Lecture 3 - Control Structures

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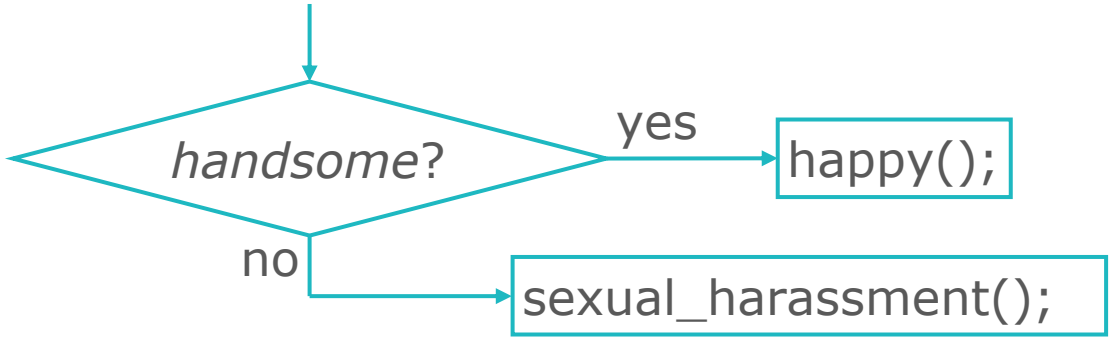
```
if(handsome)
  happy();
else
  sexual_harassment();
```



Statements

- So far, we've used `return` statements and expression 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`, and `goto`.
    (`return` also belongs in this category.)
- Other C statements:
  - Compound statement
  - Null statement

3.1 Logical Expression

Logical Expressions

- Several of C's statements must test the value of an expression to see if it is "true" or "false."
- For example, an `if` statement might need to test the expression `i < j`; a true value would indicate that `i` is less than `j`.
- In many programming languages, an expression such as `i < j` would have a special "Boolean" or "logical" type.
- In C, a comparison such as `i < j` yields an integer: either 0 (false) or 1 (true).

Relational Operators

- C's ***relational operators:***

  `<` less than
  `>` greater than
  `<=` less than or equal to
  `>=` greater than or equal to

- These operators produce 0 (false) or 1 (true) when used in expressions.
- The relational operators can be used to compare integers and floating-point numbers, with operands of mixed types allowed.
- The precedence of the relational operators is lower than that of the arithmetic operators.
  - For example, `i + j < k - 1` means `(i + j) < (k - 1)`.

Relational Operators (cont.)

- The relational operators are left associative.
- The expression

  ```
  i < j < k
  ```

  is legal, but does not test whether `j` lies between `i` and `k`.
- Since the `<` operator is left associative, this expression is equivalent to

  ```
  (i < j) < k
  ```

  The 1 or 0 produced by `i < j` is then compared to `k`.
- The correct expression is `i < j && j < k`.

Equality Operators

- C provides two ***equality operators:***

  `==` equal to
  `!=` not equal to

- The equality operators are left associative and produce either 0 (false) or 1 (true) as their result.

- The equality operators have lower precedence than the relational operators, so the expression

```
i < j == j < k
```

  is equivalent to

```
(i < j) == (j < k)
```

Logical Operators

- More complicated logical expressions can be built from simpler ones by using the ***logical operators:***

  `!` logical negation
  `&&` logical *and*
  `||` logical *or*

- The `!` operator is unary, while `&&` and `||` are binary.
- The logical operators produce 0 or 1 as their result.
- The logical operators treat any nonzero operand as a true value and any zero operand as a false value.

Logical Operators (cont.)

- Behavior of the logical operators:

  !*expr* has the value 1 if *expr* has the value 0.

  expr1 && *expr2* has the value 1 if the values of *expr1* and *expr2* are both nonzero.

  expr1 || *expr2* has the value 1 if either *expr1* or *expr2* (or both) has a nonzero value.

- In all other cases, these operators produce the value 0.

Logical Operators (cont.)

- Both `&&` and `||` perform "short-circuit" evaluation: they first evaluate the left operand, then the right one.
- If the value of the expression can be deduced from the left operand alone, the right operand isn't evaluated.
- Example: `(i != 0) && (j / i > 0)`

  `(i != 0)` is evaluated first.
- If `i` isn't equal to 0, then `(j / i > 0)` is evaluated.
- If `i` is 0, the entire expression must be false, so there's no need to evaluate `(j / i > 0)`. Without short-circuit evaluation, division by zero would have occurred.

Logical Operators (cont.)

- Thanks to the short-circuit nature of the && and || operators, side effects in logical expressions may not always occur.
- Example:
- i > 0 && ++j > 0
- If i > 0 is false, then ++j > 0 is not evaluated, so j isn't incremented.
- The problem can be fixed by changing the condition to ++j > 0 && i > 0 or, even better, by incrementing j separately.

Logical Operators (cont.)

- The `!` operator has the same precedence as the unary plus and minus operators.
- The precedence of `&&` and `||` is lower than that of the relational and equality operators.
  - For example, `i < j && k == m` means `(i < j) && (k == m)`.
- The `!` operator is right associative; `&&` and `||` are left associative.

3.2 The `if` Statement

The `if` Statement

- The `if` statement allows a program to choose between two alternatives by testing an expression.
- In its simplest form, the `if` statement has the form

  `if ( `*expression*` ) `*statement*
- When an `if` statement is executed, *expression* is evaluated; if its value is nonzero, *statement* is executed.
- Example:

```
if (line_num == MAX_LINES)
  line_num = 0;
```

The `if` Statement (cont.)

- Confusing `==` (equality) with `=` (assignment) is perhaps the most common C programming error.
- The statement

```
if (i == 0) …
```

  tests whether `i` is equal to 0.

- The statement

```
if (i = 0) …
```

  assigns 0 to `i`, then tests whether the result is nonzero.

The `if` Statement (cont.)

- Often the expression in an `if` statement will test whether a variable falls within a range of values.
- To test whether $0 \le i < n$:

```
if (0 <= i && i < n) …
```

- To test the opposite condition (`i` is outside the range):

```
if (i < 0 || i >= n) …
```

Compound Statements

- In the `if` statement template, notice that *statement* is singular, not plural:

  `if ( `*expression*` ) `*statement*

- To make an `if` statement control two or more statements, use a ***compound statement.***

- A compound statement has the form

  `{ `*statements*` }`

- Putting braces around a group of statements forces the compiler to treat it as a single statement.

Compound Statements (cont.)

- Example:

```
{ line_num = 0; page_num++; }
```

- Example of a compound statement used inside an `if` statement:

```
if (line_num == MAX_LINES) {
  line_num = 0;
  page_num++;
}
```

- Each inner statement still ends with a semicolon, but the compound statement itself does not.
- Compound statements are also common in loops and other places where the syntax of C requires a single statement.

The `else` Clause

- An `if` statement may have an `else` clause:

  `if ( `*expression*` ) `*statement*` else `*statement*

- The statement that follows the word `else` is executed if the expression has the value 0.

```
if (i > j)
   max = i;
else
   max = j;
```

- Inner statements are usually indented, but if they're short they can be put on the same line as the `if` and `else`:

```
if (i > j) max = i;
else max = j;
```

The `else` Clause (cont.)

- It's not unusual for `if` statements to be nested inside other `if` statements:

```
if (i > j)
  if (i > k)
    max = i;
  else
    max = k;
else
  if (j > k)
    max = j;
  else
    max = k;
```

- Aligning each `else` with the matching `if` makes the nesting easier to see.

The `else` Clause (cont.)

- To avoid confusion, don't hesitate to add braces:

```
if (i > j) {
  if (i > k)
    max = i;
  else
    max = k;
} else {
  if (j > k)
    max = j;
  else
    max = k;
}
```

```
if (i > j) {
  if (i > k) {
    max = i;
  } else {
    max = k;
  }
} else {
  if (j > k) {
    max = j;
  } else {
    max = k;
  }
}
```

The `else` Clause (cont.)

- Advantages of using braces even when they're not required:
  - Makes programs easier to modify, because more statements can easily be added to any `if` or `else` clause.
  - Helps avoid errors that can result from forgetting to use braces when adding statements to an `if` or `else` clause.

Cascaded `if` Statements

- A "cascaded" `if` statement is often the best way to test a series of conditions, stopping as soon as one of them is true.
- Example:

```
if (n < 0)
  printf("n is less than 0\n");
else
  if (n == 0)
    printf("n is equal to 0\n");
  else
    printf("n is greater than 0\n");
```

Cascaded `if` Statements (cont.)

- Aligning each `else` with the original `if` avoids the problem of excessive indentation when the number of tests is large:

```
if ( expression )
   statement
else if ( expression )
   statement
...
else if ( expression )
   statement
else
   statement
```

```
if (n < 0)
  printf("n is less than 0\n");
else if (n == 0)
  printf("n is equal to 0\n");
else
  printf("n is greater than 0\n");
```

Program: Calculating a Broker's Commission

- When stocks are sold or purchased through a broker, the broker's commission often depends upon the value of the stocks traded.
- Suppose that a broker charges the amounts shown in the table:
- The minimum charge is $39.
- The `broker.c` program asks the user to enter the amount of the trade, then displays the amount of the commission:

```
Enter value of trade: 30000
Commission: $166.00
```

Transaction size	*Commission rate*
Under $2,500	$30 + 1.7%
$2,500–$6,250	$56 + 0.66%
$6,250–$20,000	$76 + 0.34%
$20,000–$50,000	$100 + 0.22%
$50,000–$500,000	$155 + 0.11%
Over $500,000	$255 + 0.09%

- The heart of the program is a cascaded `if` statement that determines which range the trade falls into.

Program: Calculating a Broker's Commission (cont.)

broker.c

```
 1 #include <stdio.h>
 2 int main(void)
 3 {
 4   float commission, value;
 5   printf("Enter value of trade: ");
 6   scanf("%f", &value);
 7
 8   if (value < 2500.00f)
 9     commission = 30.00f + .017f * value;
10   else if (value < 6250.00f)
11     commission = 56.00f + .0066f * value;
12   else if (value < 20000.00f)
13     commission = 76.00f + .0034f * value;
14   else if (value < 50000.00f)
15     commission = 100.00f + .0022f * value;
16   else if (value < 500000.00f)
17     commission = 155.00f + .0011f * value;
18   else
19     commission = 255.00f + .0009f * value;
20   if (commission < 39.00f)
21     commission = 39.00f;
22
23   printf("Commission: $%.2f\n",
24     commission);
25   return 0;
26 }
```

The “Dangling else” Problem

- When `if` statements are nested, the “dangling else” problem may occur:

```
if (y != 0)
   if (x != 0)
      result = x / y;
else
   printf("Error: y is equal to 0\n");
```

- The indentation suggests that the else clause belongs to the outer if statement.
- However, C follows the rule that an else clause belongs to the nearest if statement that hasn’t already been paired with an else.

The "Dangling `else`" Problem (cont.)

- To make the `else` clause part of the outer `if` statement, we can enclose the inner `if` statement in braces:

```
if (y != 0) {
  if (x != 0)
    result = x / y;
} else
  printf("Error: y is equal to 0\n");
```

- Using braces in the original `if` statement would have avoided the problem in the first place.

Conditional Expressions

- C's ***conditional operator*** allows an expression to produce one of two values depending on the value of a condition.
- The conditional operator consists of two symbols (`?` and `:`), which must be used together:

  expr1 `?` *expr2* `:` *expr3*

- The expression is evaluated in stages: *expr1* is evaluated first;
  - if its value isn't zero, then *expr2* is evaluated, and its value is the value of the entire conditional expression.
  - if the value is zero, then the value of *expr3* is the value of the conditional.
- The conditional operator requires three operands, so it is often referred to as a ***ternary*** operator.

Conditional Expressions (cont.)

- Example:

```
int i, j, k;
i = 1;
j = 2;
k = i > j ? i : j;          /* k is now 2 */
k = (i >= 0 ? i : 0) + j;   /* k is now 3 */
```

- The parentheses are necessary, because the precedence of the conditional operator is less than that of the other operators discussed so far, with the exception of the assignment operators.
- Conditional expressions tend to make programs shorter but harder to understand, so it's probably best to use them sparingly.
- Conditional expressions are often used in `return` statements:

```
return i > j ? i : j;
```

Conditional Expressions (cont.)

- Calls of `printf` can sometimes benefit from condition expressions. Instead of

```
if (i > j)
   printf("%d\n", i);
else
   printf("%d\n", j);
```

  we could simply write

```
printf("%d\n", i > j ? i : j);
```

- Conditional expressions are also common in certain kinds of macro definitions.

Boolean Values

- C provides the `_Bool` type.
- A Boolean variable can be declared by writing

```
_Bool flag;
```

- `_Bool` is an integer type, so a `_Bool` variable is really just an integer variable in disguise.
- Unlike an ordinary integer variable, however, a `_Bool` variable can only be assigned 0 or 1.
- Attempting to store a nonzero value into a `_Bool` variable will cause the variable to be assigned 1:

```
flag = 5;    /* flag is assigned 1 */
```

Boolean Values (cont.)

- It's legal (although not advisable) to perform arithmetic on `_Bool` variables.
- It's also legal to print a `_Bool` variable (either 0 or 1 will be displayed).
- And, of course, a `_Bool` variable can be tested in an `if` statement:

```
if (flag)    /* tests whether flag is 1 */
  …
```

Boolean Values (cont.)

- C's `<stdbool.h>` header makes it easier to work with Boolean values.
- It defines a macro, `bool`, that stands for `_Bool`.
- If `<stdbool.h>` is included, we can write

```
bool flag;   /* same as _Bool flag; */
```

- `<stdbool.h>` also supplies macros named `true` and `false`, which stand for 1 and 0, respectively, making it possible to write

```
flag = false;
…
flag = true;
```

3.3 The `switch` Statement

The `switch` Statement

- A cascaded `if` statement can be used to compare an expression against a series of values:

```
if (grade == 4)
  printf("Excellent");
else if (grade == 3)
  printf("Good");
else if (grade == 2)
  printf("Average");
else if (grade == 1)
  printf("Poor");
else if (grade == 0)
  printf("Failing");
else
  printf("Illegal grade");
```

The `switch` Statement (cont.)

- The `switch` statement is an alternative:

```
switch (grade) {
  case 4:  printf("Excellent");
           break;
  case 3:  printf("Good");
           break;
  case 2:  printf("Average");
           break;
  case 1:  printf("Poor");
           break;
  case 0:  printf("Failing");
           break;
  default: printf("Illegal grade");
           break;
}
```

The `switch` Statement (cont.)

- A `switch` statement may be easier to read than a cascaded `if` statement.
- `switch` statements are often faster than `if` statements.
- Most common form of the `switch` statement:

```
switch ( expression ) {
  case constant-expression : statements
  ...
  case constant-expression : statements
  default : statements
}
```

The `switch` Statement (cont.)

- The word `switch` must be followed by an integer expression—the ***controlling expression***—in parentheses.
- Characters are treated as integers in C and thus can be tested in `switch` statements.
- Floating-point numbers and strings don't qualify, however.

The `switch` Statement (cont.)

- Each case begins with a label of the form

  `case` *constant-expression* `:`

- A ***constant expression*** is much like an ordinary expression except that it can't contain variables or function calls.
  - `5` is a constant expression, and `5 + 10` is a constant expression, but `n + 10` isn't a constant expression (unless `n` is a macro that represents a constant).
- The constant expression in a case label must evaluate to an integer (characters are acceptable).

The `switch` Statement (cont.)

- After each case label comes any number of statements.
- No braces are required around the statements.
- The last statement in each group is normally `break`.

The `switch` Statement (cont.)

- Duplicate case labels aren't allowed.
- The order of the cases doesn't matter, and the `default` case doesn't need to come last.
- Several case labels may precede a group of statements:

```
switch (grade) {
  case 4:
  case 3:
  case 2:
  case 1:  printf("Passing");
           break;
  case 0:  printf("Failing");
           break;
  default: printf("Illegal grade");
           break;
}
```

The `switch` Statement (cont.)

- To save space, several case labels can be put on the same line:

```
switch (grade) {
  case 4: case 3: case 2: case 1:
          printf("Passing");
          break;
  case 0:  printf("Failing");
          break;
  default: printf("Illegal grade");
          break;
}
```

- If the `default` case is missing and the controlling expression's value doesn't match any case label, control passes to the next statement after the `switch`.

The Role of the `break` Statement

- Executing a `break` statement causes the program to "break" out of the `switch` statement; execution continues at the next statement after the `switch`.
- The `switch` statement is really a form of "computed jump."
- When the controlling expression is evaluated, control jumps to the case label matching the value of the `switch` expression.
- A case label is nothing more than a marker indicating a position within the `switch`.

The Role of the `break` Statement (cont.)

- Without `break` (or some other jump statement) at the end of a case, control will flow into the next case.
- Example:

```
switch (grade) {
  case 4:  printf("Excellent");
  case 3:  printf("Good");
  case 2:  printf("Average");
  case 1:  printf("Poor");
  case 0:  printf("Failing");
  default: printf("Illegal grade");
}
```

- If the value of `grade` is 3, the message printed is

```
GoodAveragePoorFailingIllegal grade
```

The Role of the `break` Statement (cont.)

- Omitting `break` is sometimes done intentionally, but it's usually just an oversight.
- It's a good idea to point out deliberate omissions of `break`:

```
switch (grade) {
  case 4: case 3: case 2: case 1:
          num_passing++;
          /* FALL THROUGH */
  case 0: total_grades++;
          break;
}
```

- Although the last case never needs a `break` statement, including one makes it easy to add cases in the future.

Program: Printing a Date in Legal Form

- Contracts and other legal documents are often dated in the following way:

```
Dated this __________ day of __________ , 20__ .
```

- The `date.c` program will display a date in this form after the user enters the date in month/day/year form:

```
Enter date (mm/dd/yy): 7/19/14
Dated this 19th day of July, 2014.
```

- The program uses `switch` statements to add "th" (or "st" or "nd" or "rd") to the day, and to print the month as a word instead of a number.

Program: Printing a Date in Legal Form (cont.)

date.c

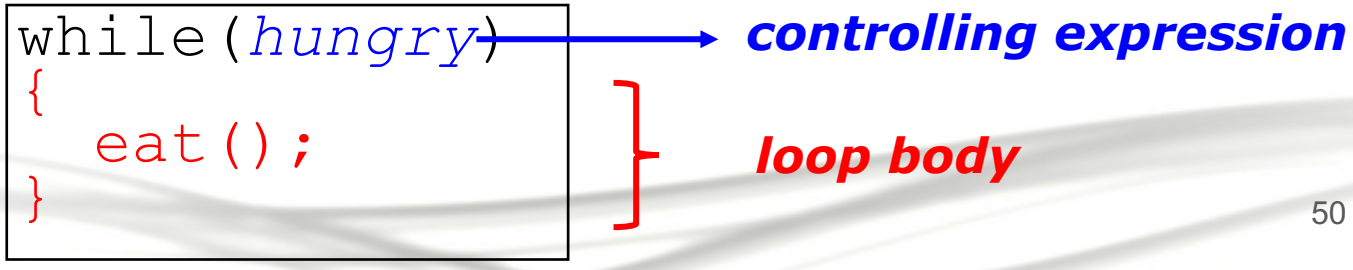
```
#include <stdio.h>
int main(void)
{
  int month, day, year;

  printf("Enter date (mm/dd/yy): ");
  scanf("%d /%d /%d", &month,
    &day, &year);

  printf("Dated this %d", day);
  switch (day) {
    case 1: case 21: case 31:
      printf("st"); break;
    case 2: case 22:
      printf("nd"); break;
    case 3: case 23:
      printf("rd"); break;
    default: printf("th"); break;
  }
  printf(" day of ");
  switch (month) {
    case 1:  printf("January");   break;
    case 2:  printf("February");  break;
    case 3:  printf("March");     break;
    case 4:  printf("April");     break;
    case 5:  printf("May");       break;
    case 6:  printf("June");      break;
    case 7:  printf("July");      break;
    case 8:  printf("August");    break;
    case 9:  printf("September"); break;
    case 10: printf("October");   break;
    case 11: printf("November");  break;
    case 12: printf("December");  break;
  }

  printf(", 20%.2d.\n", year);
  return 0;
}
```

```
Enter date (mm/dd/yy): 7/19/14
Dated this 19th day of July, 2014.
```

3.4 `while` and `do` Statement

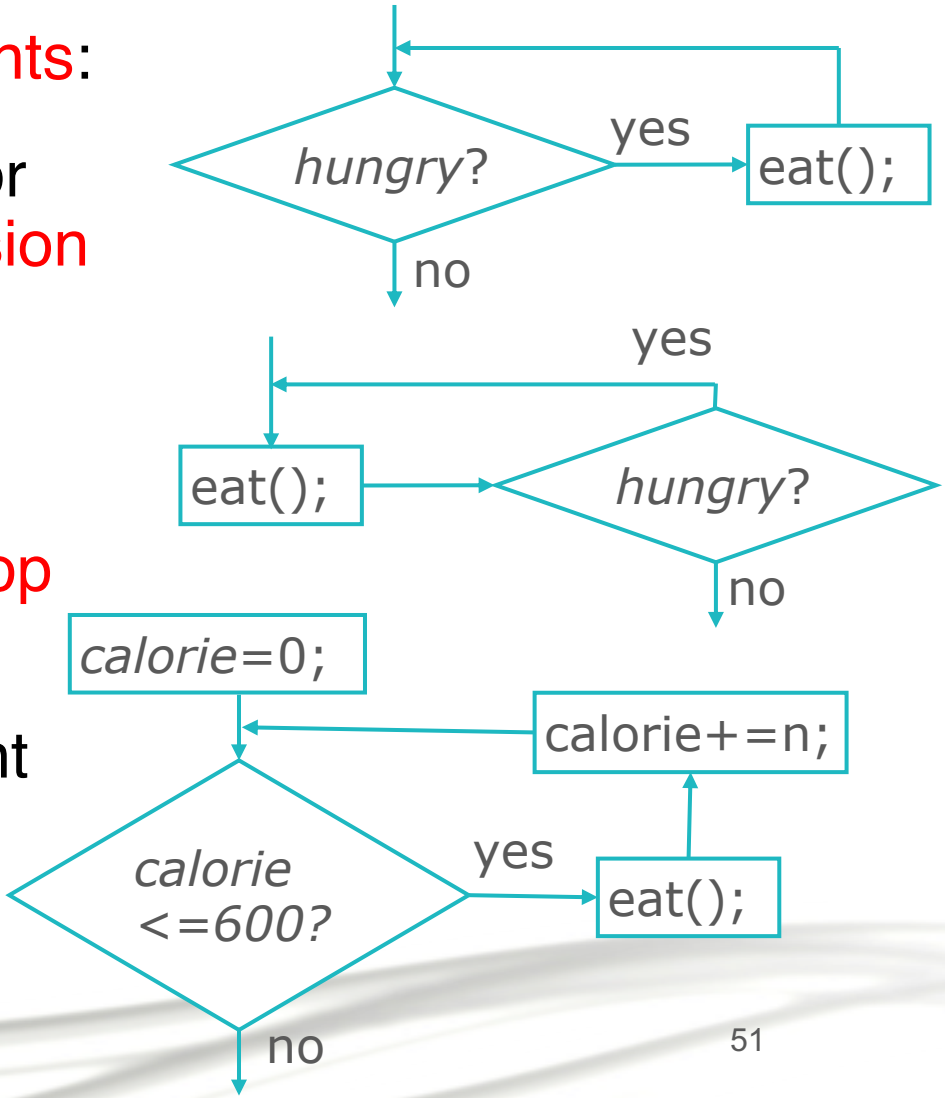
Iteration Statements

- 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.



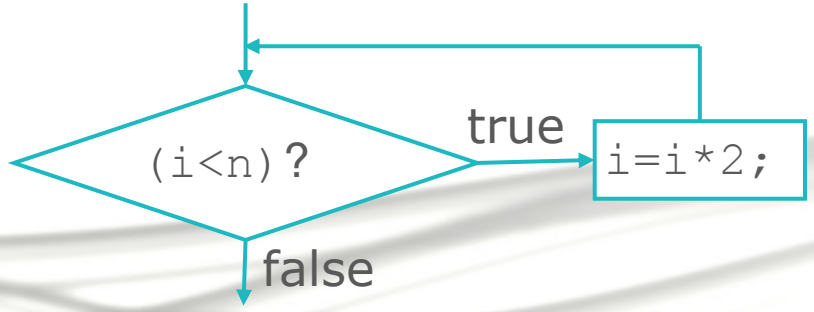
The `while` Statement

- 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;
}
```

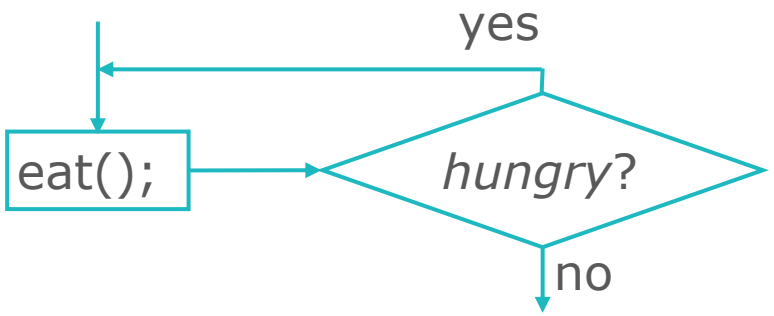
```
This program sums a series of integers.
Enter integers (0 to terminate): 8 23 71 5 0
The sum is: 107
```

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;
}
```

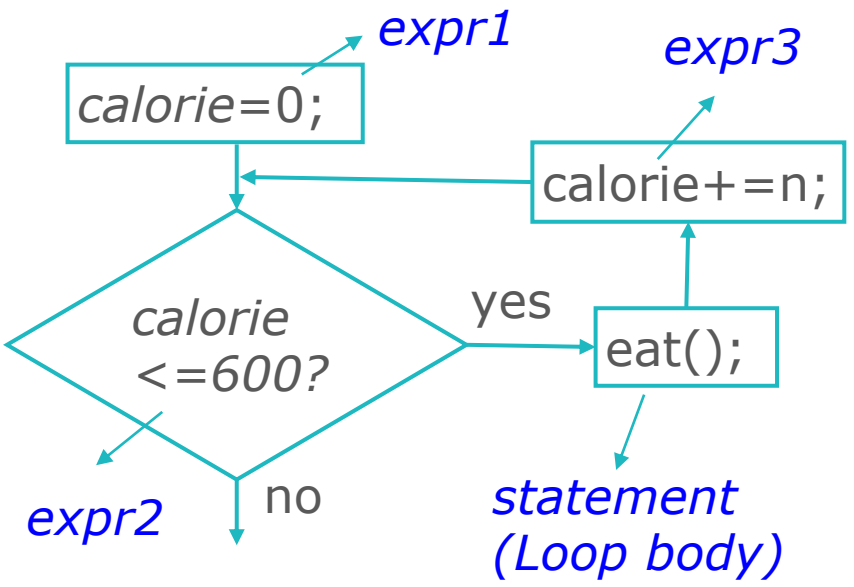
3.5 The `for` Statement

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) …`

Declare Variable in the First Expression

- 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 ***/
```

Declare Variable in the First Expression (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.)

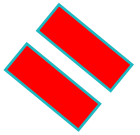
- C places no restrictions on the three expressions that control the behavior of a `for` statement.
- Although these expressions usually initialize, test, and update the same variable, there's no requirement that they be related in any way.
- The `square3.c` program is equivalent to `square2.c`, but 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;
}
```

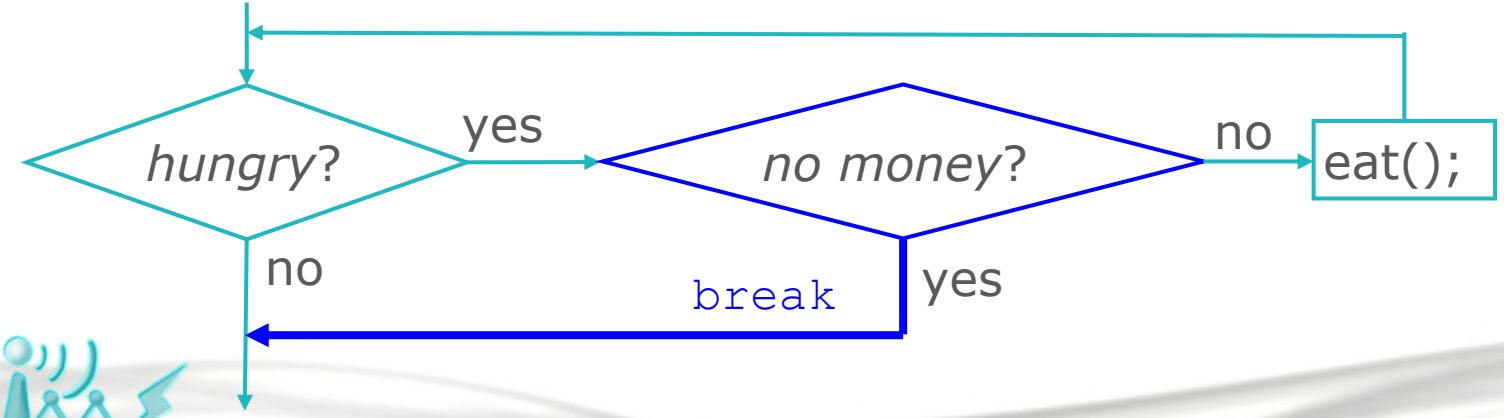


```
for (i = 1, odd = 3, square = 1; i <= n;
     ++i, square += odd, odd += 2)
  printf("%10d%10d\n", i, square);
```

3.6 Exiting from a Loop

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.)

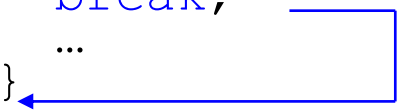
- Loops that read user input, terminating when a particular value is entered, can use `break` to exit:

```
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:

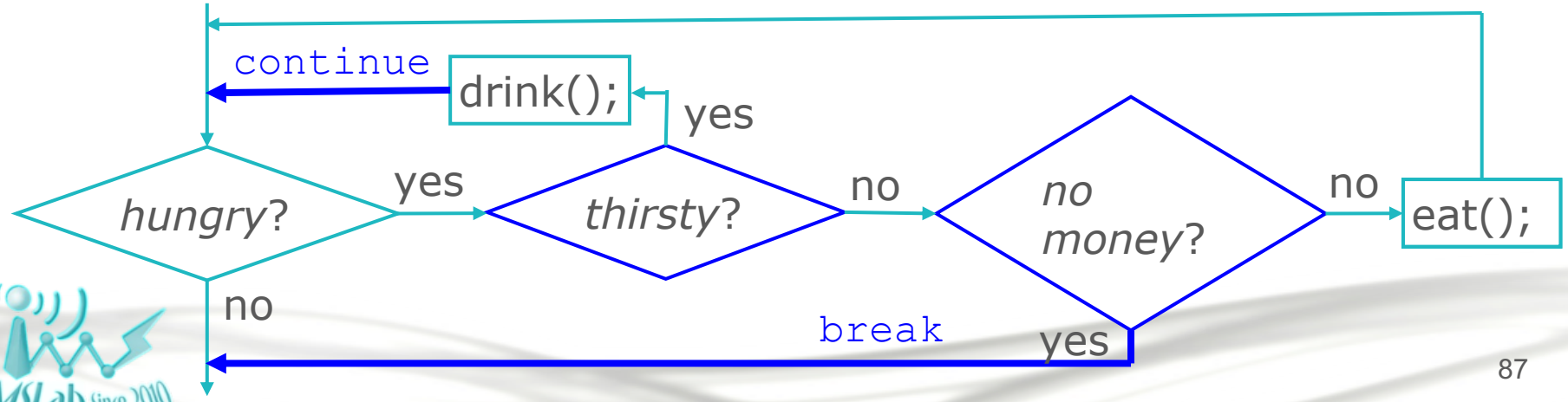
```
while (…) {
  switch (…) {
    …
    break;
    …
  }
}
```



- `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

- `if` statements
  - `if ( expression ) statement`
    `if ( expression ) {statements }`
  - `if ( expression ) statement else statement`
    `if ( expression ) {statements} else {statements}`
- Logical Expression
  - yields an integer: either 0 (false) or 1 (true).
  - Relational Operators: < > <= >=
  - Equality Operators: == !=
  - Logical Operators: ! && ||

left associative

right associative and unary

A Quick Review to This Lecture (cont.)

- To test whether `j` lies between `i` and `k`, use
  `i < j && j < k` instead of `i < j < k` 
- Logical operators treat any nonzero operand as a true value and any zero operand as a false value.
- Both `&&` and `||` perform "short-circuit" evaluation:
  `(i != 0) && (j / i > 0)`
  If the value of the expression can be deduced from the left operand alone, the right operand isn't evaluated.
- Confusing `==` with `=` is perhaps the most common error.
  `if (i == 0) …` tests whether `i` is equal to 0.
  `if (i = 0) …` assigns 0 to `i`, then tests `i` (zero/nonzero)

A Quick Review to This Lecture (cont.)

Nested `if` statement

```
if (i > j) {
  if (i > k) {
    max = i;
  } else {
    max = k;
  }
} else {
  if (j > k) {
    max = j;
  } else {
    max = k;
  }
}
```

Cascaded `if` statement

```
if (n < 0)
  printf("n is less than 0\n");
else if (n == 0)
  printf("n is equal to 0\n");
else if (n <= 1)
  printf("n is between 0 and 1\n");
else
  printf("n is greater than 1\n");
```

A Quick Review to This Lecture (cont.)

- the "dangling else" problem (using braces to avoid it)

```
if (y != 0)
   if (x != 0)
      result = x / y;
else
   printf("Error: y is equal to 0\n");
```

- Conditional Expressions

```
k = (i > j) ? i : j;
```

A Quick Review to This Lecture (cont.)

- Boolean Values
  - Using macro

```
#define BOOL int
#define TRUE 1
#define FALSE 0

BOOL flag;
flag = TRUE;
if (flag == FALSE) …    /* or if(!flag) */
```

  - Using _Bool

```
#define TRUE 1
#define FALSE 0

_Bool flag;
flag = TRUE;
if (flag == FALSE) …    /* or if(!flag) */
```

A Quick Review to This Lecture (cont.)

- Include <stdbool.h>

```
#include <stdbool.h>
bool flag;
flag = true;
if (flag == false) …    /* or if(!flag) */
```

- `switch` Statement (faster and easier to read than cascaded `if`)

No variables or function calls

integer (or character) expression

```
switch ( expression ) {
   case constant-expression : statements
   …
   case constant-expression : statements
   default : statements
}
```

A Quick Review to This Lecture (cont.)

- Without `break` (or some other jump statement) at the end of a case, control will flow into the next case.

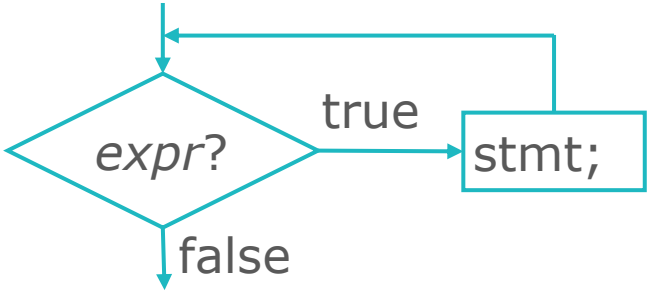
```
switch (grade) {
  case 4: case 3: case 2: case 1:
      num_passing++;
      /* FALL THROUGH */
  case 0: total_grades++;
      break;
}
```

- A case label is nothing more than a marker indicating a position within the `switch`.
- If the `default` case is missing and the controlling expression's value doesn't match any case label, control passes to the next statement after the `switch`.

A Quick Review to This Lecture (cont.)

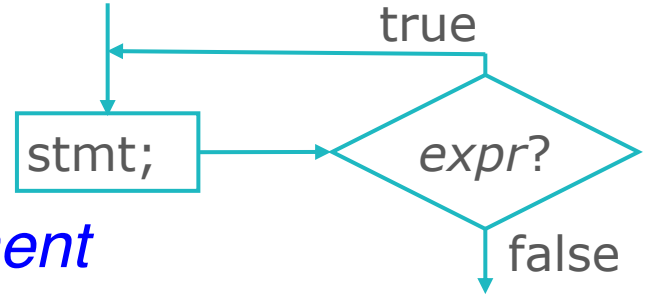
- `while` statement (the most general)

  `while ( expression ) statement`



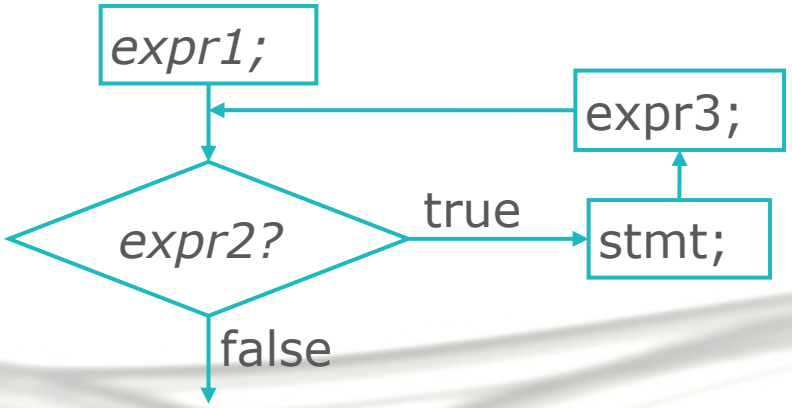
- `do` statement (execute at least once)

  `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);`