*A program without a loop and a structured variable isn't worth writing.*

*-- Alan Perlis*

# Lecture 6 - Loops

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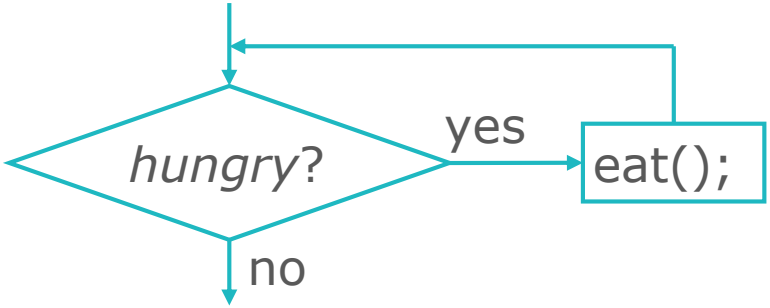
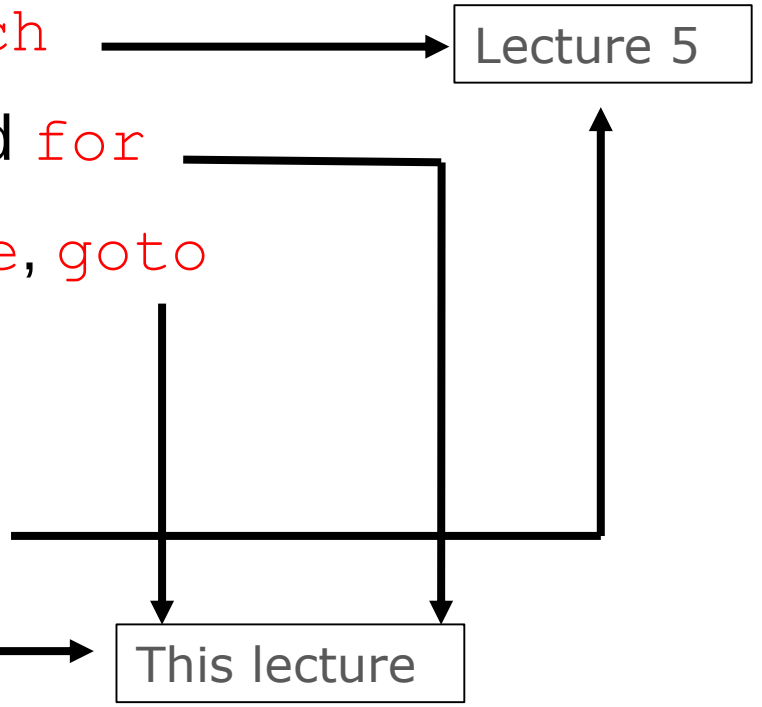
```
while(hungry){
  eat();
}
```



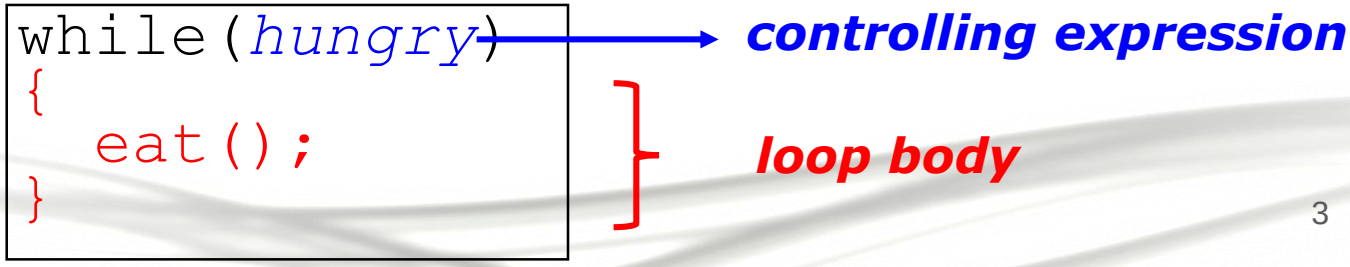
# Recall on Statements

- Most of C's remaining statements fall into three categories:
  - ***Selection statements***: `if` and `switch`
  - ***Iteration statements***: `while`, `do`, and `for`
  - ***Jump statements***: `break`, `continue`, `goto` and `return`.
- Other C statements:
  - Compound statement : `{stmts}`
  - Null statement : `;`
  - Expression statements : `i++;`



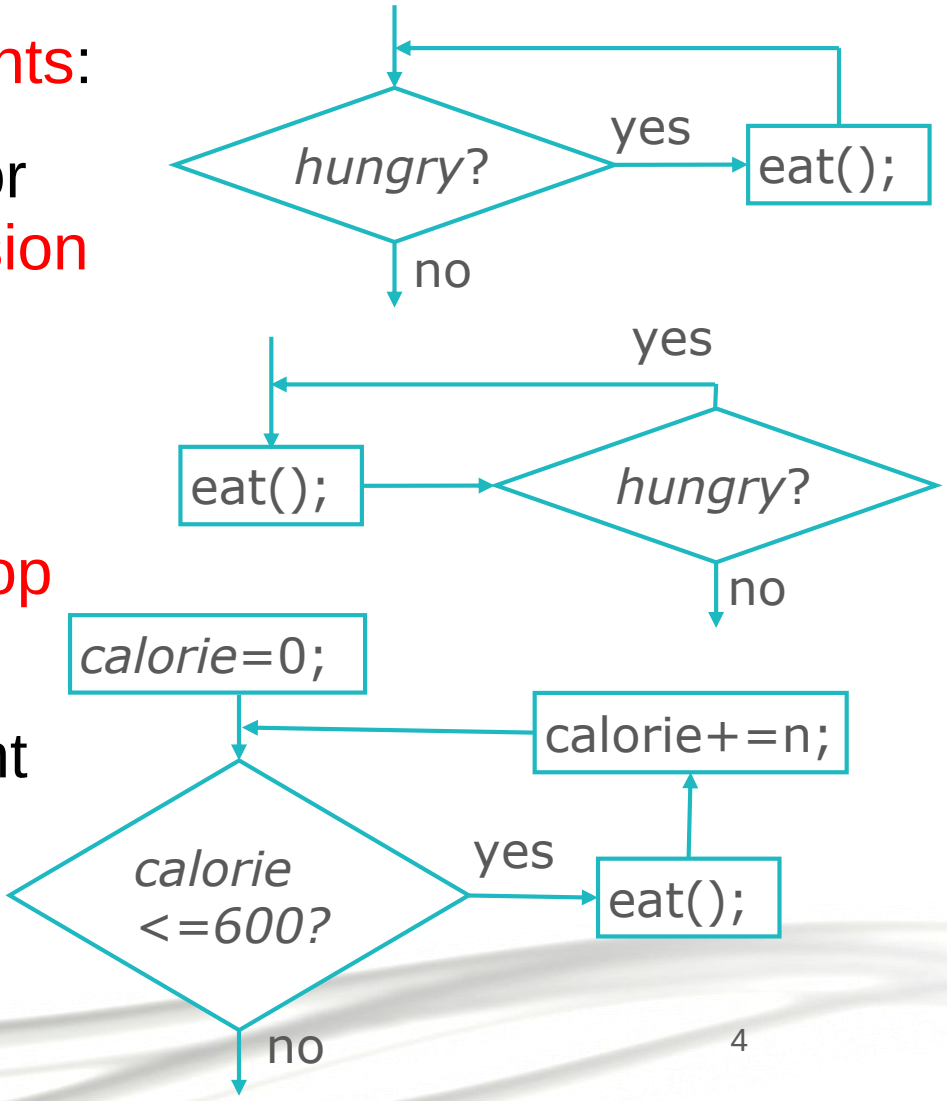
# Iteration Statements

- C's iteration statements are used to set up loops.
- A ***loop*** is a statement whose job is to repeatedly execute some other statement (the ***loop body***).
- In C, every loop has a ***controlling expression***.
- Each time the loop body is executed (an ***iteration*** of the loop), the controlling expression is evaluated.
  - If the expression is true (has a value that's not zero) the loop continues to execute.



# Iteration Statements (cont.)

- C provides three iteration statements:
  - The `while` statement is used for loops whose controlling expression is tested *before* the loop body is executed.
  - The `do` statement is used if the expression is tested *after* the loop body is executed.
  - The `for` statement is convenient for loops that increment or decrement a counting variable.



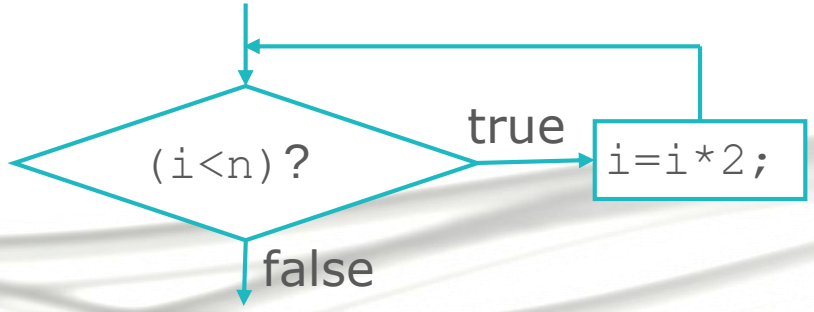
# The `while` Statement

- The `while` statement has the form

  `while ( expression ) statement`

```
while (i < n)
    i = i * 2;
```

- *expression* is the controlling expression; *statement* is the loop body.
- When a `while` statement is executed, the controlling expression is evaluated first.
- If its value is nonzero (true), the loop body is executed and the expression is tested again.
- The process continues until the controlling expression eventually has the value zero.



# The `while` Statement (cont.)

- A `while` statement that computes the smallest power of 2 that is greater than or equal to a number `n`:

```
i = 1;
while (i < n)
   i = i * 2;
```

- A trace of the loop when `n` has the value 10:

| Iteration | Controlling expression | Loop body |
|---|---|---|
| 1 | `1 < 10` (true) | `i = 1 * 2 (= 2)` |
| 2 | `2 < 10` (true) | `i = 2 * 2 ( = 4)` |
| 3 | `4 < 10` (true) | `i = 4 * 2 (=8)` |
| 4 | `8 < 10` (true) | `i = 8 * 2 ( = 16)` |
| 5 | `16 < 10` (false) | |

`i` is 16 after the loop

# The `while` Statement (cont.)

- If multiple statements are needed, use braces to create a single compound statement:

```
while (i > 0) {
  printf("T minus %d and counting\n", i);
  i--;
}
```

- Some programmers always use braces, even when they're not strictly necessary:

```
while (i < n) {
  i = i * 2;
}
```

# The `while` Statement (cont.)

- The following statements display a series of “countdown” messages:

```
i = 10;
while (i > 0) {
  printf("T minus %d and counting\n", i);
  i--;
}
```

```
T minus 10 and counting
T minus 9 and counting
T minus 8 and counting
T minus 7 and counting
T minus 6 and counting
T minus 5 and counting
T minus 4 and counting
T minus 3 and counting
T minus 2 and counting
T minus 1 and counting
```

# The **`while`** Statement (cont.)

- Observations about the `while` statement:
  - The controlling expression is false when a `while` loop terminates. Thus, when a loop controlled by `i > 0` terminates, `i` must be less than or equal to 0.
  - The body of a `while` loop may not be executed at all, because the controlling expression is tested *before* the body is executed.
  - A `while` statement can often be written in a variety of ways. A more concise version of the countdown loop:

```
while (i > 0)
  printf("T minus %d and counting\n", i--);
```

# Infinite Loops

- A `while` statement won't terminate if the controlling expression always has a nonzero value.
- C programmers sometimes deliberately create an ***infinite loop*** by using a nonzero constant as the controlling expression:

```
while (1) …
```

- A `while` statement of this form will execute forever unless its body contains a statement that transfers control out of the loop (`break`, `goto`, `return`) or calls a function that causes the program to terminate.

# Program: Printing a Table of Squares

square.c

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

  printf("This program prints a table of squares.\n");
  printf("Enter number of entries in table: ");
  scanf("%d", &n);

  i = 1;
  while (i <= n) {
    printf("%10d%10d\n", i,
           i * i);
    i++;
  }
  return 0;
}
```

```
This program prints a table of squares.
Enter number of entries in table: 5
         1         1
         2         4
         3         9
         4        16
         5        25
```

# Program: Summing a Series of Numbers

**sum.c**

```
#include <stdio.h>

int main(void)
{
  int n, sum = 0;

  printf("This program sums a series of integers.\n");
  printf("Enter integers (0 to terminate): ");

  scanf("%d", &n);
  while (n != 0) {
    sum += n;
    scanf("%d", &n);
  }
  printf("The sum is: %d\n", sum);

  return 0;
}
```

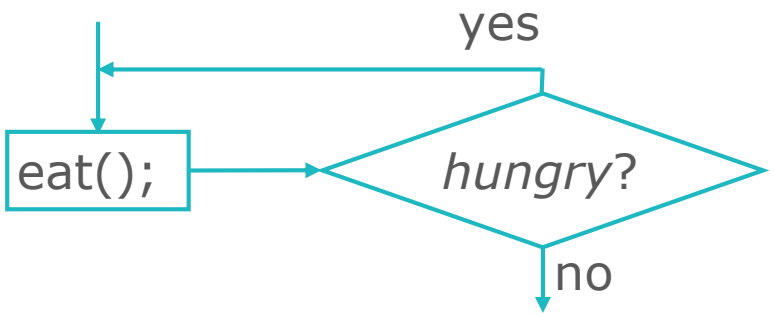
```
This program sums a series of integers.
Enter integers (0 to terminate): 8 23 71 5 0
The sum is: 107
```

# The do Statement

- General form of the `do` statement:

  `do` *statement* `while ( expression ) ;`

- When a `do` statement is executed, the loop body is executed first, then the controlling expression is evaluated.
- If the value of the expression is nonzero, the loop body is executed again and then the expression is evaluated once more.



# The do Statement (cont.)

- The countdown example rewritten as a `do` statement:

```
i = 10;
do {
  printf("T minus %d and counting\n", i);
  --i;
} while (i > 0);
```

- The `do` statement is often indistinguishable from the `while` statement.
- The only difference is that the body of a `do` statement is always executed at least once.

# The `do` Statement (cont.)

- It's a good idea to use braces in *all* `do` statements, whether or not they're needed, because a `do` statement without braces can easily be mistaken for a `while` statement:

```
do
  printf("T minus %d and counting\n", i--);
while (i > 0);
```

- A careless reader might think that the word `while` was the beginning of a `while` statement.

# Program: Calculating the Number of Digits in an Integer

- The `numdigits.c` program calculates the number of digits in an integer entered by the user:

```
Enter a nonnegative integer: 60
The number has 2 digit(s).
```

- The program will divide the user's input by 10 repeatedly until it becomes 0; the number of divisions performed is the number of digits.
- Writing this loop as a `do` statement is better than using a `while` statement, because every integer—even 0—has at least one digit.

# Program: Calculating the Number of Digits in an Integer (cont.)

numdigits.c

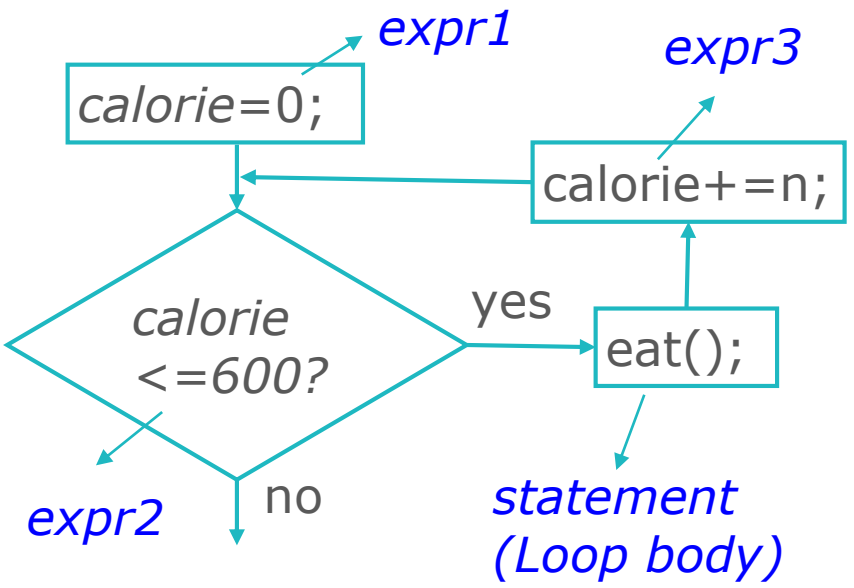
```
#include <stdio.h>
int main(void)
{
  int digits = 0, n;

  printf("Enter a nonnegative integer: ");
  scanf("%d", &n);

  do {
    n /= 10;
    digits++;
  } while (n > 0);

  printf("The number has %d digit(s).\n", digits);

  return 0;
}
```

# The `for` Statement

- General form of the `for` statement:

  `for` ( *expr1* ; *expr2* ; *expr3* ) *statement*

- *expr1* is an initialization step that's performed only once, before the loop begins to execute.
- *expr2* controls loop termination (the loop continues executing as long as the value of *expr2* is nonzero).
- *expr3* is performed at the end of each loop iteration.



# The `for` Statement (cont.)

- The `for` statement is ideal for loops that have a "counting" variable, but it's versatile enough to be used for other kinds of loops as well.
- Except in a few rare cases, a `for` loop can always be replaced by an equivalent `while` loop:

```
expr1;
while ( expr2 ) {
   statement
   expr3;
}
```

```
i = 10;
while (i > 0) {
  printf("T minus %d and counting\n",i);
  i--;
}
```

=

```
for (i = 10; i > 0; i--)
   printf("T minus %d and counting\n", i);
```

# The `for` Statement (cont.)

- Since the first and third expressions in a `for` statement are executed as statements, their values are irrelevant—they're useful only for their side effects.
- Consequently, these two expressions are usually assignments or increment/decrement expressions.

# `for` Statement Idioms

- The `for` statement is usually the best choice for loops that "count up" (increment a variable) or "count down" (decrement a variable).
- A `for` statement that counts up or down a total of `n` times will usually have one of the following forms:

***Counting up from 0 to n–1:***

```
for (i = 0; i < n; i++) …
```

***Counting up from 1 to n:***

```
for (i = 1; i <= n; i++) …
```

***Counting down from n–1 to 0:***

```
for (i = n - 1; i >= 0; i--) …
```

***Counting down from n to 1:***

```
for (i = n; i > 0; i--) …
```

# `for` Statement Idioms (cont.)

- Common `for` statement errors:
  - Using `<` instead of `>` (or vice versa) in the controlling expression. “Counting up” loops should use the `<` or `<=` operator. “Counting down” loops should use `>` or `>=`.
  - Using `==` in the controlling expression instead of `<`, `<=`, `>`, or `>=`.
  - “Off-by-one” errors such as writing the controlling expression as `i <= n` instead of `i < n`.

# Omitting Expressions in a `for` Statement

- C allows any or all of the expressions that control a `for` statement to be omitted.
- If the *first* expression is omitted, no initialization is performed before the loop is executed:

```
i = 10;
for ( ; i > 0; --i)
  printf("T minus %d and counting\n", i);
```

- If the *third* expression is omitted, the loop body is responsible for ensuring that the value of the second expression eventually becomes false:

```
for (i = 10; i > 0;  )
  printf("T minus %d and counting\n", i--);
```

# Omitting Expressions in a `for` Statement (cont.)

- When the *first* and *third* expressions are both omitted, the resulting loop is nothing more than a while statement in disguise:

```
for ( ; i > 0; )
  printf("T minus %d and counting\n", i--);
```

  is the same as

```
while (i > 0)
  printf("T minus %d and counting\n", i--);
```

- The `while` version is clearer and therefore preferable.
- If the *second* expression is missing, it defaults to a true value, so the `for` statement doesn't terminate (unless stopped in some other fashion).

`for (;;) …` = `while (1) …`

# `for` Statements in C99

- In C99, the first expression in a `for` statement can be replaced by a declaration.
- This feature allows the programmer to declare a variable for use by the loop.
- A variable declared by a `for` statement can't be accessed outside the body of the loop (we say that it's not ***visible*** outside the loop):

```
for (int i = 0; i < n; i++) {
   printf("%d", i); /* legal; i is visible here */
}
printf("%d", i);    /*** WRONG ***/
```

# `for` Statements in C99 (cont.)

- Having a `for` statement declare its own control variable is usually a good idea: it's convenient and it can make programs easier to understand.
- However, if the program needs to access the variable after loop termination, it's necessary to use the older form of the `for` statement.
- A `for` statement may declare more than one variable, provided that all variables have the same type:

```
for (int i = 0, j = 0; i < n; i++)
  …
```

# The Comma Operator

- On occasion, a `for` statement may need to have two (or more) initialization expressions or one that increments several variables each time through the loop.
- This effect can be accomplished by using a ***comma expression*** as the first or third expression in the `for` statement.
- A comma expression has the form

  *expr1* , *expr2*

  where *expr1* and *expr2* are any two expressions.

# The Comma Operator (cont.)

- A comma expression is evaluated in two steps:
  - First, *expr1* is evaluated and its value discarded.
  - Second, *expr2* is evaluated; its value is the value of the entire expression.
- Evaluating *expr1* should always have a side effect; if it doesn't, then *expr1* serves no purpose.
- When the comma expression `++i, i + j` is evaluated, `i` is first incremented, then `i + j` is evaluated.
  - If `i` and `j` have the values 1 and 5, respectively, the value of the expression will be 7, and `i` will be incremented to 2.

# The Comma Operator (cont.)

- The comma operator is left associative, so the compiler interprets

```
i = 1, j = 2, k = i + j
```

  as

```
((i = 1), (j = 2)), (k = (i + j))
```

- Since the left operand in a comma expression is evaluated before the right operand, the assignments `i = 1, j = 2`, and `k = i + j` will be performed from left to right.

# The Comma Operator (cont.)

- The comma operator makes it possible to "glue" two expressions together to form a single expression.
- Certain macro definitions can benefit from the comma operator.
- The `for` statement is the only other place where the comma operator is likely to be found.
- Example:

```
for (sum = 0, i = 1; i <= N; i++)
  sum += i;
```

- With additional commas, the `for` statement could initialize more than two variables.

# Program: Printing a Table of Squares (Revisited)

- The `square.c` program can be improved by converting its `while` loop to a `for` loop.

**square2.c**

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

  printf("This program prints a table of squares.\n");
  printf("Enter number of entries in table: ");
  scanf("%d", &n);

  for (i = 1; i <= n; i++)
    printf("%10d%10d\n", i, i * i);

  return 0;
}
```

```
i = 1;
while (i <= n) {
  printf("%10d%10d\n", i,
                       i * i);
  i++;
}
```

# Program: Printing a Table of Squares (Revisited) (cont.)

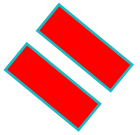
- C places no restrictions on the three expressions that control the behavior of a `for` statement.
- Although these expressions usually initialize, test, and update the same variable, there's no requirement that they be related in any way.
- The `square3.c` program is equivalent to `square2.c`, but contains a `for` statement that initializes one variable (`square`), tests another (`i`), and increments a third (`odd`).
- The flexibility of the `for` statement can sometimes be useful, but in this case the original program was clearer.

# Program: Printing a Table of Squares (Revisited) (cont.)

**square3.c**

$(x+1)^2 - x^2 = x^2+2x+1 - x^2 = 2x + 1$

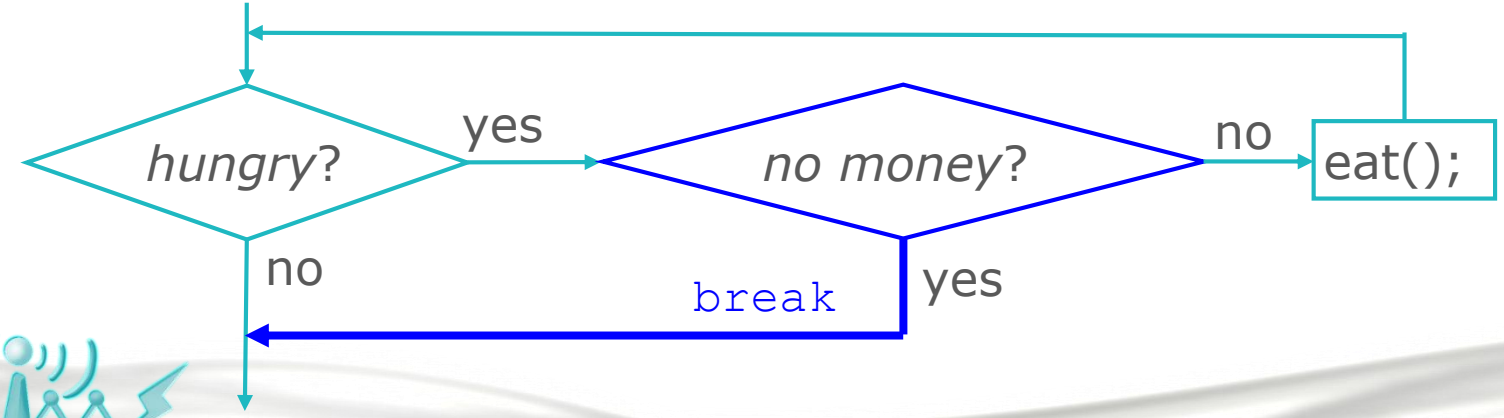
```
#include <stdio.h>
int main(void)
{
  int i, n, odd, square;

  printf("This program prints a table of squares.\n");
  printf("Enter number of entries in table: ");
  scanf("%d", &n);

  i = 1;
  odd = 3;
  for (square = 1; i <= n; odd += 2) {
    printf("%10d%10d\n", i, square);
    ++i;
    square += odd;
  }

  return 0;
}
```



```
for (i = 1, odd = 3, square = 1; i <= n;
     ++i, square += odd, odd += 2)
  printf("%10d%10d\n", i, square);
```

# Exiting from a Loop

- The normal exit point for a loop is at the beginning (as in a `while` or `for` statement) or at the end (the `do` statement).
- Using the `break` statement, it's possible to write a loop with an exit point in the middle or a loop with more than one exit point.
- The `break` statement can transfer control out of a switch statement, but it can also be used to jump out of a `while`, `do`, or `for` loop.



# The **break** Statement

- A loop that checks whether a number `n` is prime can use a `break` statement to terminate the loop as soon as a divisor is found:

```
for (d = 2; d < n; d++)
  if (n % d == 0)
    break;
```

- After the loop has terminated, an `if` statement can be used to determine whether termination was premature (hence `n` isn't prime) or normal (`n` is prime):

```
if (d < n)
  printf("%d is divisible by %d\n", n, d);
else
  printf("%d is prime\n", n);
```

# The **break** Statement (cont.)

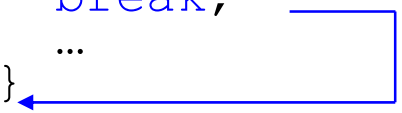
- Loops that read user input, terminating when a particular value is entered, can use `break` to exit:

```
for (;;) {
  printf("Enter a number (enter 0 to stop): ");
  scanf("%d", &n);
  if (n == 0)
    break;
  printf("%d cubed is %d\n", n, n * n * n);
}
```

# The **`break`** Statement (cont.)

- A `break` statement transfers control out of the innermost enclosing `while`, `do`, `for`, or `switch`.
- When these statements are nested, the `break` statement can escape only one level of nesting.
- Example:

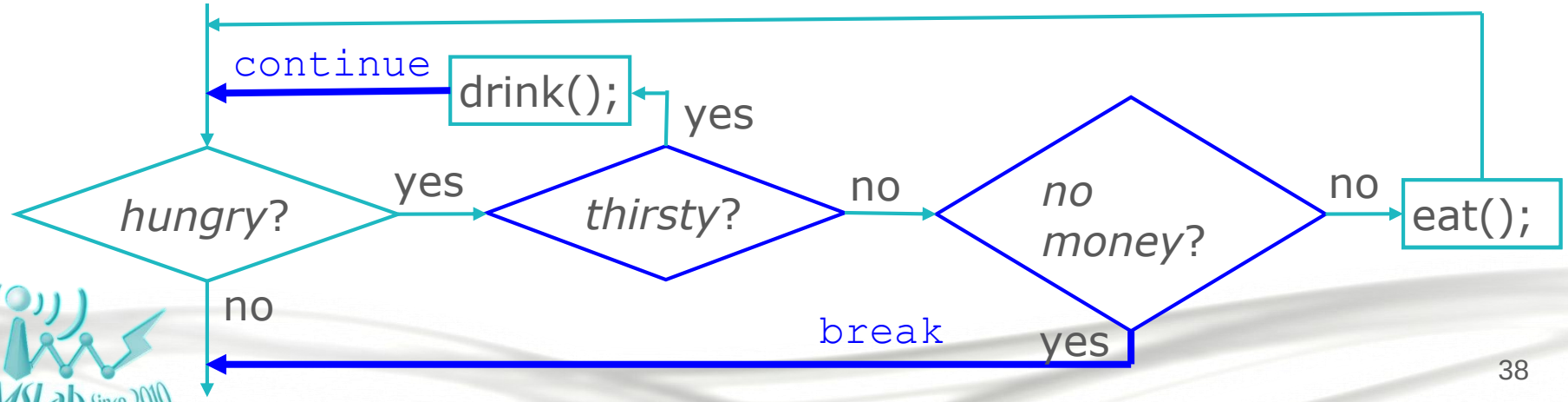
```
while (…) {
  switch (…) {
    …
    break;
    …
  }
}
```



- `break` transfers control out of the `switch` statement, but not out of the `while` loop.

# The `continue` Statement

- The `continue` statement is similar to `break`:
  - `break` transfers control just past the end of a loop.
  - `continue` transfers control to a point just before the end of the loop body.
- With `break`, control leaves the loop; with `continue`, control remains inside the loop.



# The `continue` Statement (cont.)

- There's another difference between `break` and `continue`: `break` can be used in `switch` statements and loops (`while`, `do`, and `for`), whereas `continue` is limited to loops.
- A loop that uses the `continue` statement:

```
n = 0;
sum = 0;
while (n < 10) {
  scanf("%d", &i);
  if (i == 0)
    continue;
  sum += i;
  n++;
}
```

without-`continue` version

```
n = 0;
sum = 0;
while (n < 10) {
  scanf("%d", &i);
  if (i != 0) {
    sum += i;
    n++;
  }
}
```

# The `goto` Statement

- The `goto` statement is capable of jumping to any statement in a function, provided that the statement has a ***label.***
- A label is just an identifier placed at the beginning of a statement:

  *identifier* **:** *statement*

- A statement may have more than one label.
- The `goto` statement itself has the form

  `goto` *identifier* **;**

- Executing the statement `goto` *L*`;` transfers control to the statement that follows the label *L*, which must be in the same function as the `goto` statement itself.

# The `goto` Statement (cont.)

- If C didn't have a `break` statement, a `goto` statement could be used to exit from a loop:

```
for (d = 2; d < n; d++)
  if (n % d == 0)
    goto done;
done:
if (d < n)
  printf("%d is divisible by %d\n", n, d);
else
  printf("%d is prime\n", n);
```

# The `goto` Statement (cont.)

- The `goto` statement is rarely needed in everyday C programming.
- The `break`, `continue`, and `return` statements—which are essentially restricted `goto` statements—and the `exit` function are sufficient to handle most situations that might require a `goto` in other languages.
- Nonetheless, the `goto` statement can be helpful once in a while.

# The goto Statement (cont.)

- Consider the problem of exiting a loop from within a `switch` statement.
- The `break` statement doesn't have the desired effect: it exits from the `switch`, but not from the loop.
- A `goto` statement solves the problem:

```
while (…) {
  switch (…) {
    …
    goto loop_done;    /* break won't work here */
  }
}
loop_done: …
```

- The `goto` statement is also useful for exiting from nested loops.

# Program: Balancing a Checkbook

- Many simple interactive programs present the user with a list of commands to choose from.
- Once a command is entered, the program performs the desired action, then prompts the user for another command.
- This process continues until the user selects an “exit” or “quit” command.

```
for (;;) {
  prompt user to enter command;
  read command;
  switch (command) {
    case command1: perform operation1; break;
     …
    case commandexit: exit loop;
    default: print error message; break;
  }
}
```

# Program: Balancing a Checkbook (cont.)

- The program allows the user to clear the account balance, credit money to the account, debit money from the account, display the current balance, and exit the program.

```
*** ACME checkbook-balancing program ***
Commands: 0=clear, 1=credit, 2=debit, 3=balance, 4=exit
Enter command: 1
Enter amount of credit: 1042.56
Enter command: 2
Enter amount of debit: 133.79
Enter command: 1
Enter amount of credit: 1754.32
Enter command: 2
Enter amount of debit: 1400
Enter command: 2
Enter amount of debit: 68
Enter command: 2
Enter amount of debit: 50
Enter command: 3
Current balance: $1145.09
Enter command: 4
```

# Program: Balancing a Checkbook (cont.)

checking.c

```
#include <stdio.h>
int main(void)
{
  int cmd;
  float balance = 0.0f, credit, debit;

  printf("*** ACME checkbook-balancing program ***\n");
  printf("Commands: 0=clear, 1=credit, 2=debit, ");
  printf("3=balance, 4=exit\n\n");
  for (;;) {
    printf("Enter command: ");
    scanf("%d", &cmd);
    switch (cmd) {
      case 0:  /* clear */
        balance = 0.0f;
        break;
```

# Program: Balancing a Checkbook (cont.)

```
    case 1:  /* credit */
      printf("Enter amount of credit: ");
      scanf("%f", &credit);
      balance += credit;
      break;
    case 2:  /* debit */
      printf("Enter amount of debit: ");
      scanf("%f", &debit);
      balance -= debit;
      break;
    case 3:  /* display */
      printf("Current balance: $%.2f\n", balance);
      break;
    case 4:  /* exit */
      return 0;
    default:
      printf("Commands: 0=clear, 1=credit, 2=debit, ");
      printf("3=balance, 4=exit\n\n");
      break;
  }
 }
}
```

# The Null Statement

- A statement can be ***null***—devoid of symbols except for the semicolon at the end.
- The following line contains three statements:

```
i = 0; ; j = 1;
```

- The null statement is primarily good for one thing: writing loops whose bodies are empty.

# The Null Statement (cont.)

- Consider the following prime-finding loop:

```
for (d = 2; d < n; d++)
  if (n % d == 0)
    break;
```

- If the `n % d == 0` condition is moved into the loop's controlling expression, the body of the loop becomes empty:

```
for (d = 2; d < n && n % d != 0; d++)
  /* empty loop body */ ;
```

- To avoid confusion, C programmers customarily put the null statement on a line by itself.

# The Null Statement (cont.)

- Accidentally putting a semicolon after the parentheses in an `if`, `while`, or `for` statement creates a null statement.
- Example 1:

```
if (d == 0);                                /*** WRONG ***/
  printf("Error: Division by zero\n");
```

  The call of `printf` isn't inside the `if` statement, so it's performed regardless of whether `d` is equal to 0.

- Example 2:

```
i = 10;
while (i > 0);                              /*** WRONG ***/
{
  printf("T minus %d and counting\n", i);
  --i;
}
```

  The extra semicolon creates an infinite loop.

# The Null Statement (cont.)

- Example 3:

```
i = 11;
while (--i > 0);                        /*** WRONG ***/
  printf("T minus %d and counting\n", i);
```

The loop body is executed only once; the message printed is:

```
T minus 0 and counting
```

- Example 4:

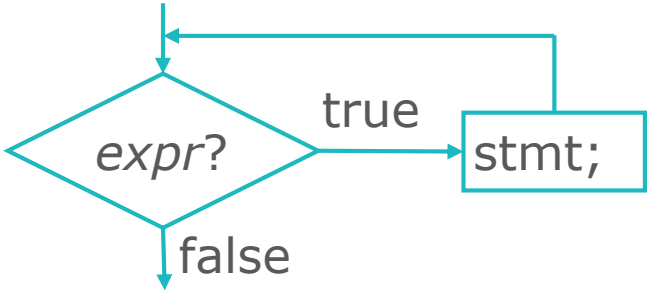
```
for (i = 10; i > 0; i--);               /*** WRONG ***/
  printf("T minus %d and counting\n", i);
```

Again, the loop body is executed only once, and the same message is printed as in Example 3.

# A Quick Review to This Lecture

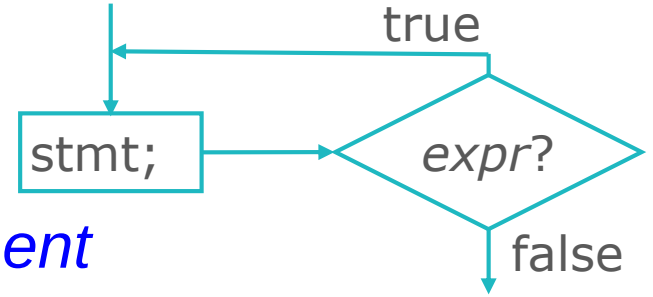
- `while` statement (the most general)

  `while ( expression ) statement`



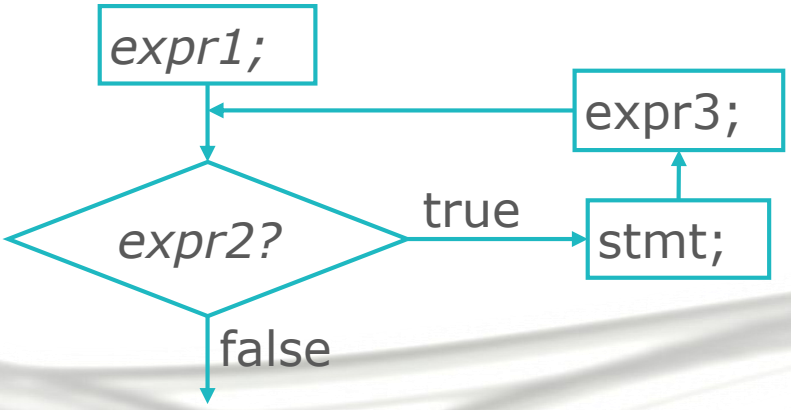

- `do` statement (execute at least once)

  `do statement while ( expression ) ;`




- `for` statement (with counting variable)

  `for ( expr1 ; expr2 ; expr3 ) statement`



# A Quick Review to This Lecture (cont.)

- Infinite Loop (needs `break`, `goto`, `return` or `exit()` to leave)
  - `while (1) …`
  - `do … while (1);  /* rarely used */`
  - `for(;;) …`
- `for` statement with declaration (variable not visible outside)

```
for (int i = 0; i < n; i++) …
for (int i = 0, j = 0; i < n; i++) …
```

- Comma operator (used in macro definition and `for` statement)

*expr1* , *expr2*

should have side effect

value of the entire expression

# A Quick Review to This Lecture (cont.)

- `break` jumps out one level of `switch`, `while`, `do` or `for`
- (carefully used) `continue` jumps to the end (inside) of `while`, `do` or `for`
- (rarely used) `goto` jumps to any statement with specified label (inside function)

```
while (hungry) {
    if(thirsty) {
        drink();
        continue;
    } else if (phone_ring) {
        answer_the_phone();
        goto LOOP_END;
    }else if (nomoney) break;
    else eat();
LOOP_END:  ;
}
```

# A Quick Review to This Lecture (cont.)

- Null statement (useful for loops with empty body)

```
for (d = 2; d < n && n % d != 0; d++)
            ;
```

- Careless usage (body missing)
  - `if (d == 0);`
    `printf("always executed (once, of course)\n");`
  - `while (i > 0);`
    `printf("never executed (infinite loop) i=%d\n", i++);`
  - `while (--i > 0);`
    `printf("executed only once\n", i);`
  - `for (i = 10; i > 0; i--);`
    `printf(" executed only once\n", i);`