CSE / ENGR 142 Programming I

Iteration

Chapter 5

Read Sections 5.1-5.6, 5.10

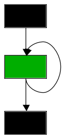
- **5.1 Introduction**
- **5.2-5.3 While statement**
- **5.4 For statement**
- **5.5-5.6 Loop design**
- **5.7 Nested Loops**
- **5.8 Do-while and flag-controlled loops**
- **5.11 Common errors**

What's "Wrong" with Fahrenheit/Celsius Program?

- User has to rerun the program for every new temperature
  - Wouldn't it be nice if the program could process repeated requests?
- Program ends immediately if user types a bad input
  - Wouldn't it be nice the program politely asked the user again (and again, etc. if necessary)?

One More Type of Control Flow

Sometimes we want to repeat a block of code. This is called a *loop*.



Loops

- A "loop" is a repeated ("iterated") sequence of statements
- Like conditionals, loops (iteration) will give us a huge increase in the power of our programs
- Alert: loops are harder to master than *if* statements
  - Even experienced programmers often make subtle errors when writing loops

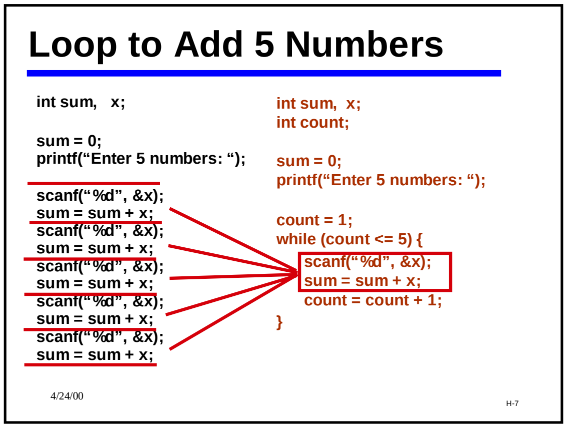
Motivating Loops

Problem: add 5 numbers entered at the keyboard.
Here's a solution:

```
int sum;
int x1, x2, x3, x4, x5;

printf("Enter 5 numbers: ");
scanf("%d%d%d%d%d", &x1, &x2, &x3, &x4, &x5);
sum = x1 + x2 + x3 + x4 + x5;
```

This works perfectly!
But... what if we had 15 numbers? or 50? or 5000?



Loop to Add 5 Numbers

```
int sum,   x;

sum = 0;
printf(“Enter 5 numbers: “);

scanf(“%d”, &x);
sum = sum + x;
scanf(“%d”, &x);
sum = sum + x;
scanf(“%d”, &x);
sum = sum + x;
scanf(“%d”, &x);
sum = sum + x;
scanf(“%d”, &x);
sum = sum + x;
```

```
int sum,  x;
int count;

sum = 0;
printf(“Enter 5 numbers: “);

count = 1;
while (count <= 5) {
    scanf(“%d”, &x);
    sum = sum + x;
    count = count + 1;
}
```

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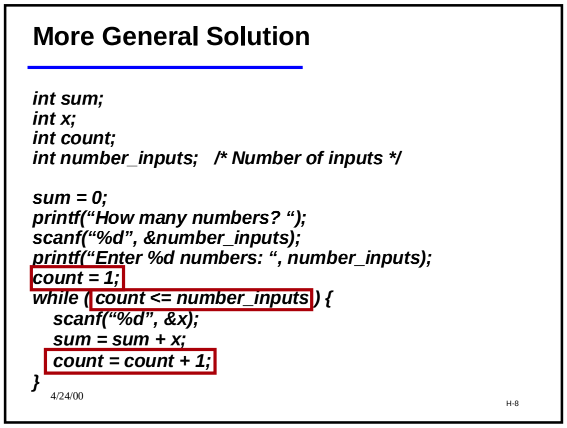

More General Solution

```
int sum;
int x;
int count;
int number_inputs;    /* Number of inputs */

sum = 0;
printf(“How many numbers? “);
scanf(“%d”, &number_inputs);
printf(“Enter %d numbers: “, number_inputs);
count = 1;
while ( count <= number_inputs ) {
   scanf(“%d”, &x);
   sum = sum + x;
   count = count + 1;
}
```

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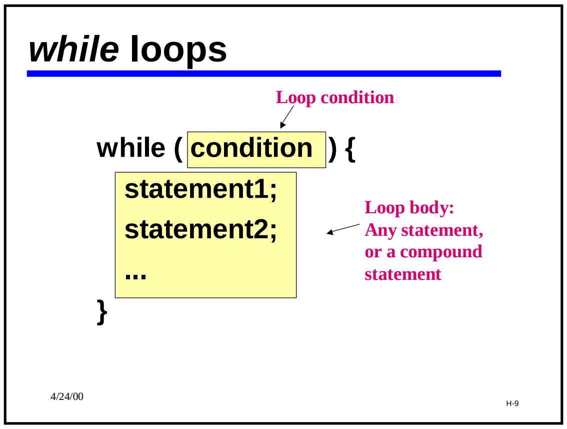

while loops

Loop condition

```
while ( condition ) {
    statement1;
    statement2;
    ...
}
```

Loop body:
Any statement,
or a compound
statement

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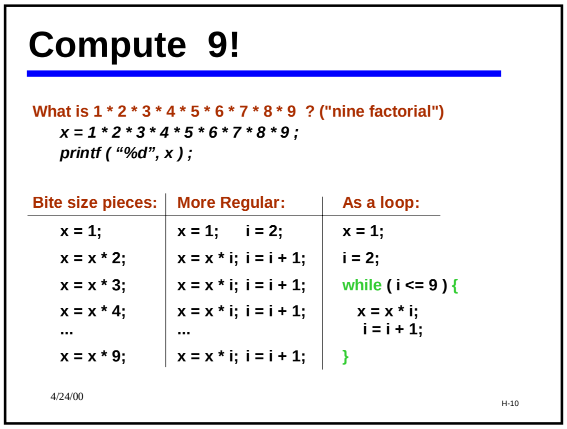

Compute 9!

What is 1 * 2 * 3 * 4 * 5 * 6 * 7 * 8 * 9 ? ("nine factorial")

```
x = 1 * 2 * 3 * 4 * 5 * 6 * 7 * 8 * 9 ;
printf ( “%d”, x ) ;
```

Bite size pieces:	More Regular:	As a loop:
x = 1;	x = 1; i = 2;	x = 1;
x = x * 2;	x = x * i; i = i + 1;	i = 2;
x = x * 3;	x = x * i; i = i + 1;	while (i <= 9) {

x = x * 4;
...
	x = x * i; i = i + 1;
	...
		x = x * i;
		i = i + 1;

x = x * 9;	x = x * i; i = i + 1;	}

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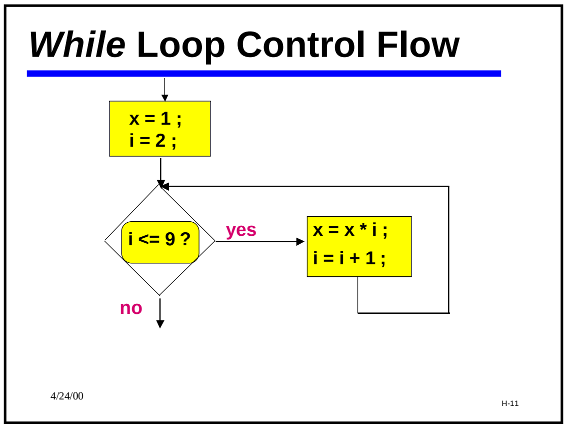

While Loop Control Flow

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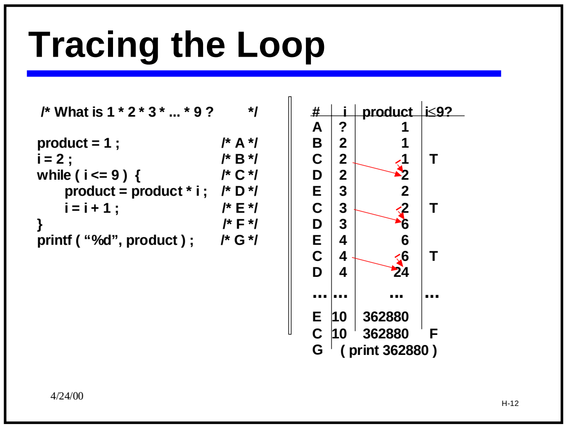

Tracing the Loop

```
/* What is 1 * 2 * 3 * ... * 9 ?          */

product = 1 ;                          /* A */
i = 2 ;                                /* B */
while ( i <= 9 )  {                    /* C */
      product = product * i ;          /* D */
      i = i + 1 ;                      /* E */
}                                      /* F */
printf ( “%d”, product ) ;             /* G */
```

#	i	product	i≤9?
A	?	1	
B	2	1	
C	2	1	T
D	2	2	
E	3	2	
C	3	2	T
D	3	6	
E	4	6	
C	4	6	T
D	4	24	
...	...	...	...
E	10	362880	
C	10	362880	F
G	(print 362880)		

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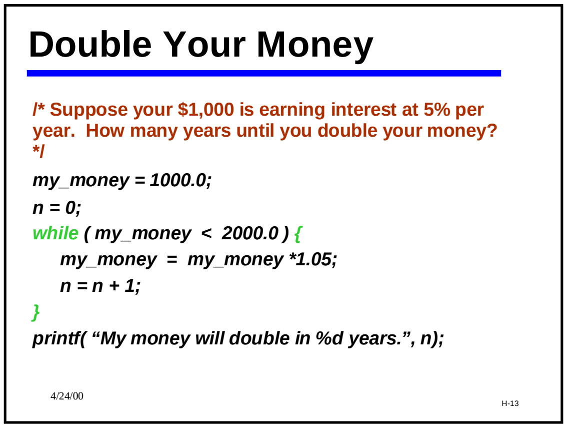

Double Your Money

```
/* Suppose your $1,000 is earning interest at 5% per
year.  How many years until you double your money?
*/
my_money = 1000.0;
n = 0;
while ( my_money  <  2000.0 ) {
    my_money  =  my_money *1.05;
    n = n + 1;
}
printf( “My money will double in %d years.”, n);
```

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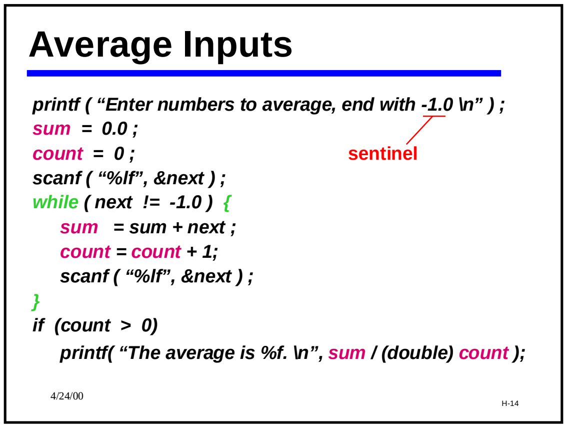

Average Inputs

```
printf ( “Enter numbers to average, end with -1.0 \n” ) ;
sum  =  0.0 ;
count  =  0 ;                                sentinel
scanf ( “%lf”, &next ) ;
while ( next  !=  -1.0 )  {
    sum   = sum + next ;
    count = count + 1;
    scanf ( “%lf”, &next ) ;
}
if  (count  >  0)
    printf( “The average is %f. \n”, sum / (double) count );
```

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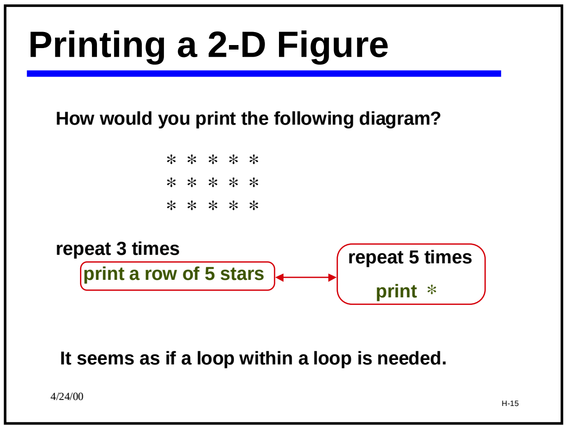

Printing a 2-D Figure

How would you print the following diagram?

```
* * * * *
* * * * *
* * * * *
```

repeat 3 times

print a row of 5 stars

repeat 5 times

print *

It seems as if a loop within a loop is needed.

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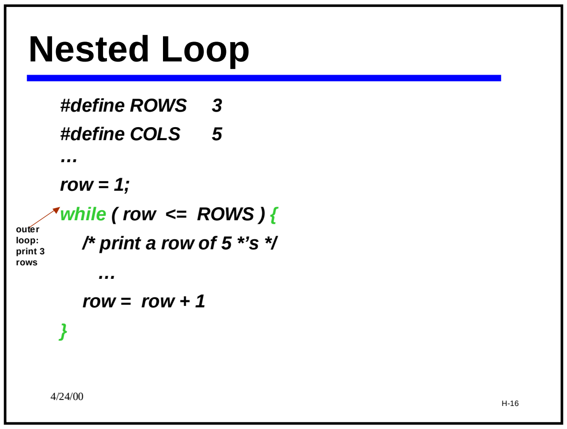

Nested Loop

```
    #define ROWS     3
    #define COLS     5
    …
    row = 1;
    while ( row  <=  ROWS ) {
        /* print a row of 5 *’s */
          …
        row =  row + 1
    }
```

outer loop: print 3 rows

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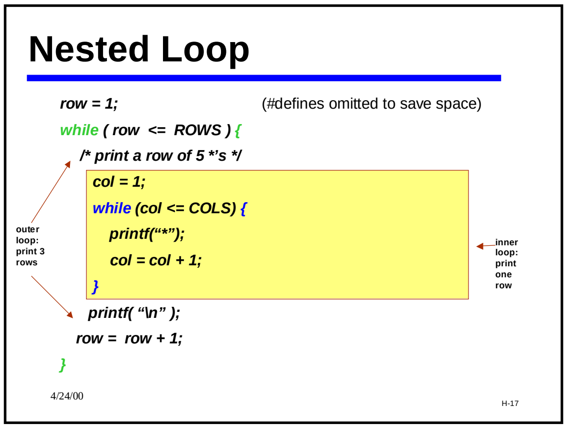

Nested Loop

```
row = 1;                              (#defines omitted to save space)
while ( row  <=  ROWS ) {
    /* print a row of 5 *’s */
     col = 1;
     while (col <= COLS) {
         printf(“*”);
         col = col + 1;
     }
     printf( “\n” );
   row =  row + 1;
}
```

outer loop: print 3 rows

inner loop: print one row

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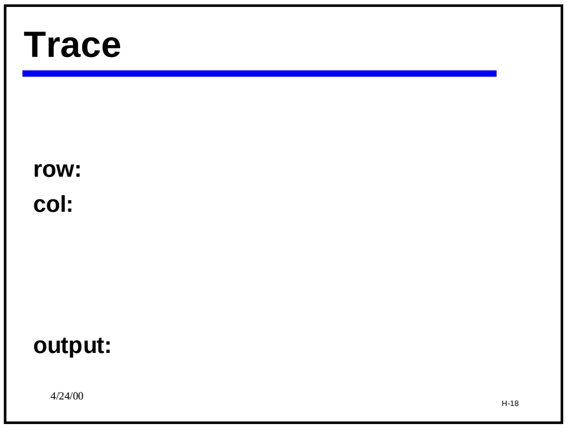

Trace

row:

col:

output:

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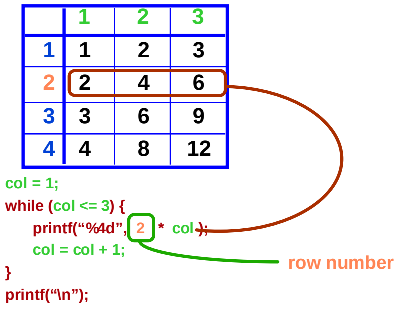
Print a Multiplication Table

	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9
4	4	8	12

	1	2	3
1	1 * 1	1 * 2	1 * 3
2	2 * 1	2 * 2	2 * 3
3	3 * 1	3 * 2	3 * 3
4	4 * 1	4 * 2	4 * 3

Print Row 2

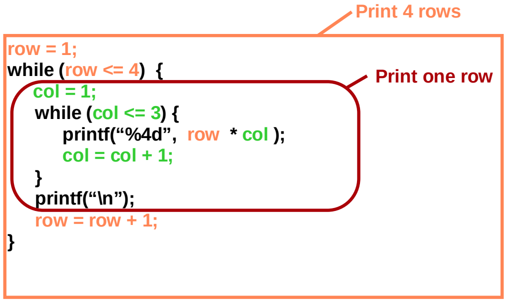


	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9
4	4	8	12

```
col = 1;
while (col <= 3) {
     printf("%4d", 2 *  col );
     col = col + 1;
}
printf("\n");
```

row number

Nested Loops



Print 4 rows

Print one row

```
row = 1;
while (row <= 4)  {
    col = 1;
    while (col <= 3) {
         printf("%4d",  row  * col );
         col = col + 1;
    }
    printf("\n");
    row = row + 1;
}
```

Loop Trace

```
row  col
 1    1     print 1
      2     print 2
      3     print 3
        print \n
 2    1     print 2
      2     print 4
      3     print 6
        print \n
 3    1     print 3
      2     print 6
      3     print 9
        print \n
 4    1     print 4
      2     print 8
      3     print 12
        print \n
```

Loop Trace (Detailed)

```
row  col              statement

 1    ?                1a
 1    ?  (TRUE)        1b
 1    1                2a
 1    1  (TRUE)        2b
 1    1   print 1      3
 1    2                2c
 1    2   (TRUE)       2b
 1    2   print 2      3
 1    3                 2c
 1    3   (TRUE)       2b
 1    3   print 3      3
 1    4                 2c
 1    4   (FALSE)      2b
 1    4    print \n    4
 2    4                1c
 2    4   (TRUE)       1b
 2    1                2a
          • • •
```

Notes About Loop Conditions

- They offer all the same possibilities as conditions in *if*-statements
  - Can use &&, ||, !
- Condition is reevaluated each time through the loop
- A common loop pattern: counting the times through the loop
  - Occurs so often there is a separate statement type based on that pattern: the *for*-statement

for Loops

```
/* What is 1 * 2 * 3 * ... * n ? */

product = 1 ;
i = 2 ;                          /* initialize */
while ( i <= n )  {              /* test */
     product = product * i ;
     i = i+1;                    /* update */
}
printf ( “%d”, product ) ;
```

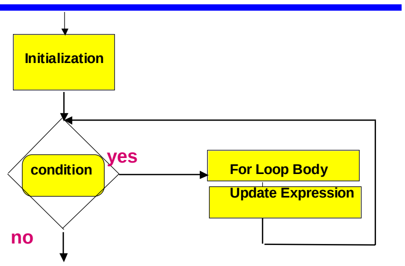
```
product = 1 ;
for ( i = 2 ; i <= n ; i = i+1 ) {
     product = product * i ;
}
printf ( “%d”, product ) ;
```

for Loops Syntax

```
for ( initialization;
      condition;
      update expression ) {
    statement1;
    statement2;
    ...
}
```

“Update” is written at the front of the loop, but executed at the end

for Loop Control Flow



for Loops vs *while* Loops

- Any *for* loop can be written as a *while* loop
- These two loops mean exactly the same thing:

```
for (initialization; condition; update)
        statement;

initialization;
while (condition) {
        statement;
        update;
}
```

- So *for* provides no new capabilities, but the notation is often convenient.

Counting in *for* Loops

```
/* Print n asterisks */
for ( count = 1 ; count <= n ;  count = count + 1 ) {
     printf ( “*” ) ;
}
```

```
/* Different style of counting */
for (  count = 0 ; count < n ;  count = count + 1 ) {
     printf ( “*” );
}
/* could also use count <= n-1 */
```

“3 Rows of 5” as a Nested *for* Loop

```
#define ROWS     3
#define COLS     5
...
for ( row = 1;  row  <=  ROWS ;  row =  row + 1 ) {
   for ( col = 1 ;  col <= COLS ;  col = col + 1 ) {
      printf( “*” );
   }
   printf( “\n” );
}
```

outer loop: print 3 rows

inner loop: print one row

Trace

row:

col:

output:

Yet Another 2-D Figure

How would you print the following diagram?

```
*
* *
* * *
* * * *
* * * * *
```

For every row (row = 1, 2, 3, 4, 5)

Print row stars

Solution: Another Nested Loop

```
#define ROWS 5
...
int  row, col ;
for ( row = 1 ;  row <= ROWS ;  row = row + 1 ) {
    for ( col = 1 ;  col <= row;  col = col + 1) {
        printf( "*" ) ;
    }
    printf( "\n" );
}
```

Trace

row:

col:

output:

Yet One More 2-D Figure

How would you print the following diagram?

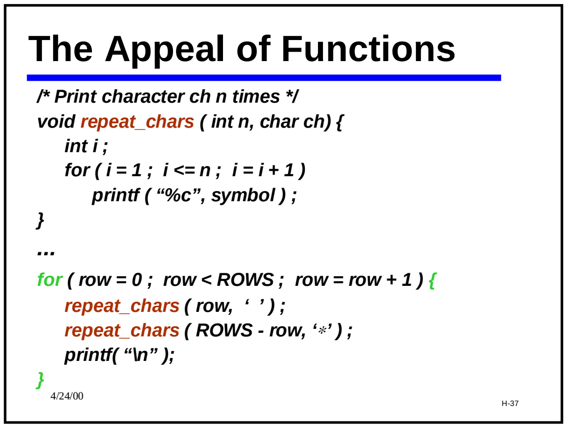
```
* * * * *
  * * * *
    * * *
      * *
        *
```

For every row (row = 0, 1, 2, 3, 4)

Print row spaces followed by (5 - row) stars

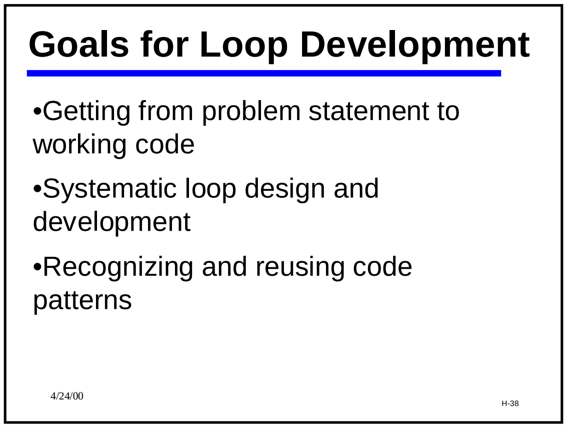
Yet Another Nested Loop

```
#define ROWS 5
...
int  row, col ;
for ( row = 0 ;  row < ROWS ;  row = row + 1 ) {
    for ( col = 1 ;  col <= row ;  col = col + 1)
        printf( "  " ) ;
    for ( col = 1 ;  col <= ROWS – row ;  col = col + 1)
        printf( "*" ) ;
    printf( "\n" );
}
```



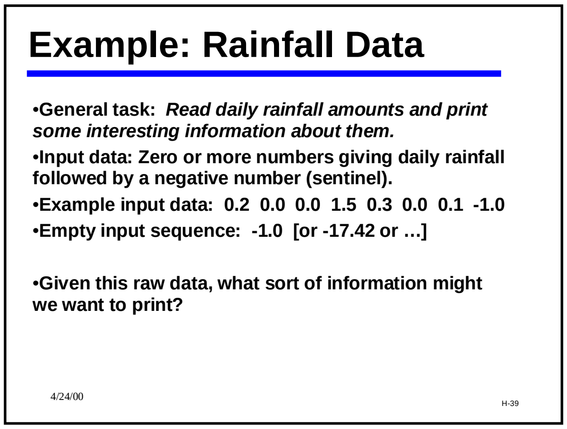
The Appeal of Functions

```
/* Print character ch n times */
void repeat_chars ( int n, char ch) {
     int i ;
     for ( i = 1 ;  i <= n ;  i = i + 1 )
          printf ( “%c”, symbol ) ;
}
...
for ( row = 0 ;  row < ROWS ;  row = row + 1 ) {
     repeat_chars ( row,  ‘  ’ ) ;
     repeat_chars ( ROWS - row, ‘*’ ) ;
     printf( “\n” );
}
```



Goals for Loop Development

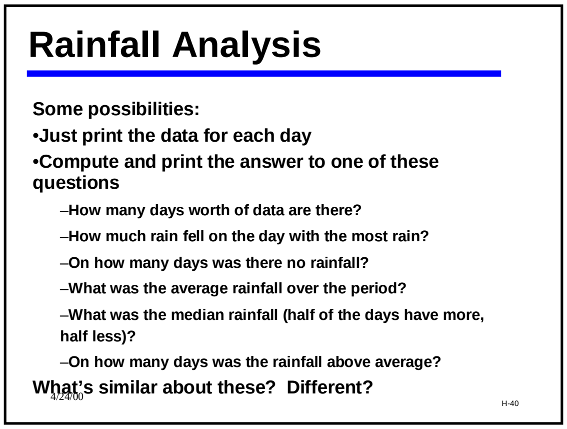
- Getting from problem statement to working code
- Systematic loop design and development
- Recognizing and reusing code patterns



Example: Rainfall Data

- General task: *Read daily rainfall amounts and print some interesting information about them.*
- Input data: Zero or more numbers giving daily rainfall followed by a negative number (sentinel).
- Example input data: 0.2 0.0 0.0 1.5 0.3 0.0 0.1 -1.0
- Empty input sequence: -1.0 [or -17.42 or …]

- Given this raw data, what sort of information might we want to print?

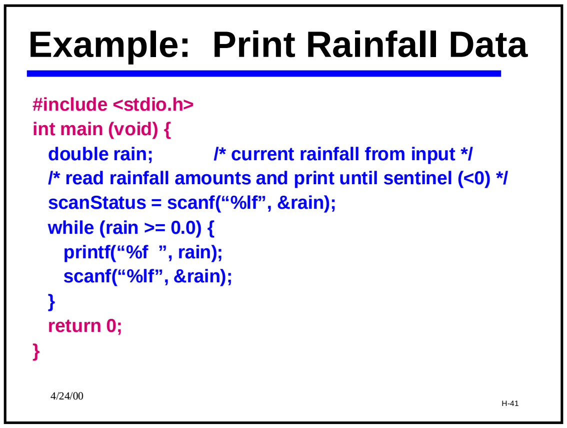


Rainfall Analysis

Some possibilities:

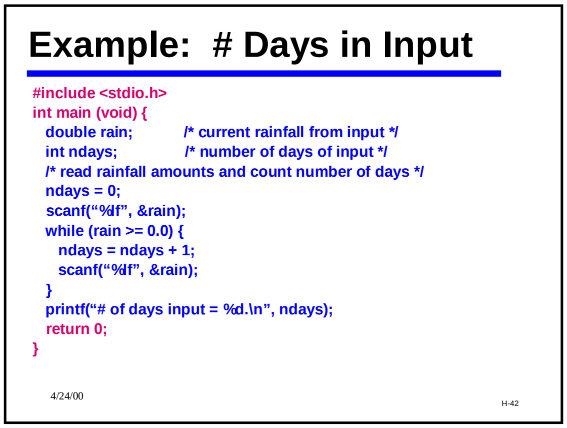
- Just print the data for each day
- Compute and print the answer to one of these questions
  - –How many days worth of data are there?
  - –How much rain fell on the day with the most rain?
  - –On how many days was there no rainfall?
  - –What was the average rainfall over the period?
  - –What was the median rainfall (half of the days have more, half less)?
  - –On how many days was the rainfall above average?

What’s similar about these? Different?



Example: Print Rainfall Data

```
#include <stdio.h>
int main (void) {
   double rain;          /* current rainfall from input */
   /* read rainfall amounts and print until sentinel (<0) */
   scanStatus = scanf(“%lf”, &rain);
   while (rain >= 0.0) {
      printf(“%f  ”, rain);
      scanf(“%lf”, &rain);
   }
   return 0;
}
```



Example: # Days in Input

```
#include <stdio.h>
int main (void) {
   double rain;          /* current rainfall from input */
   int ndays;            /* number of days of input */
   /* read rainfall amounts and count number of days */
   ndays = 0;
   scanf(“%lf”, &rain);
   while (rain >= 0.0) {
      ndays = ndays + 1;
      scanf(“%lf”, &rain);
   }
   printf(“# of days input = %d.\n”, ndays);
   return 0;
}
```

Is There a Pattern Here?

```
#include <stdio.h>
int main (void) {
  double rain;   /* current rainfall */

  /* read rainfall amounts */

  scanf(“%lf”, &rain);
  while (rain >= 0.0) {
    printf(“%f  ”, rain);
    scanf(“%lf”, &rain);
  }

  return 0;
}
```

```
#include <stdio.h>
int main (void) {
  double rain;          /* current rainfall */
  int ndays;            /* # input numbers */
  /* read rainfall amounts */
  ndays = 0;
  scanf(“%lf”, &rain);
  while (rain >= 0.0) {
    ndays = ndays + 1;
    scanf(“%lf”, &rain);
  }
  printf(“# of days input = %d.\n”, ndays);
  return 0;
}
```

Program Schema

- A program schema is a pattern of code that solves a general problem.
- Learn patterns through experience, observation.
- If you encounter a similar problem, reuse the pattern.
- Work the problem by hand to gain insight into possible solutions. Ask yourself “what am I doing?”
- Check your code by hand-tracing on simple test data.

Schema: Read until Sentinel

```
#include <stdio.h>
int main (void) {
  double variable;        /* current input */
  declarations;
  initial;
  scanf(“%lf”, &variable);
  while (variable is not sentinel) {
    process;
    scanf(“%lf”, &variable);
  }
  final;
  return 0;
}
```

Schema Placeholders

- In the schema, *variable*, *declarations*, *sentinel*, *initial*, *process*, and *final* are placeholders.
- *variable* holds the current data from input. It should be replaced each place it occurs with the same appropriately named variable.
- *sentinel* is the value that signals end of input.
- *declarations* are any additional variables needed.
- *initial* is any statements needed to initialize variables before any processing is done.
- *process* is the “processing step” - work done for each input value.
- *final* is any necessary operations needed after all input has been processed.

Schema instance for Rainfall

```
#include <stdio.h>
int main (void) {
  double rain;        /* current rainfall */
  declarations;
  initial;
  scanf(“%lf”, &rain);
  while (rain >= 0.0) {
    process;
    scanf(“%lf”, &rain);
  }
  final;
  return 0;
}
```

Loop Development Tips

Some useful ideas

- Do you know an appropriate schema? Use it!
- Declare variables as you discover you need them.
  - When you create a variable, write a comment describing what’s in it!
- Often helps to start with
  - What has to be done to *process* one more input value?
  - What information is needed for *final*?
- Often easiest to write *initial* last
  - *initial* is “what’s needed so the loop works the 1st time”
  - Often obvious after writing rest of the loop

Print Rainfall Data

```
               #include <stdio.h>
               int main (void) {
                   double rain;        /* current rainfall */
declarations:
      initial:
                   scanf(“%lf”, &rain);
                   while (rain >= 0.0) {
     process:
                       scanf(“%lf”, &rain);
                   }
       final:
                   return 0;
               }
```

Print # Days With No Rain

```
               #include <stdio.h>
               int main (void) {
                   double rain;        /* current rainfall */
declarations:
      initial:
                   scanf(“%lf”, &rain);
                   while (rain >= 0.0) {
     process:
                       scanf(“%lf”, &rain);
                   }
       final:
                   return 0;
               }
```

Print Largest Daily Rainfall

```
               #include <stdio.h>
               int main (void) {
                   double rain;        /* current rainfall */
declarations:
      initial:
                   scanf(“%lf”, &rain);
                   while (rain >= 0.0) {
     process:
                       scanf(“%lf”, &rain);
                   }
       final:
                   return 0;
               }
```

Print Average Daily Rainfall

```
               #include <stdio.h>
               int main (void) {
                   double rain;        /* current rainfall */
declarations:
      initial:
                   scanf(“%lf”, &rain);
                   while (rain >= 0.0) {
     process:
                       scanf(“%lf”, &rain);
                   }
       final:
                   return 0;
               }
```

Print Average Daily Rainfall (2)

```
               #include <stdio.h>
               int main (void) {
                   double rain;        /* current rainfall */
declarations:
      initial:
                   scanf(“%lf”, &rain);
                   while (rain >= 0.0) {
     process:
                       scanf(“%lf”, &rain);
                   }
       final:
                   return 0;
               }
```

Some Loop Pitfalls

```
while ( sum < 10 ) ;      for ( i = 0; i <= 10; i = i + 1) ;
    sum = sum + 2;            sum = sum + i ;
```

```
for ( i = 1;  i != 10 ; i = i + 2 )
    sum = sum + i ;
```

```
double x ;
for ( x = 0.0 ; x < 10.0 ; x = x + 0.2 )
    printf(“%.18f”, x) ;
```

Double Delight

What you expect:	What you might get:
0.000000000000000000	0.000000000000000000
0.200000000000000000	0.200000000000000000
0.400000000000000000	0.400000000000000000
...	...
9.000000000000000000	8.999999999999999997
9.200000000000000000	9.199999999999999996
9.400000000000000000	9.399999999999999996
9.600000000000000000	9.599999999999999996
9.800000000000000000	9.799999999999999996
	9.999999999999999996

Use *ints* as Loop Counters

```
int i ;
double x ;
for ( i = 0 ; i < 50 ; i = i + 1 )
{
    x = (double) i / 5.0 ;
    printf(“%.18f”, x) ;
}
```

Counting in Loops

To "increment:" increase (often by 1)

To "decrement:" decrease (often by 1)

Many loops increment or decrement a loop counter:

```
for ( i = 1 ;  i <= limit ;  i = i+1 ) { . . . }
```

```
times_to_go = limit;
while ( times_to_go > 0 ) {
    • • •
    times_to_go = times_to_go - 1;
}
```

Handy Shorthand

Post-increment (x++), Post-decrement (x--)

Used by itself,

x++ means the same as *x = x+1*

x-- means the same as *x = x-1*

Very often used with loop counters:

```
for ( i=1 ;  i <= limit ;  i++ ) { . . . }
```

```
times_to_go = limit;
while ( times_to_go > 0 ) {
    • • •
    times_to_go-- ;
}
```

Surgeon General’s Warning

- ++ and -- are unary operators.
- Pre-increment (++x) and pre-decrement (--x) exist, too.
- For CSE142, use only in isolation. Don’t combine these with other operators in expressions!

  E.g., don’t try x = y++ / (3 * --x--)

Iteration Summary

- General pattern:
  - initialize
  - test
  - do stuff
  - update
  - go back to re-test, re-do stuff, re-update, ...
- “while” and "for" are equally general in C
- use “for” when initialize/test/update are closely related and simple, especially when counting

Event-Driven Programming

- Modern programs tend to be "event-driven"
  - – Program starts, sets itself up.
  - – Program enters a loop, waiting for some event or command to happen:
    - mouse click, key click, timer, menu selection, etc.
  - – Program performs operation ("handles" the event or command)
  - – Program goes back to its wait loop
- GP142 programs follow this model

Simple Command Interpreter

Repeatedly read in "commands" and handle them.

Input (symbolized by single characters)

a -- execute command A by calling *A_handler( )*

b -- execute command B by calling *B_handler( )*

q -- quit

Pseudocode for main loop:

```
get next command
if a, execute command A
if b, execute command B
if q, signal quit
```

Command Interpreter Loop Control Schema

repeat until quit signal

use variable “done” to indicate when done

```
set done to false
while not done {
    body statements
    if quit command, set done to true
}
```

Command Interpreter main ( )

```
#define FALSE 0
#define TRUE   1

int main(void) {
    char command;
    int done;

    done = FALSE;
    while (! done){
                        /* Input command from user */
        command = ReadCommand( );

        switch (command){
        case ‘A’:
        case ‘a’:
            A_handler();        /* Execute command A */
            break;
        case ‘B’:
        case ‘b’:
            B_handler();        /* Execute command B */
            break;
        case ‘Q’:
        case ‘q’:
            done = TRUE;        /* quit */
            break;
        default:
            printf(“Unrecognized command\n”);
        }
    }
    return 0;
}
```

do ... while

•Sometimes we want a loop to execute its body at least once before checking its condition

–The command interpreter loop is a good example!

•In C, we can do this with a *do ... while* loop

•Similar to regular *while*, but condition is written (and tested) after the loop body

```
do  {
    ...  /*loop body */
}
while (condition);
```

•Potentially dangerous and tricky – the loop always executes once even if it shouldn’t. Generally don’t use this unless you have no reasonable option.

Command Interpreter main ( ) with do...while

```
#define FALSE 0
#define TRUE   1

int main(void) {
    char command;
    int done;

    done = FALSE;
    do  {
        command = ReadCommand( );

        switch (command){
        case ‘A’:
        case ‘a’:
            A_handler();        /* Execute command A */
            break;
        case ‘B’:
        case ‘b’:
            B_handler();        /* Execute command B */
            break;
        case ‘Q’:
        case ‘q’:
            done = TRUE;        /* quit */
            break;
        default:
            printf(“Unrecognized command\n”);
        }
    }  while (! done);
    return 0;
}
```