Chapter 4

C Program Control

Chapter 4 – C Program Control

Outline

Objectives

- In this chapter, you will learn:
  - To be able to use the `for` and `do…while` repetition statements.
  - To understand multiple selection using the `switch` selection statement.
  - To be able to use the `break` and `continue` program control statements
  - To be able to use the logical operators.

4.1 Introduction

- This chapter introduces
  - Additional repetition control structures
    - `for`
    - `Do...while`
  - `switch` multiple selection statement
  - `break` statement
    - Used for exiting immediately and rapidly from certain control structures
  - `continue` statement
    - Used for skipping the remainder of the body of a repetition structure and proceeding with the next iteration of the loop

4.2 The Essentials of Repetition

- Loop
  - Group of instructions computer executes repeatedly while some condition remains `true`
- Counter-controlled repetition
  - Definite repetition: know how many times loop will execute
  - Control variable used to count repetitions
- Sentinel-controlled repetition
  - Indefinite repetition
  - Used when number of repetitions not known
  - Sentinel value indicates "end of data"

4.3 Essentials of Counter-Controlled Repetition

- Counter-controlled repetition requires
  - The name of a control variable (or loop counter)
  - The initial value of the control variable
  - An increment (or decrement) by which the control variable is modified each time through the loop
  - A condition that tests for the final value of the control variable (i.e., whether looping should continue)

4.3 Essentials of Counter-Controlled Repetition

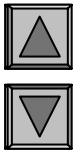
- Example:

```
int counter = 1;           // initialization
while ( counter <= 10 ) { // repetition condition
   printf( "%d\n", counter );
   ++counter;              // increment
}
```

  - The statement

```
int counter = 1;
```

    - Names `counter`
    - Defines it to be an integer
    - Reserves space for it in memory
    - Sets it to an initial value of `1`



Outline

fig04_01.c

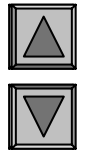
```
1  /* Fig. 4.1: fig04_01.c
2     Counter-controlled repetition */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int counter = 1;              /* initialization */
9
10    while ( counter <= 10 ) {      /* repetition condition */
11       printf ( "%d\n", counter ); /* display counter */
12       ++counter;                  /* increment */
13    } /* end while */
14
15    return 0; /* indicate program ended successfully */
16
17 } /* end function main */
```

Program Output

```
1
2
3
4
5
6
7
8
9
10
```

4.3 Essentials of Counter-Controlled Repetition

- Condensed code
  - C Programmers would make the program more concise
  - Initialize `counter` to `0`
    -
```
while ( ++counter <= 10 )
      printf( “%d\n, counter );
```

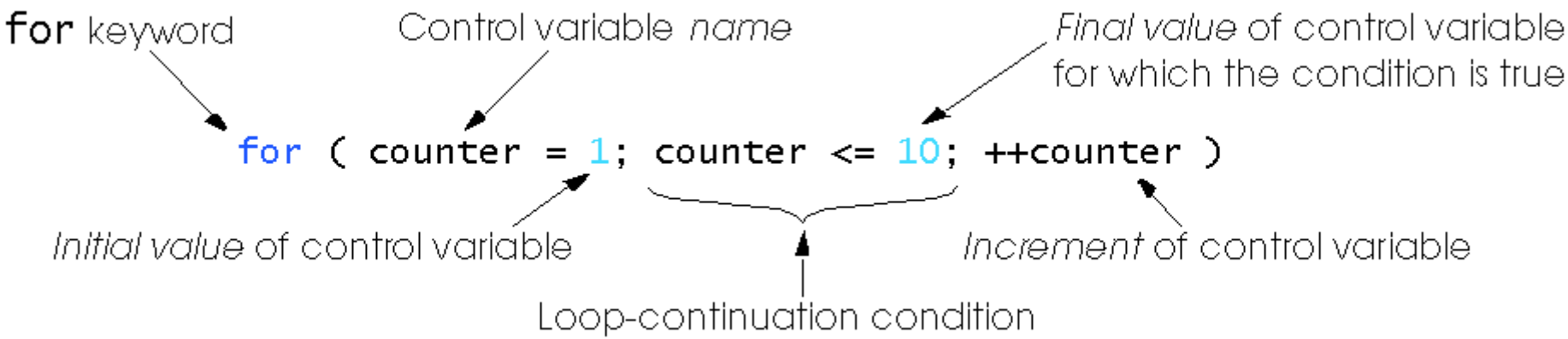


Outline

fig04_02.c

```
1  /* Fig. 4.2: fig04_02.c
2     Counter-controlled repetition with the for statement */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int counter; /* define counter */
9
10    /* initialization, repetition condition, and increment
11       are all included in the for statement header. */
12    for ( counter = 1; counter <= 10; counter++ ) {
13       printf( "%d\n", counter );
14    } /* end for */
15
16    return 0; /* indicate program ended successfully */
17
18 } /* end function main */
```

4.4 The `for` Repetition Statement



4.4 The `for` Repetition Statement

- Format when using `for` loops

  `for` (*initialization*; *loopContinuationTest*; *increment*)
  statement

- Example:

```
for( int counter = 1; counter <= 10; counter++ )
   printf( "%d\n", counter );
```

  – Prints the integers from one to ten

No semicolon (`;`) after last expression

4.4 The `for` Repetition Statement

- For loops can usually be rewritten as while loops:

```
initialization;
while ( loopContinuationTest ) {
   statement;
   increment;
}
```

- Initialization and increment
  - Can be comma-separated lists
  - Example:

```
for (int i = 0, j = 0;  j + i <= 10; j++, i++)
   printf( "%d\n", j + i );
```

4.5 The `for` Statement : Notes and Observations

- Arithmetic expressions
  - Initialization, loop-continuation, and increment can contain arithmetic expressions. If `x` equals `2` and `y` equals `10`

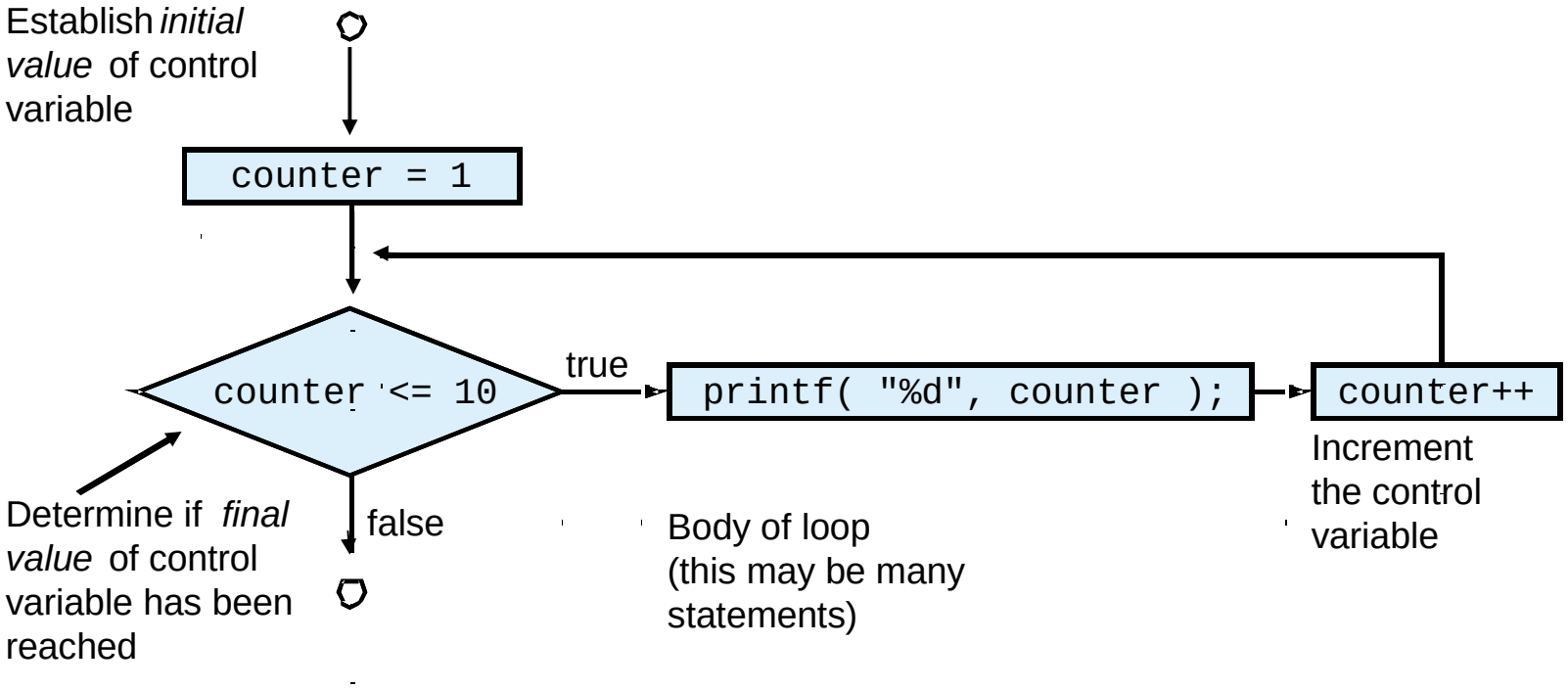
    ```
    for ( j = x; j <= 4 * x * y; j += y / x )
    ```

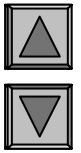
    is equivalent to

    ```
    for ( j = 2; j <= 80; j += 5 )
    ```

- Notes about the `for` statement:
  - "Increment" may be negative (decrement)
  - If the loop continuation condition is initially `false`
    - The body of the `for` statement is not performed
    - Control proceeds with the next statement after the `for` statement
  - Control variable
    - Often printed or used inside for body, but not necessary

4.5 The `for` Statement : Notes and Observations





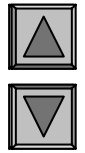
Outline

fig04_05.c

```
1  /* Fig. 4.5: fig04_05.c
2     Summation with for */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int sum = 0; /* initialize sum */
9     int number;  /* number to be added to sum */
10
11    for ( number = 2; number <= 100; number += 2 ) {
12       sum += number; /* add number to sum */
13    } /* end for */
14
15    printf( "Sum is %d\n", sum ); /* output sum */
16
17    return 0; /* indicate program ended successfully */
18
19 } /* end function main */
```

Program Output

```
Sum is 2550
```



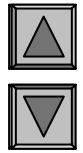
Outline

fig04_06.c (Part 1 of 2)

```
1  /* Fig. 4.6: fig04_06.c
2     Calculating compound interest */
3  #include <stdio.h>
4  #include <math.h>
5
6  /* function main begins program execution */
7  int main()
8  {
9     double amount;             /* amount on deposit */
10    double principal = 1000.0; /* starting principal */
11    double rate = .05;         /* interest rate */
12    int year;                  /* year counter */
13
14    /* output table column head */
15    printf( "%4s%21s\n", "Year", "Amount on deposit" );
16
17    /* calculate amount on deposit for each of ten years */
18    for ( year = 1; year <= 10; year++ ) {
19
20       /* calculate new amount for specified year */
21       amount = principal * pow( 1.0 + rate, year );
22
23       /* output one table row */
24       printf( "%4d%21.2f\n", year, amount );
25    } /* end for */
26
```

```
27    return 0; /* indicate program ended successfully */
28
29 } /* end function main */
```

```
Year    Amount on deposit
   1              1050.00
   2              1102.50
   3              1157.63
   4              1215.51
   5              1276.28
   6              1340.10
   7              1407.10
   8              1477.46
   9              1551.33
  10              1628.89
```



Outline

fig04_06.c (Part 2 of 2)

Program Output

4.7 The `switch` Multiple-Selection Statement

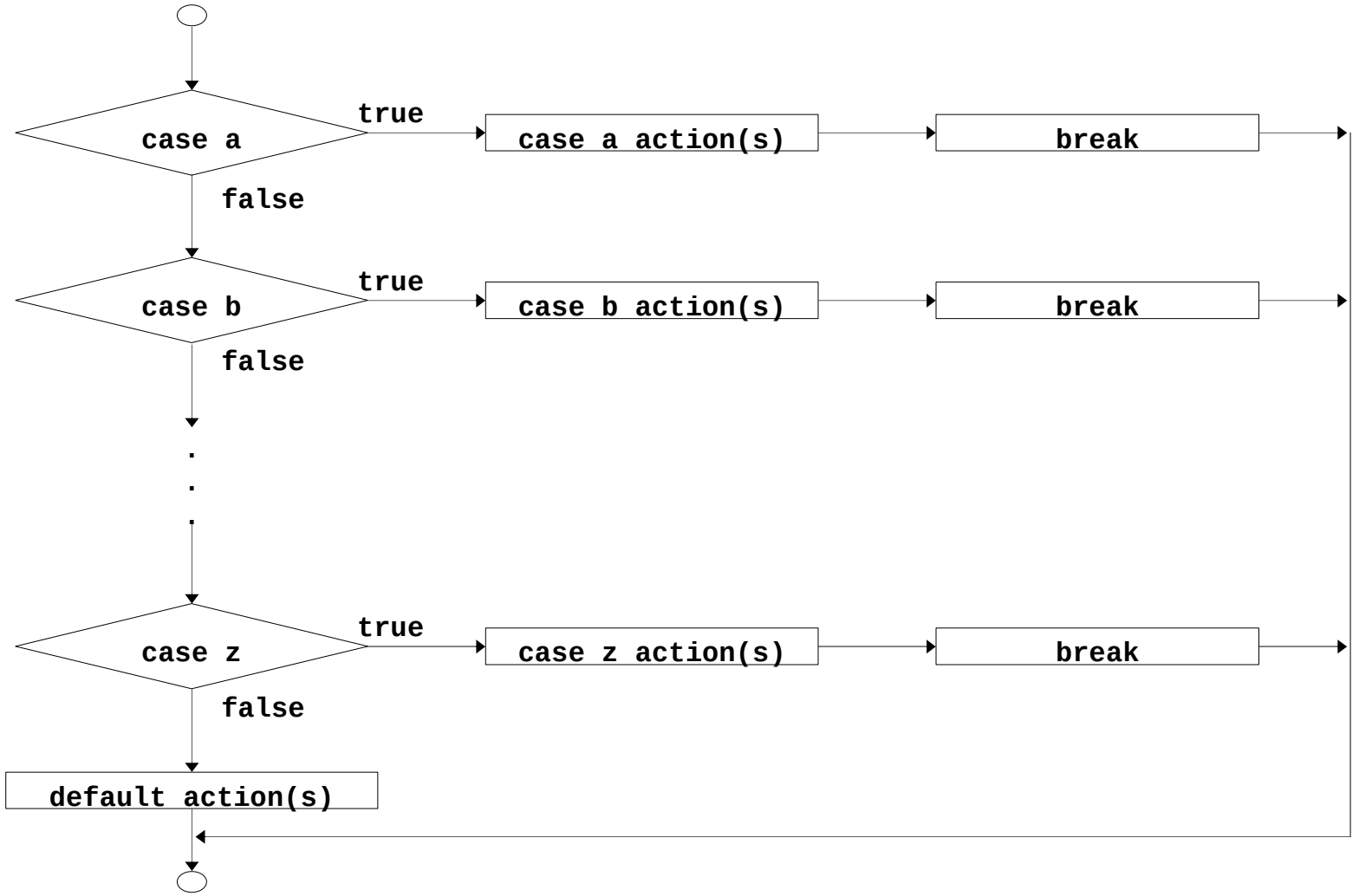
- `switch`
  - Useful when a variable or expression is tested for all the values it can assume and different actions are taken
- Format
  - Series of `case` labels and an optional `default` case

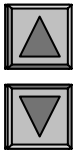
```
switch ( value ){
   case '1':
      actions
   case '2':
      actions
   default:
      actions
   }
```

  - `break;` exits from statement

4.7 The `switch` Multiple-Selection Statement

- Flowchart of the `switch` statement

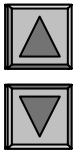




Outline

fig04_07.c (Part 1 of 3)

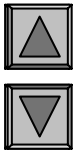
```
1  /* Fig. 4.7: fig04_07.c
2     Counting letter grades */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int grade;      /* one grade */
9     int aCount = 0; /* number of As */
10    int bCount = 0; /* number of Bs */
11    int cCount = 0; /* number of Cs */
12    int dCount = 0; /* number of Ds */
13    int fCount = 0; /* number of Fs */
14
15    printf(  "Enter the letter grades.\n"  );
16    printf(  "Enter the EOF character to end input.\n"  );
17
18    /* loop until user types end-of-file key sequence */
19    while ( ( grade = getchar() ) != EOF ) {
20
21       /* determine which grade was input */
22       switch ( grade ) { /* switch nested in while */
23
24          case 'A':    /* grade was uppercase A */
25          case 'a':    /* or lowercase a */
26             ++aCount; /* increment aCount */
27             break;    /* necessary to exit switch */
28
```



Outline

```
29          case 'B':    /* grade was uppercase B */
30          case 'b':    /* or lowercase b */
31             ++bCount; /* increment bCount */
32             break;    /* exit switch */
33
34          case 'C':    /* grade was uppercase C */
35          case 'c':    /* or lowercase c */
36             ++cCount; /* increment cCount */
37             break;    /* exit switch */
38
39          case 'D':    /* grade was uppercase D */
40          case 'd':    /* or lowercase d */
41             ++dCount; /* increment dCount */
42             break;    /* exit switch */
43
44          case 'F':    /* grade was uppercase F */
45          case 'f':    /* or lowercase f */
46             ++fCount; /* increment fCount */
47             break;    /* exit switch */
48
49          case '\n':   /* ignore newlines, */
50          case '\t':   /* tabs, */
51          case ' ':    /* and spaces in input */
52             break;    /* exit switch */
53
```

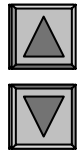
fig04_07.c (Part 2 of 3)



Outline

```
54          default:     /* catch all other characters */
55             printf( "Incorrect letter grade entered." );
56             printf( " Enter a new grade.\n" );
57             break;    /* optional; will exit switch anyway */
58       } /* end switch */
59
60    } /* end while */
61
62    /* output summary of results */
63    printf( "\nTotals for each letter grade are:\n" );
64    printf( "A: %d\n", aCount ); /* display number of A grades */
65    printf( "B: %d\n", bCount ); /* display number of B grades */
66    printf( "C: %d\n", cCount ); /* display number of C grades */
67    printf( "D: %d\n", dCount ); /* display number of D grades */
68    printf( "F: %d\n", fCount ); /* display number of F grades */
69
70    return 0; /* indicate program ended successfully */
71
72 } /* end function main */
```

fig04_07.c (Part 3 of 3)



Outline

Program Output

```
Enter the letter grades.
Enter the EOF character to end input.
a
b
c
C
A
d
f
C
E
Incorrect letter grade entered. Enter a new grade.
D
A
b
^Z

Totals for each letter grade are:
A: 3
B: 2
C: 3
D: 2
F: 1
```

4.8 The `do...while` Repetition Statement

- The `do...while` repetition statement
  - Similar to the `while` structure
  - Condition for repetition tested after the body of the loop is performed
    - All actions are performed at least once
  - Format:

```
do {
   statement;
} while ( condition );
```

4.8 The `do...while` Repetition Statement

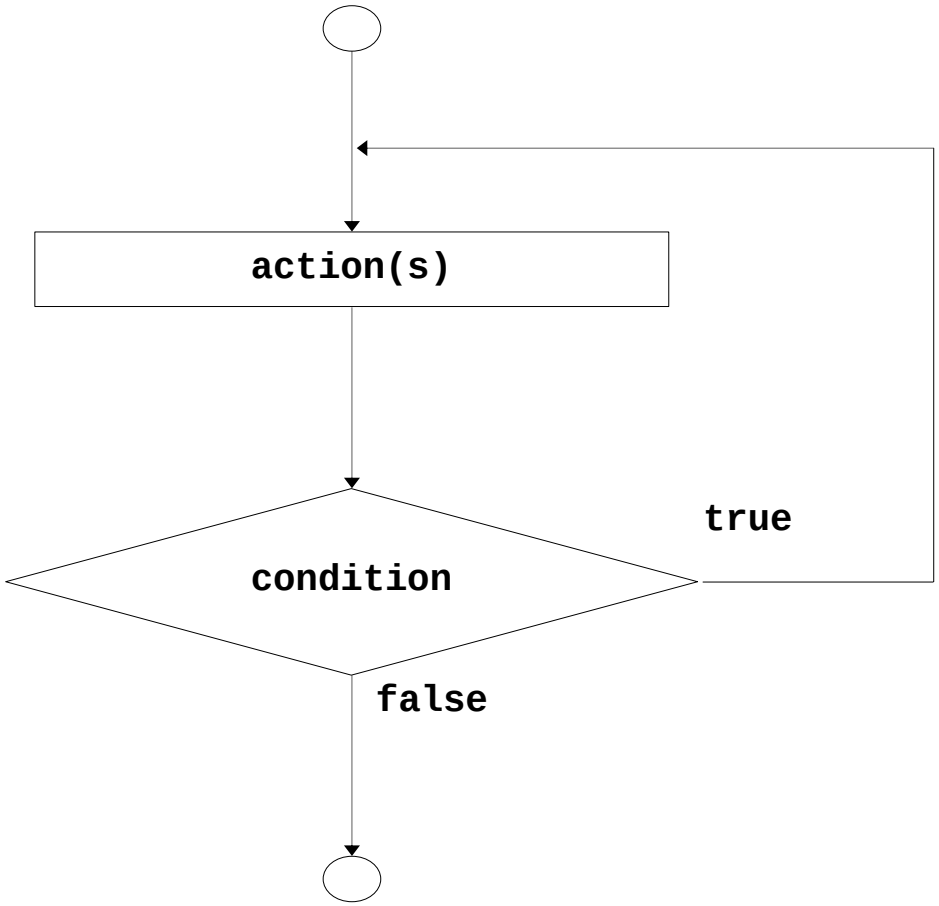
- Example (letting counter = 1):

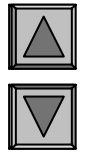
```
do {
   printf( "%d  ", counter );
} while (++counter <= 10);
```

  - Prints the integers from `1` to `10`

4.8 The `do...while` Repetition Statement

- Flowchart of the `do...while` repetition statement





Outline

fig04_09.c

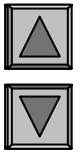
```
1  /* Fig. 4.9: fig04_09.c
2     Using the do/while repetition statement */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int counter = 1; /* initialize counter */
9
10    do {
11       printf( "%d  ", counter ); /* display counter */
12    } while ( ++counter <= 10 ); /* end do...while */
13
14    return 0; /* indicate program ended successfully */
15
16 } /* end function main */
```

Program Output

```
1  2  3  4  5  6  7  8  9  10
```

4.9 The `break` and `continue` Statements

- `break`
  - Causes immediate exit from a `while`, `for`, `do...while` or `switch` statement
  - Program execution continues with the first statement after the structure
  - Common uses of the `break` statement
    - Escape early from a loop
    - Skip the remainder of a `switch` statement



Outline

fig04_11.c

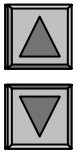
```
1  /* Fig. 4.11: fig04_11.c
2     Using the break statement in a for statement */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int x; /* counter */
9
10    /* loop 10 times */
11    for ( x = 1; x <= 10; x++ ) {
12
13       /* if x is 5, terminate loop */
14       if ( x == 5 ) {
15          break; /* break loop only if x is 5 */
16       } /* end if */
17
18       printf( "%d ", x ); /* display value of x */
19    } /* end for */
20
21    printf( "\nBroke out of loop at x == %d\n", x );
22
23    return 0; /* indicate program ended successfully */
24
25 } /* end function main */
```

Program Output

```
1 2 3 4
Broke out of loop at x == 5
```

4.9 The `break` and `continue` Statements

- `continue`
  - Skips the remaining statements in the body of a `while`, `for` or `do...while` statement
    - Proceeds with the next iteration of the loop
  - `while` and `do...while`
    - Loop-continuation test is evaluated immediately after the `continue` statement is executed
  - `for`
    - Increment expression is executed, then the loop-continuation test is evaluated



Outline

fig04_12.c

```
1  /* Fig. 4.12: fig04_12.c
2     Using the continue statement in a for statement */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main()
7  {
8     int x; /* counter */
9
10    /* loop 10 times */
11    for ( x = 1; x <= 10; x++ ) {
12
13       /* if x is 5, continue with next iteration of loop */
14       if ( x == 5 ) {
15          continue; /* skip remaining code in loop body */
16       } /* end if */
17
18       printf( "%d ", x ); /* display value of x */
19    } /* end for */
20
21    printf( "\nUsed continue to skip printing the value 5\n" );
22
23    return 0; /* indicate program ended successfully */
24
25 } /* end function main */
```

Program Output

```
1 2 3 4 6 7 8 9 10
Used continue to skip printing the value 5
```

4.10 Logical Operators

- && (logical AND)
  - Returns `true` if both conditions are `true`
- || (logical OR)
  - Returns `true` if either of its conditions are `true`
- ! (logical NOT, logical negation)
  - Reverses the truth/falsity of its condition
  - Unary operator, has one operand
- Useful as conditions in loops

Expression	Result
`true && false`	`false`
`true || false`	`true`
`!false`	`true`

4.10 Logical Operators

expression1	expression2	expression1 && expression2
0	0	0
0	nonzero	0
nonzero	0	0
nonzero	nonzero	1

Fig. 4.13 Truth table for the && (logical AND) operator.

expression1	expression2	expression1 || expression2
0	0	0
0	nonzero	1
nonzero	0	1
nonzero	nonzero	1

Fig. 4.14 Truth table for the logical OR (||) operator.

expression	! expression
0	1
nonzero	0

Fig. 4.15 Truth table for operator ! (logical negation).

4.10 Logical Operators

Operators						Associativity	Type
++	--	+	-	!	(type)	right to left	unary
*	/	%				left to right	multiplicative
+	-					left to right	additive
<	<=	>	>=			left to right	relational
==	!=					left to right	equality
&&						left to right	logical AND
||						left to right	logical OR
?:						right to left	conditional
=	+=	-=	*=	/=	%=	right to left	assignment
,						left to right	comma

Fig. 4.16 Operator precedence and associativity.

4.11 Confusing Equality (==) and Assignment (=) Operators

- Dangerous error
  - Does not ordinarily cause syntax errors
  - Any expression that produces a value can be used in control structures
  - Nonzero values are `true`, zero values are `false`
  - Example using ==:

```
if ( payCode == 4 )
   printf( "You get a bonus!\n" );
```

    - Checks `payCode`, if it is `4` then a bonus is awarded

4.11 Confusing Equality (==) and Assignment (=) Operators

– Example, replacing == with =:

```
if ( payCode = 4 )
   printf( "You get a bonus!\n" );
```

  - This sets `payCode` to `4`
  - `4` is nonzero, so expression is `true`, and bonus awarded no matter what the `payCode` was

– Logic error, not a syntax error

4.11 Confusing Equality (==) and Assignment (=) Operators

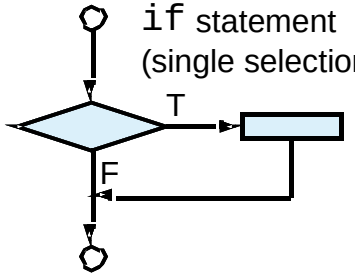
- lvalues
  - Expressions that can appear on the left side of an equation
  - Their values can be changed, such as variable names
    - `x = 4;`
- rvalues
  - Expressions that can only appear on the right side of an equation
  - Constants, such as numbers
    - **Cannot write `4 = x;`**
    - **Must write `x = 4;`**
  - lvalues can be used as rvalues, but not vice versa
    - `y = x;`

4.12 Structured-Programming Summary

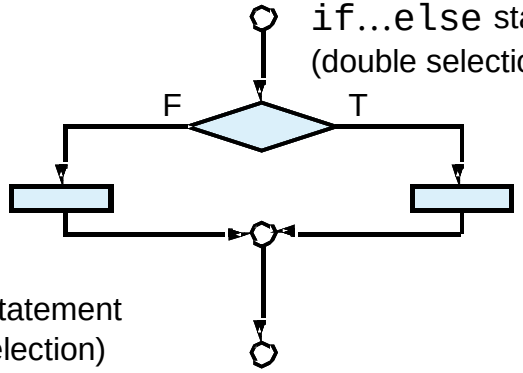
Sequence

Selection

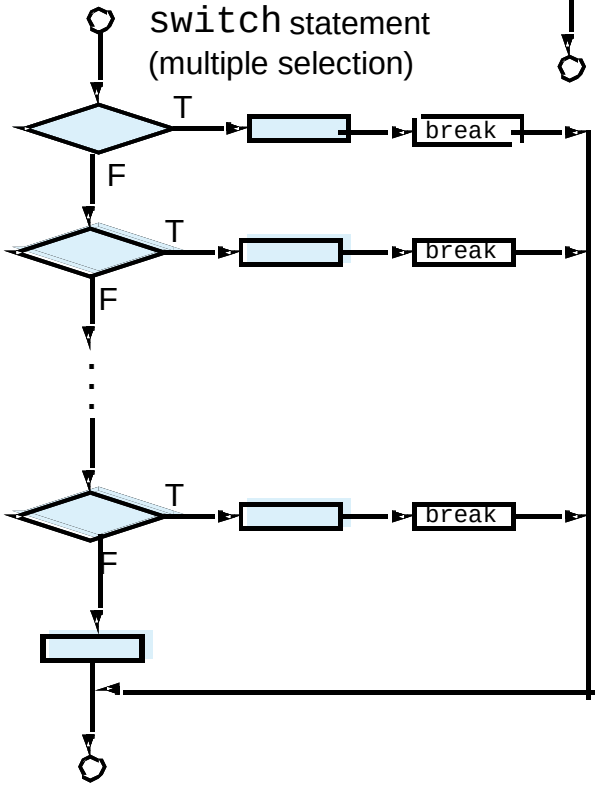
`if` statement
(single selection)



`if...else` statement
(double selection)



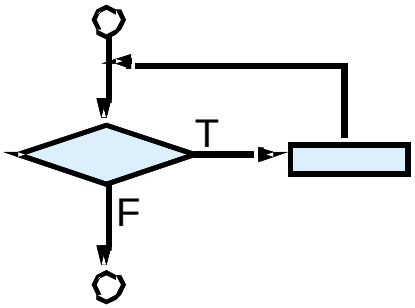
`switch` statement
(multiple selection)



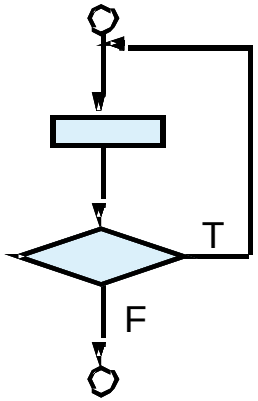
4.12 Structured-Programming Summary

Repetition

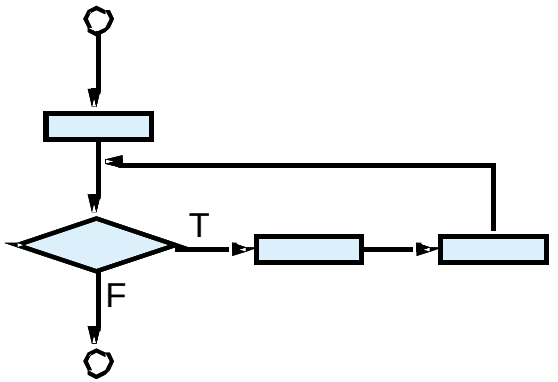
`while` statement



`do..while` statement



`for` statement



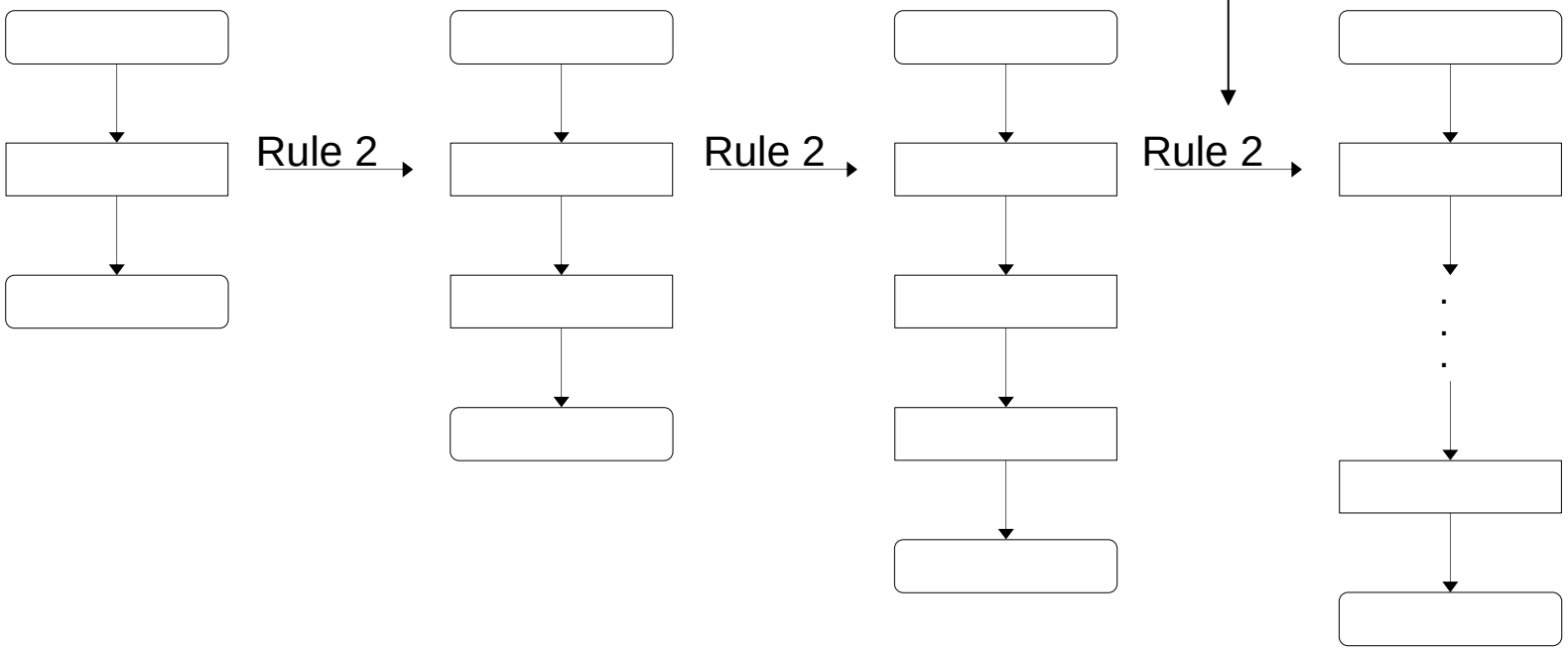
4.12 Structured-Programming Summary

- Structured programming
  - Easier than unstructured programs to understand, test, debug and, modify programs
- Rules for structured programming
  - Rules developed by programming community
  - Only single-entry/single-exit control structures are used
  - Rules:
    1. Begin with the “simplest flowchart”
    2. Stacking rule: Any rectangle (action) can be replaced by two rectangles (actions) in sequence
    3. Nesting rule: Any rectangle (action) can be replaced by any control structure (sequence, `if`, `if...else`, `switch`, `while`, `do...while` or `for`)
    4. Rules 2 and 3 can be applied in any order and multiple times

4.12 Structured-Programming Summary

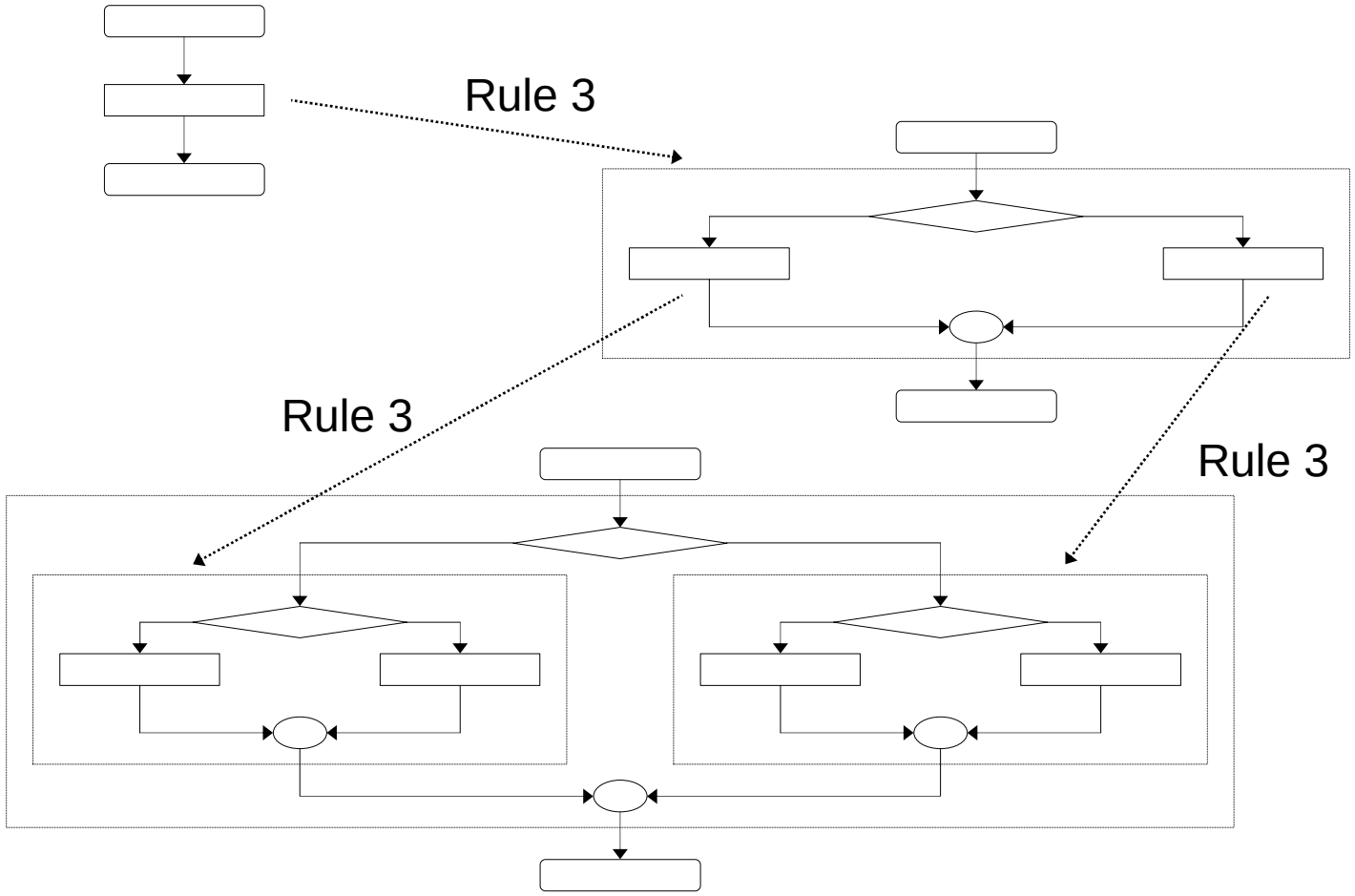
Rule 1 - Begin with the simplest flowchart

Rule 2 - Any rectangle can be replaced by two rectangles in sequence



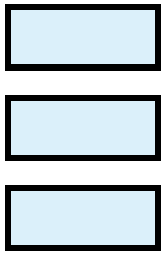
4.12 Structured-Programming Summary

Rule 3 - Replace any rectangle with a control structure

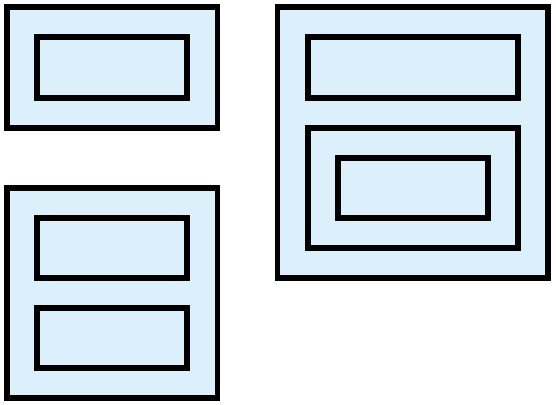


4.12 Structured-Programming Summary

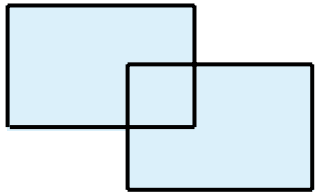
Stacked building blocks



Nested building blocks

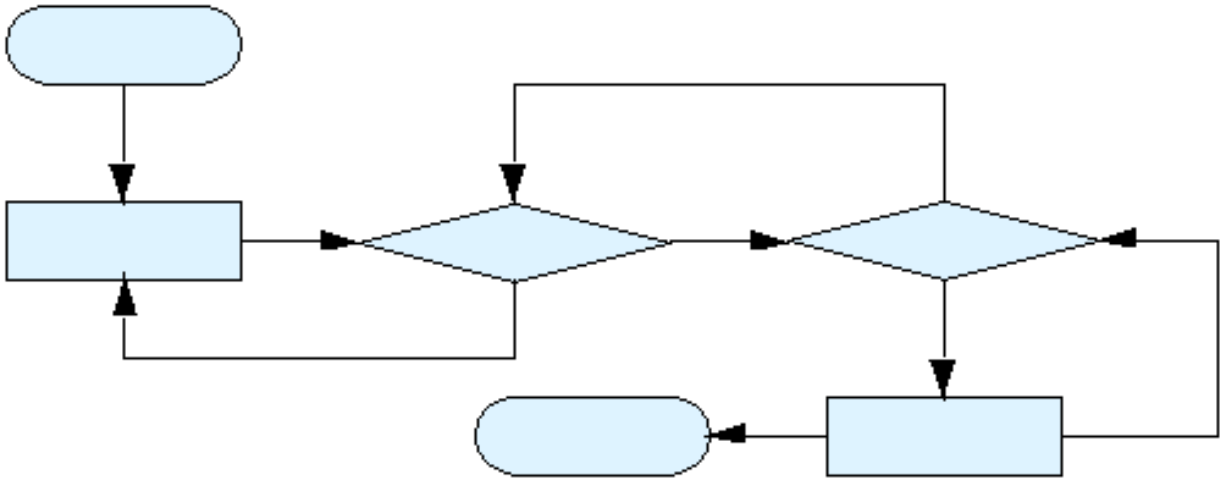


Overlapping building blocks
(Illegal in structured programs)



4.12 Structured-Programming Summary

Figure 4.23 An unstructured flowchart.



4.12 Structured-Programming Summary

- All programs can be broken down into 3 controls
  - Sequence – handled automatically by compiler
  - Selection – `if`, `if...else` or `switch`
  - Repetition – `while`, `do...while` or `for`
    - Can only be combined in two ways
      - Nesting (rule 3)
      - Stacking (rule 2)
  - Any selection can be rewritten as an `if` statement, and any repetition can be rewritten as a `while` statement