



C Programming Examples

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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

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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

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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

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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;
```

Why `int` instead of `char`?

```
    c = getchar();
```

```
    putchar(c);
```

```
    return 0;
```

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?

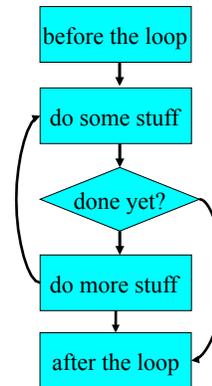
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Read and Write Until End-Of-File



- 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;
}
```



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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();
}
```

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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: `!=`

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Example #2: Convert to 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
```

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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

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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

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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

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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.

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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)) ← Returns non-zero
            c = toupper(c); (true) iff c is a lowercase
        putchar(c);        character
    }
    return 0;
}
```

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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
%
```

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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;
}
```

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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...
```

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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

So far, the action the program takes is based only on the input (the character it reads)

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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 the program 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 receive a phone call I shouldn't take it
 - I'm in my room
=> If I receive 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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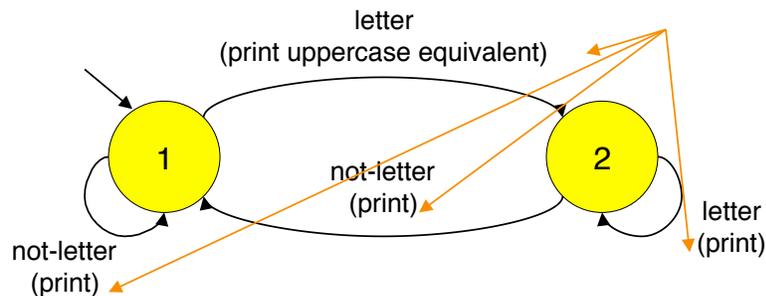
Deterministic Finite Automaton



Deterministic Finite Automaton (DFA)

- States
 - State 1: I'm not 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



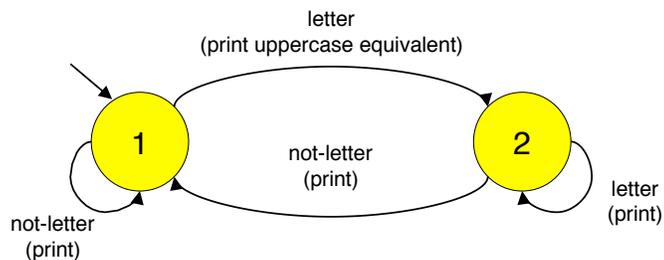
```
#include <stdio.h>
#include <ctype.h>
int main (void) {
    int c;
    for ( ; ; ) {
        c = getchar();
        if (c == EOF) break;
        <process one character>
    }
    return 0;
}
```

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Implementation Skeleton

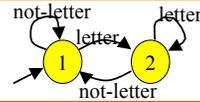


- Process one character:
 - Check current state
 - Check input character
 - Based on state and character, check DFA and execute:
 - a transition to new state, or stay in same state
 - the indicated action
 - Note: same input can lead to different actions



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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;

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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;

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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;
}
```

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It works!



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

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Your grade



B

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OK, That's a B



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

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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

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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;
}
```

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It still works, no magic constants



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

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Ask and you shall not receive ...



B+

40

Huh?



- Works correctly, but
 - No modularity
- Seriously, professor? 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

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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;
}
```

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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;
}
```

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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;
}
```

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It's a thing of beauty ...



A-

45

Seriously?? Lots of -ve ratings for professor



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

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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**

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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

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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;
}
```

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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;
}
```

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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;
}
```

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Review of Example #3



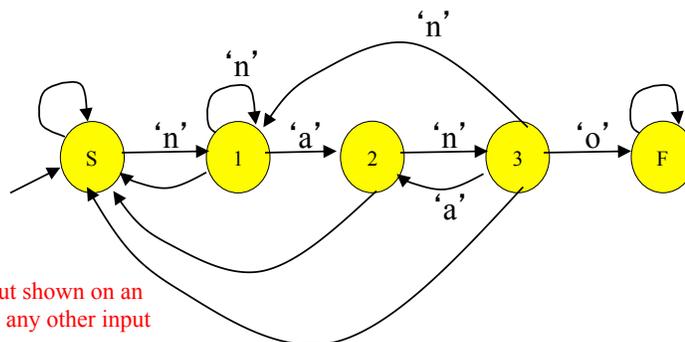
- **Deterministic finite state automaton**
 - Two or more states
 - Transitions between states
 - Next state is a function of current state and current input
 - Actions can occur during transitions
- **Expectations for COS 217 assignments**
 - Readable
 - Meaningful names for variables and values
 - qq 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

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Another DFA Example



- Does the string have “nano” in it?
 - “banano”
 - “nnnnnnnanofff”
 - “banananonano”
 - “banananashanana”



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Yet Another DFA Example



Question #4 from fall 2005 midterm

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

- | | |
|---|---|
| <ul style="list-style-type: none">• Valid numbers<ul style="list-style-type: none">• “-34”• “78.1”• “+298.3”• “-34.7e-1”• “34.7E-1”• “7.”• “.7”• “999.99e99” | <ul style="list-style-type: none">• Invalid numbers<ul style="list-style-type: none">• “abc”• “-e9”• “1e”• “+”• “17.9A”• “0.38+”• “.”• “38.38f9” |
|---|---|

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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