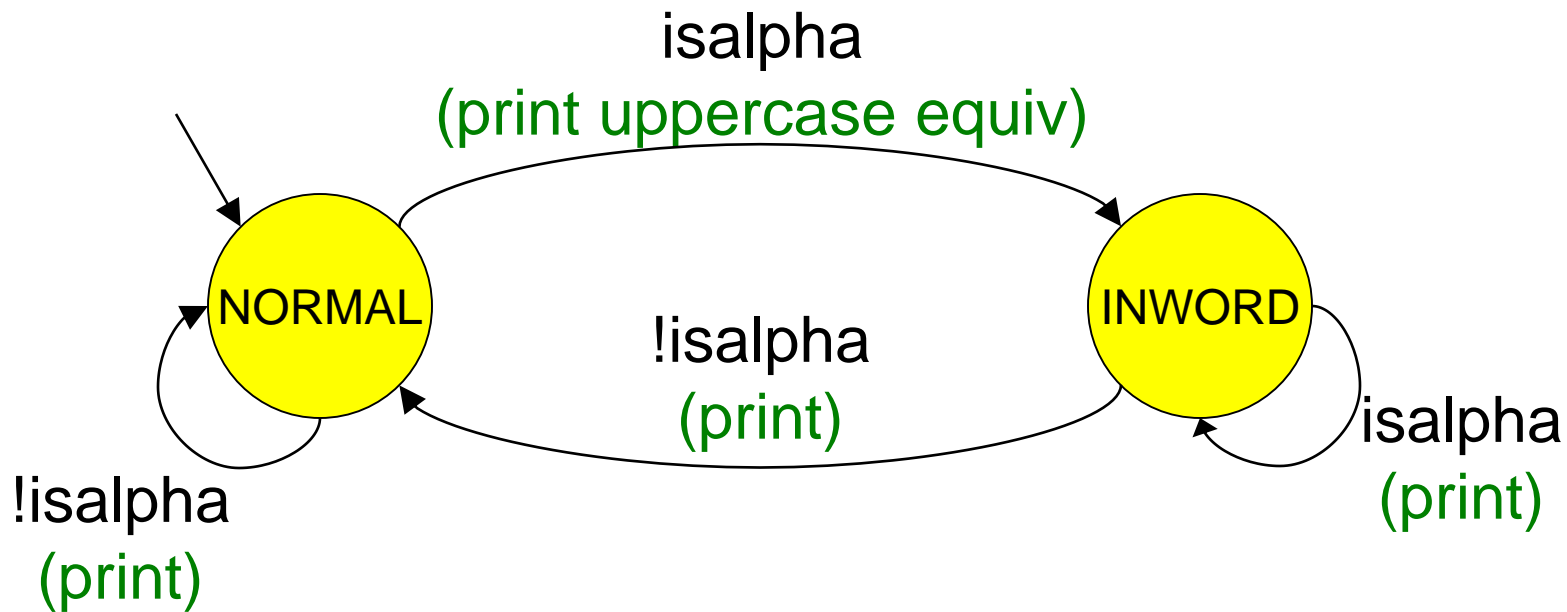
## Solution

- Maintain some extra information
- “In a word” vs “not in a word”



# Deterministic Finite Automaton

## Deterministic Finite State Automaton (DFA)



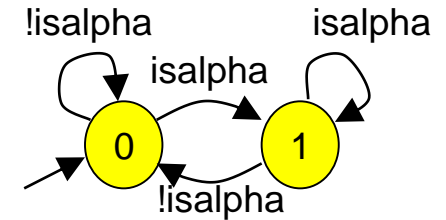
- **States**, one of which is denoted the **start** state
- **Transitions** labeled by chars or char categories
- Optionally, **actions** on transitions



# “upper1” Version 1



```
#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?

# “upper1” Toward Version 2



## 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

# “upper1” Version 2



```
#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;
}
```

That's a B+.  
What's wrong?

# “upper1” Toward Version 3



## Problem:

- The program works, but...
- Deeply nested statements
- No modularity

## Solution:

- Handle each state in a separate function

# “upper1” Version 3



```
#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?

# “upper1” Toward Final Version



## 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” Final Version



```
/*-----*/  
/* upper1.c */  
/* Author: Bob Dondero */  
/*-----*/  
  
#include <stdio.h>  
#include <ctype.h>  
  
enum Statetype {NORMAL, INWORD};
```

Continued on  
next page

# “upper1” Final Version



```
/*-----*/  
  
/* 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;  
}
```

Continued on  
next page

# “upper1” Final Version



```
/*-----*/  
  
/* 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;  
}
```

Continued on  
next page

# “upper1” Final Version



```
/*-----*/

/* 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. */

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



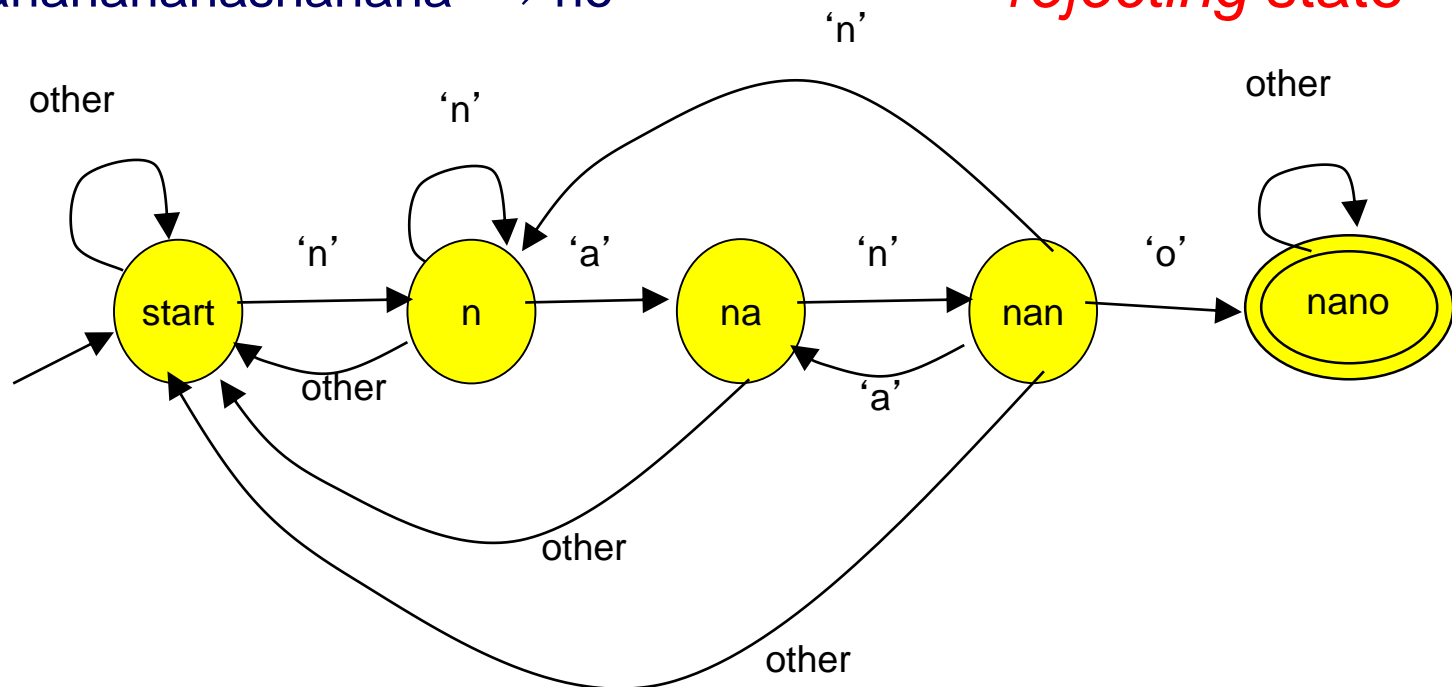
# Another DFA Example

Does the string have “nano” in it?

- “banano”  $\Rightarrow$  yes
- “nnnnnnnanoff”  $\Rightarrow$  yes
- “banananonano”  $\Rightarrow$  yes
- “bananananashanana”  $\Rightarrow$  no

Double circle is *accepting state*

Single circle is *rejecting state*







# Yet Another DFA Example

## 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”