# C Programming Examples



## Goals of this Lecture

- Help you learn about:
  - The fundamentals of C
    - Program structure, control statements, character I/O
  - Deterministic finite state automata (DFA)
  - Some expectations for programming assignments
- Why?
  - The fundamentals of C provide a foundation for the systematic coverage of C that will follow
  - A power programmer knows the fundamentals of C well
  - DFA are useful in many contexts
    - A very important context: Assignment 1
- How?
  - Through some examples



## Overview of this Lecture

- C programming examples
  - Echo input to output
  - Convert all lowercase letters to uppercase
  - Convert first letter of each word to uppercase
- Glossing over some details related to "pointers"
  - … which will be covered subsequently in the course



## Example #1: Echo

- Problem: Echo input directly to output
- Program design
  - Include the Standard Input/Output header file (stdio.h)

```
#include <stdio.h>
```

    - Allows your program to use standard I/O calls
    - Makes declarations of I/O functions available to compiler
    - Allows compiler to check your calls of I/O functions
  - Define main() function

```
int main(void) { … }
int main(int argc, char *argv[]) { … }
```

    - Starting point of the program, a standard boilerplate
    - Hand-waving: `argc` and `argv` are for input arguments

## Example #1: Echo (cont.)

- Within the main program
  - Read a single character
    `c = getchar();`
    - Read a single character from the "standard input stream" (stdin) and return it
  - Write a single character
    `putchar(c);`
    - Write a single character to the "standard output stream" (stdout)

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## Putting it All Together

```
#include <stdio.h>

int main(void) {
   int c;

   c = getchar();
   putchar(c);

   return 0;
}
```

Why **int** instead of **char**?

Why return a value?

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## Read and Write Ten Characters

- Loop to repeat a set of lines (e.g., `for` loop)
  - Three expressions: initialization, condition, and increment
  - E.g., start at 0, test for less than 10, and increment per iteration

```
#include <stdio.h>
int main(void) {
  int c, i;

  for (i=0; i<10; i++) {
    c = getchar();
    putchar(c);
  }

  return 0;
}
```

Why not this instead:
**for (i = 1; i <= 10; i++)**

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## Read and Write Forever

- Infinite `for` loop
  - Simply leave the expressions blank
  - E.g., `for ( ; ; )`
  - No initial value, no per-iteration test, no increment at end of iteration

```
#include <stdio.h>
int main(void) {
  int c;

  for ( ; ; ) {
    c = getchar();
    putchar(c);
  }

  return 0;
}
```

When will this be executed?

How would you terminate this program?

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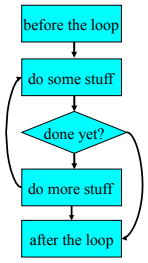
## Read and Write Until End-Of-File

- Test for end-of-file
  - `EOF` is a global constant, defined in stdio.h
  - The `break` statement jumps out of the innermost enclosing loop

```
#include <stdio.h>
int main(void) {
  int c;
  for ( ; ; ) {
     c = getchar();
     if (c == EOF)
        break;
     putchar(c);
  }
  return 0;
}
```






## Many Ways to Do the Same Job

```
for (c=getchar(); c!=EOF; c=getchar())
  putchar(c);
```

Which approach is best?

```
while ((c=getchar())!=EOF)
  putchar(c);
```

← Typical idiom in C, but messy side-effect in loop test

```
for (;;)  {
 c = getchar();
 if (c == EOF)
   break;
 putchar(c);
}
```

```
c = getchar();
while (c!= EOF){
  putchar(c);
  c = getchar();
}
```



## Review of Example #1

- Character I/O
  - Including `stdio.h`
  - Functions `getchar()` and `putchar()`
  - 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 operator: `=`
  - Increment operator: `++`
  - Relational operator to compare for equality: `==`
  - Relational operator to compare for inequality: `!=`



## Example #2: Convert Uppercase

- Problem: Write a program to convert a file to all uppercase
  - Leave non-alphabetic characters alone
- Program design:

```
repeat in a loop
    Read a character
    If unsuccessful, break out of loop
    If the character is lower-case, convert to upper-
case
    Write the character
```

## 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 | SOH | STX | ETX | EOT | ENQ | ACK | BEL | BS | HT | LF | VT | FF | CR | SO | SI |
| 16 | DLE | DC1 | DC2 | DC3 | DC4 | NAK | SYN | ETB | CAN | EM | SUB | ESC | FS | GS | RS | US |
| 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 | { | \| | } | ~ | DEL |

Lower case: 97-122 and upper case: 65-90
E.g., 'a' is 97 and 'A' is 65 (i.e., 32 apart)

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## Implementation in C

```
#include <stdio.h>
int main(void) {
   int c;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      if ((c >= 97) && (c < 123))
         c -= 32;
      putchar(c);
   }
   return 0;
}
```

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## It works!

- Submit
- Receive your grade with quiet confidence

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## It's a …

B-

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## What? But it works …

- A good program is:
  - Clean
  - Readable
  - Maintainable
- It's not enough that your program works!
- We take this seriously in COS 217
  - Seriously == It affects your grade substantially



## Avoid Hard-coded Numbers

```
#include <stdio.h>
int main(void) {
   int c;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      if ((c >= 97) && (c < 123))
         c -= 32;
      putchar(c);
   }
   return 0;
}
```

Ugly.
And works for ASCII only



## Improvement: Character Constants

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

Better.
But still assumes that alphabetic character codes are contiguous



## Improvement: Existing Functions

Standard C Library Functions — ctype(3C) — Section 3C is for C library functions

NAME

ctype, isdigit, isxdigit, islower, isupper, isalpha, isalnum, isspace, iscntrl, ispunct, isprint, isgraph, isascii - character handling

SYNOPSIS

```
#include <ctype.h>
int isalpha(int c);
int isupper(int c);
int islower(int c);
int isdigit(int c);
int isalnum(int c);
int isspace(int c);
int ispunct(int c);
int isprint(int c);
int isgraph(int c);
int iscntrl(int c);
int toupper(int c);
int tolower(int c);
```

DESCRIPTION

These macros classify character-coded integer values. Each is a predicate returning non-zero for true, 0 for false...

The toupper() function has as a domain a type int, the value of which is representable as an unsigned char or the value of EOF.... If the argument of toupper() represents a lower-case letter ... the result is the corresponding upper-case letter. All other arguments in the domain are returned unchanged.

## Using the ctype Functions

```
#include <stdio.h>
#include <ctype.h>
int main(void) {
   int c;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      if (islower(c))
         c = toupper(c);
      putchar(c);
   }
   return 0;
}
```

Returns non-zero (true) iff c is a lowercase character



## Building and Running

```
% ls
upper.c
% gcc217 upper.c -o upper
% ls
upper upper.c
% upper
We'll be on time today!
WE'LL BE ON TIME TODAY!
^D
%
```



## Run the Code on Itself

```
% upper < upper.c
#INCLUDE <STDIO.H>
#INCLUDE <CTYPE.H>
INT MAIN(VOID) {
   INT C;
   FOR ( ; ; ) {
      C = GETCHAR();
      IF (C == EOF) BREAK;
      IF (ISLOWER(C))
         C = TOUPPER(C);
      PUTCHAR(C);
   }
   RETURN 0;
}
```



## Output Redirection

```
% upper < upper.c > junk.c
% gcc217 junk.c -o junk
test.c:1:2: invalid preprocessing directive #INCLUDE
test.c:2:2: invalid preprocessing directive #INCLUDE
test.c:3: syntax error before "MAIN"
etc...
```

## Review of Example #2

- Representing characters
  - ASCII character set
  - Character constants (e.g., 'A' or 'a')
- Manipulating characters
  - Arithmetic on characters
  - Functions like `islower()` and `toupper()`
- Compiling and running C code
  - Compile to generate executable file
  - Invoke executable to run program
  - Can redirect stdin and/or stdout

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## Example #3: Capitalize First Letter

- Capitalize the first letter of each word
  - "cos 217 rocks" → "Cos 217 Rocks"
- Sequence through the string, one letter at a time
  - Print either the character, or the uppercase version
- Challenge: need to remember where you are
  - Capitalize "c" in "cos", but not "o" in "cos" or "c" in "rocks"
- The program should do different things for the same input letter,
  - "c" in "cos" (capitalize) versus "c" in rocks (don't)
  - Depends on "where it is" right now

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## States

- Where am I?
  - I'm inside a word
    - I've seen the first letter of it but not yet the space after it
    - If I see a letter now, I should not capitalize it
  - I'm not inside a word
    - If I see a letter now, I should capitalize it
  - I'm in my car
    - If I get a phone call I shouldn't take it
  - I'm in my room
    - If I get a phone call I can take it
- What am I doing?
  - I'm awake, I'm asleep, …

Program needs a way to keep track of states, and take actions not only based on inputs but also on states

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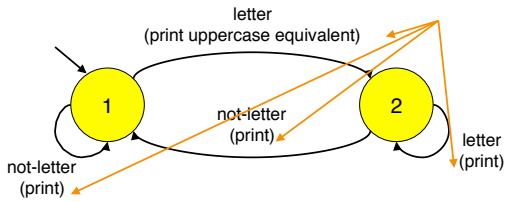
## Deterministic Finite Automaton

Deterministic Finite Automaton (DFA)

- States
  - State 1: I'm not already inside a word
  - State 2: I'm already inside a word
- Inputs: cause state transitions
- (Actions: determined by state+input)

Actions are not part of DFA formalism; but they're helpful

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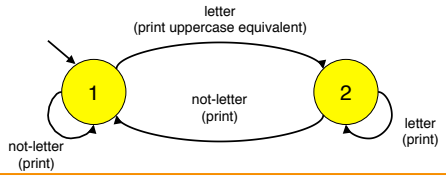
## Implementation Skeleton

```
#include <stdio.h>
#include <ctype.h>
int main (void) {
   int c;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      <process one character>
   }
   return 0;
}
```



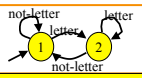
## Implementation Skeleton

- Process one character:
  - Check current state
  - Check input character
  - Based on state and character, check DFA and execute:
    - a transition to new state, or stay in same state
    - the indicated action
    - Note: same input can lead to different actions






## Implementation




```
Process one character:

switch (state) {
   case 1:
      <state 1 input check and action>
      break;
   case 2:
      <state 2 input check and action>
      break;
   default:
      <this should never happen>
}
```

```
if input char is a letter {
   print uppercase (since
first letter of new word);
   move to state 2 (in word);
}
otherwise print char as is;
```

```
if input not a letter
   change state to 1 (not in
word);
in any case, print char as is;
```



## Complete Implementation

```
#include <stdio.h>
#include <ctype.h>
int main(void) {
   int c; int state=1;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      switch (state) {
         case 1:
            if (isalpha(c)) {
               putchar(toupper(c));
               state = 2;
            } else putchar(c);
            break;
         case 2:
            if (!isalpha(c)) state = 1;
            putchar(c);
            break;
      }
   }
   return 0;
}
```

```
if input char is a letter {
   print uppercase (since
first letter of new word);
   move to state 2 (in word);
}
otherwise print char as is;
```

```
if input is not a letter
   change state to 1 (not
in word);
in any case, print char;
```

## Running Code on Itself

```
% gcc217 upper1.c -o upper1
% upper1 < upper1.c
#Include <Stdio.H>
#Include <Ctype.H>
Int Main(Void) {
   Int C; Int State=1;
   For ( ; ; ) {
      C = Getchar();
      If (C == EOF) Break;
      Switch (State) {
         Case 1:
            If (Isalpha(C)) {
               Putchar(Toupper(C));
               State = 2;
            } Else Putchar(C);
            Break;
         Case 2:
            If (!Isalpha(C)) State = 1;
            Putchar(C);
            Break;
      }
   }
   Return 0;
}
```



## It works!

- Submit
- What did I get? What did I get?



## Your grade

B



## OK, That's a B

- Works correctly, but
  - Mysterious integer constants ("magic numbers")
- What now?
  - States should have names, not just 1, 2

## Improvement: Names for States

- Define your own named constants

```
enum Statetype {NOT_IN_WORD,IN_WORD};
```
- Define an enumeration type

```
enum Statetype state;
```
- Define a variable of that type



## Improvement: Names for States

```
#include <stdio.h>
#include <ctype.h>
enum Statetype {NOT_IN_WORD,IN_WORD};
int main(void) {
   int c; enum Statetype state = NOT_IN_WORD;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      switch (state) {
         case NOT_IN_WORD:
            if (isalpha(c)) {
               putchar(toupper(c));
               state = IN_WORD;
            } else putchar(c);
            break;
         case IN_WORD:
            if (!isalpha(c)) state = NOT_IN_WORD;
            putchar(c);
            break;
      }
   }
   return 0;
}
```



## It still works, no magic constants

- Submit
- Can I have my A+ please? I have a party to go to.



## Ask and you shall not receive …

B+

## Huh?

- Works correctly, but
  - No modularity
- What now?
  - Should handle each state in a separate function
  - Each state handling function does the work for a given state, including reading the input and taking the action
  - It returns the new state, which we will store in the "state" variable for the next iteration of our infinite loop



## Improvement: Modularity

```
#include <stdio.h>
#include <ctype.h>
enum Statetype {NOT_IN_WORD,IN_WORD};
enum Statetype handleNotInwordState(int c) {...}
enum Statetype handleInwordState(int c) {...}
int main(void) {
   int c;
   enum Statetype state = NORMAL;
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      switch (state) {
         case NOT_IN_WORD:
            state = handleNotInwordState(c);
            break;
         case IN_WORD:
            state = handleInwordState(c);
            break;
      }
   }
   return 0;
}
```



## Improvement: Modularity

```
enum Statetype handleNotInwordState(int c) {
   enum Statetype state;
   if (isalpha(c)) {
      putchar(toupper(c));
      state = IN_WORD;
   }
   else {
      putchar(c);
      state = NOT_IN_WORD;
   }
   return state;
}
```



## Improvement: Modularity

```
enum Statetype handleInwordState(int c) {
   enum Statetype state;
   putchar(c);
   if (!isalpha(c))
      state = NOT_IN_WORD;
   else
      state = IN_WORD;
   return state;
}
```

## It's a thing of beauty …

# A-



## Seriously??

- No comments
- Should add (at least) function-level comments



## Function Comments

- A function's comment should:
  - Describe **what the function does**
    - Describe input to the function
      - Parameters, input streams
    - Describe output from the function
      - Return value, output streams, (call-by-reference parameters)
  - **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 point of view

## An "A" Effort

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

enum Statetype {NOT_IN_WORD, IN_WORD};

/*--------------------------------------------------------------*/
/* handleNormalState: Implement the NOT_IN_WORD state of the DFA.  */
/* c is the current DFA character.  Return the next state.      */
/*--------------------------------------------------------------*/
enum Statetype handleNotInwordState(int c) {
   enum Statetype state;
   if (isalpha(c)) {
      putchar(toupper(c));
      state = IN_WORD;
   }
   else {
      putchar(c);
      state = NOT_IN_WORD;
   }
   return state;
}
```



## An "A" Effort

```
/*--------------------------------------------------------------*/
/* handleInwordState: Implement the IN_WORD state of the DFA.  */
/* c is the current DFA character.  Return the next state.      */
/*--------------------------------------------------------------*/
enum Statetype handleInwordState(int c) {
   enum Statetype state;
   putchar(c);
   if (!isalpha(c))
      state = NOT_IN_WORD;
   else
      state = IN_WORD;
   return state;
}
```



## An "A" Effort

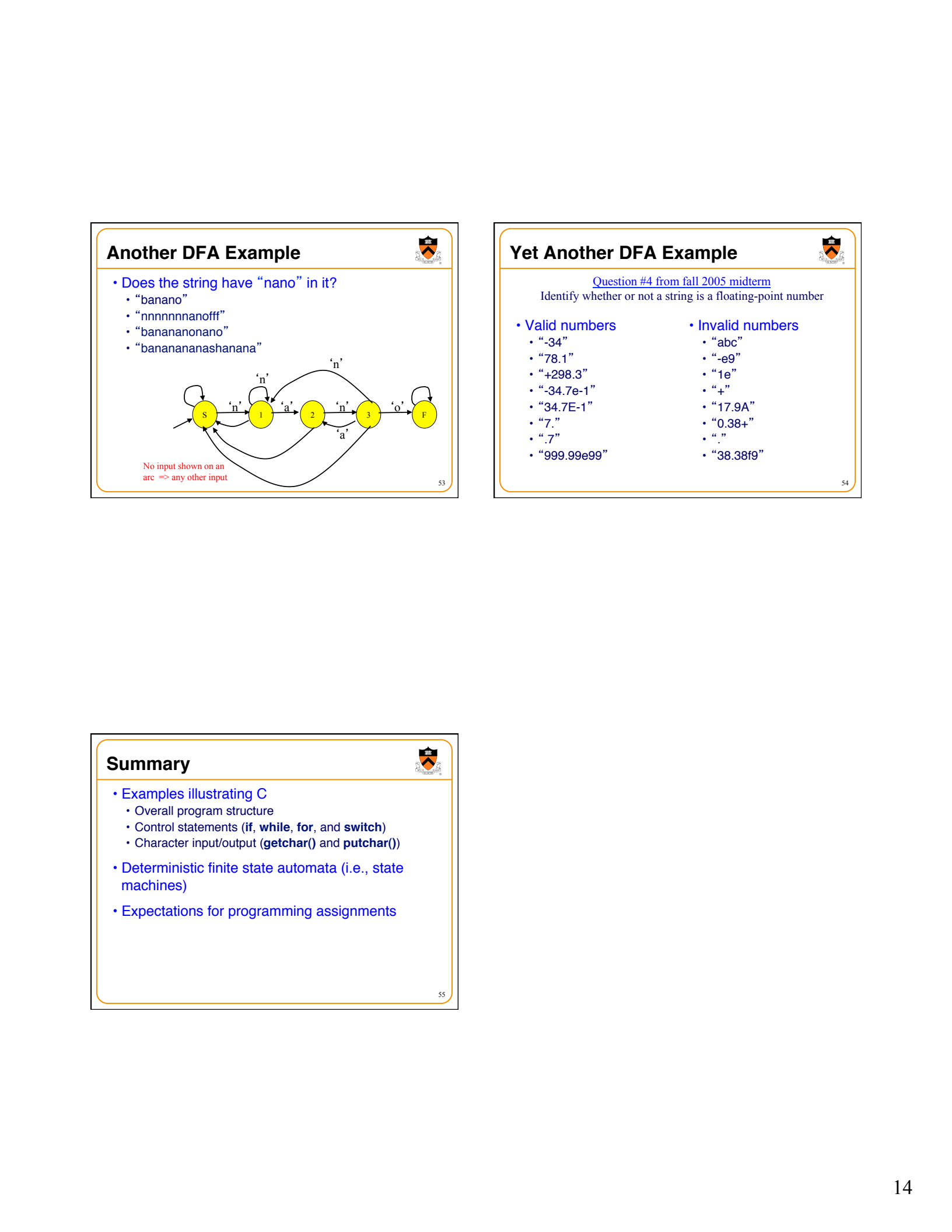
```
/*--------------------------------------------------------------*/
/* main: Read text from stdin. Convert the first character      */
/* of each "word" to uppercase, where a word is a sequence of */
/* letters. Write the result to stdout. Return 0.               */
/*--------------------------------------------------------------*/
int main(void) {
   int c;
   enum Statetype state = NOT_IN_WORD;
   /* Use a DFA approach.  state indicates the state of the DFA. */
   for ( ; ; ) {
      c = getchar();
      if (c == EOF) break;
      switch (state) {
         case NOT_IN_WORD:
            state = handleNotInwordState(c);
            break;
         case IN_WORD:
            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 input
  - Actions can occur during transitions
- Expectations for COS 217 assignments
  - Readable
    - Meaningful names for variables and values
    - qqq is not meaningful. Nor are foo and bar
  - 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

## Another DFA Example



- Does the string have "nano" in it?
  - "banano"
  - "nnnnnnnanofff"
  - "banananonano"
  - "bananananashanana"



No input shown on an arc => any other input



## Yet Another DFA Example



Question #4 from fall 2005 midterm

Identify whether or not a string is a floating-point number

- Valid numbers
  - "-34"
  - "78.1"
  - "+298.3"
  - "-34.7e-1"
  - "34.7E-1"
  - "7."
  - ".7"
  - "999.99e99"
- Invalid numbers
  - "abc"
  - "-e9"
  - "1e"
  - "+"
  - "17.9A"
  - "0.38+"
  - "."
  - "38.38f9"



## Summary



- Examples illustrating C
  - Overall program structure
  - Control statements (**if**, **while**, **for**, and **switch**)
  - Character input/output (**getchar()** and **putchar()**)
- Deterministic finite state automata (i.e., state machines)
- Expectations for programming assignments