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PowerPoint to accompany

Introduction to MATLAB 7 for Engineers

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Chapter 4
Programming with MATLAB

Algorithms and Control Structures

Algorithm: an ordered sequence of precisely defined instructions that performs some task in a finite amount of time. *Ordered* means that the instructions can be numbered, but an algorithm must have the ability to alter the order of its instructions using a *control structure*. There are three categories of algorithmic operations:

Sequential operations: Instructions executed in order.

Conditional operations: *C*ontrol structures that first ask a question to be answered with a true/false answer and then select the next instruction based on the answer.

*Iterative operations (loops): C*ontrol structures that repeat the execution of a block of instructions.

Structured Programming

A technique for designing programs in which a hierarchy of *modules* is used, each having a single entry and a single exit point, and in which control is passed downward through the structure without unconditional branches to higher levels of the structure.

In MATLAB these modules can be built-in or user-defined functions.

Advantages of structured programming

1. Structured programs are easier to write because the programmer can study the overall problem first and then deal with the details later.

2. Modules (functions) written for one application can be used for other applications (this is called *reusable code*).

3. Structured programs are easier to debug because each module is designed to perform just one task and thus it can be tested separately from the other modules.

(continued …)

Advantages of structured programming (continued)

4. Structured programming is effective in a teamwork environment because several people can work on a common program, each person developing one or more modules.

5. Structured programs are easier to understand and modify, especially if meaningful names are chosen for the modules and if the documentation clearly identifies the module's task.

More? See pages 184-185

Steps for developing a computer solution: **Table 4.1–1**

1. State the problem concisely.

2. Specify the data to be used by the program. This is the "input."

3. Specify the information to be generated by the program. This is the "output."

4. Work through the solution steps by hand or with a calculator; use a simpler set of data if necessary.

(continued …)

Steps for developing a computer solution (continued)

5. Write and run the program.

6. Check the output of the program with your hand solution.

7. Run the program with your input data and perform a reality check on the output.

8. If you will use the program as a general tool in the future, test it by running it for a range of reasonable data values; perform a reality check on the results.

Effective documentation can be accomplished with the use of

1. Proper selection of variable names to reflect the quantities they represent.

2. Use of comments within the program.

3. Use of structure charts.

4. Use of flowcharts.

5. A verbal description of the program, often in *pseudocode*.

Documenting with Charts

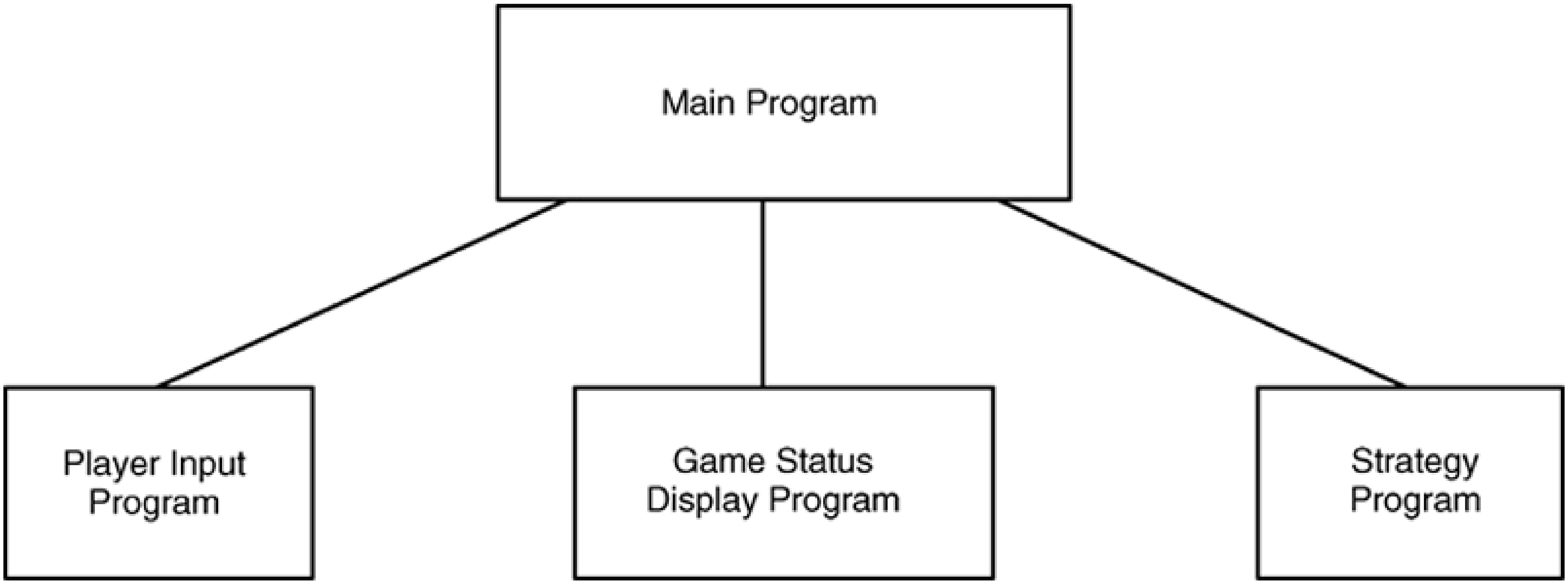
Two types of charts aid in developing structured programs and in documenting them.

These are *structure charts* and *flowcharts*.

A structure chart is a graphical description showing how the different parts of the program are connected together.

Structure chart of a game program.

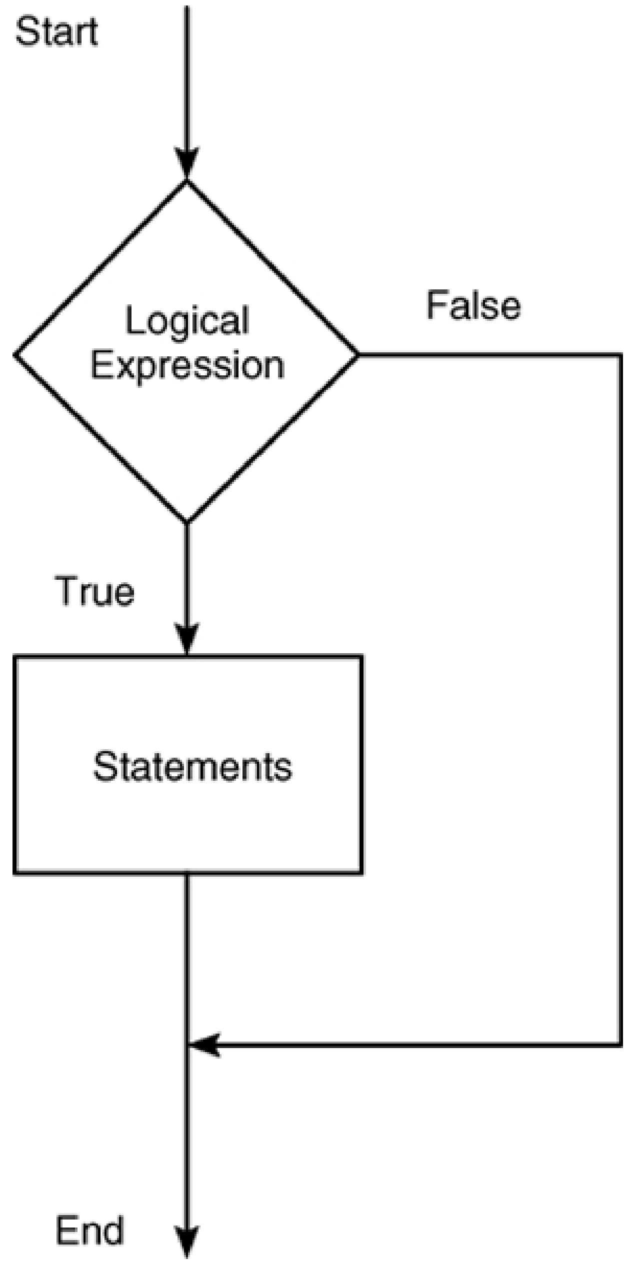
Figure 4.1–1



Flowcharts are useful for developing and documenting programs that contain conditional statements, because they can display the various paths (called “branches”) that a program can take, depending on how the conditional statements are executed.

Flowchart representation of the `if` statement.

Figure 4.1–2



Documenting with Pseudocode

We can document with *pseudocode,* in which natural language and mathematical expressions are used to construct statements that look like computer statements but without detailed syntax.

Each pseudocode instruction may be numbered, but should be unambiguous and computable.

More? See pages 185-190.

Finding Bugs

Debugging a program is the process of finding and removing the “bugs,” or errors, in a program. Such errors usually fall into one of the following categories.

1. Syntax errors such as omitting a parenthesis or comma, or spelling a command name incorrectly. MATLAB usually detects the more obvious errors and displays a message describing the error and its location.

2. Errors due to an incorrect mathematical procedure. These are called *runtime errors*. They do not necessarily occur every time the program is executed; their occurrence often depends on the particular input data. A common example is division by zero.

To locate a runtime error, try the following:

1. Always test your program with a simple version of the problem, whose answers can be checked by hand calculations.

2. Display any intermediate calculations by removing semicolons at the end of statements.

(continued …)

Finding runtime errors (continued)

3. To test user-defined functions, try commenting out the `function` line and running the file as a script.

4. Use the debugging features of the Editor/Debugger, which is discussed in Section 4.7.

Development of Large Programs

1. Writing and testing of individual modules (the *unit-testing* phase).

2. Writing of the top-level program that uses the modules (the *build* phase). Not all modules are included in the initial testing. As the build proceeds, more modules are included.

(continued …)

Development of Large Programs (continued)

3. Testing of the first complete program (the *alpha release* phase). This is usually done only in-house by technical people closely involved with the program development. There might be several alpha releases as bugs are discovered and removed.

4. Testing of the final alpha release by in-house personnel and by familiar and trusted outside users, who often must sign a confidentiality agreement. This is the *beta release* phase, and there might be several beta releases.

Relational operators

Table 4.2–1

Operator	Meaning
<	Less than.
<=	Less than or equal to.
>	Greater than.
>=	Greater than or equal to.
==	Equal to.
~=	Not equal to.

For example, suppose that `x = [6,3,9]` and `y = [14,2,9].` The following MATLAB session shows some examples.

```
>>z = (x < y)
z =
   1   0   0
>>z = (x ~= y)
z =
   1   1   0
>>z = (x > 8)
z =
   0   0   1
```

The relational operators can be used for array addressing.

For example, with `x = [6,3,9]` and `y = [14,2,9]`, typing

```
z = x(x<y)
```

finds all the elements in x that are less than the corresponding elements in y. The result is `z = 6`.

The arithmetic operators +, -, *, /, and \ have precedence over the relational operators. Thus the statement

```
z = 5 > 2 + 7
```

is equivalent to

```
z = 5 >(2+7)
```

and returns the result `z = 0`.

We can use parentheses to change the order of precedence; for example, `z = (5 > 2) + 7` evaluates to `z = 8`.

More? See pages 191-192.

The logical Class

When the relational operators are used, such as

```
x = (5 > 2)
```

they create a *logical* variable, in this case, x.

Prior to MATLAB 6.5 *logical* was an attribute of any numeric data type. Now logical is a first-class data type and a MATLAB class, and so logical is now equivalent to other first-class types such as character and cell arrays.

Logical variables may have only the values 1 (true) and 0 (false).

Just because an array contains only 0s and 1s, however, it is not necessarily a logical array. For example, in the following session `k` and `w` appear the same, but `k` is a logical array and `w` is a numeric array, and thus an error message is issued.

```
>>x = [-2:2]; k = (abs(x)>1)
k =
    1    0    0     0     1
>>z = x(k)
z =
    -2   2
>>w = [1,0,0,0,1]; v = x(w)
??? Subscript indices must either be real
  positive... integers or logicals.
```


More? See pages 192-193.

Accessing Arrays Using Logical Arrays

When a logical array is used to address another array, it extracts from that array the elements in the locations where the logical array has 1s.

So typing A(B), where B is a logical array of the same size as A, returns the values of A at the indices where B is 1.

(continued …)

Accessing Arrays Using Logical Arrays (continued)

Specifying array subscripts with logical arrays extracts the elements that correspond to the true (1) elements in the logical array.

Given `A =[5,6,7;8,9,10;11,12,13]` and `B = logical(eye(3))`, we can extract the diagonal elements of `A` by typing `C = A(B)` to obtain `C = [5;9;13]`.

More? See page 194.

Logical operators

Table 4.3–1

<table>
<tr><th>Operator</th><th>Name</th><th>Definition</th></tr>
<tr><td>~</td><td>NOT</td><td>~A returns an array the same dimension as A; the new array has ones where A is zero and zeros where A is nonzero.</td></tr>
<tr><td>&</td><td>AND</td><td>A & B returns an array the same dimension as A and B; the new array has ones where both A and B have nonzero elements and zeros where either A or B is zero.</td></tr>
<tr><td>|</td><td>OR</td><td>A | B returns an array the same dimension as A and B; the new array has ones where at least one element in A or B is nonzero and zeros where A and B are both zero.</td></tr>
</table>

(continued …)

Table 4.3–1 (continued)

Operator	Name	Definition
&&	Short-Circuit AND	Operator for scalar logical expressions. A && B returns true if both A and B evaluate to true, and false if they do not.
||	Short-Circuit OR	Operator for scalar logical expressions. A || B returns true if either A or B or both evaluate to true, and false if they do not.

Order of precedence for operator types. Table 4.3–2

Precedence	Operator type
First	Parentheses; evaluated starting with the innermost pair.
Second	Arithmetic operators and logical NOT (~); evaluated from left to right.
Third	Relational operators; evaluated from left to right.
Fourth	Logical AND.
Fifth	Logical OR.

Logical functions: Table 4.3–4

Logical function	**Definition**
`all(x)`	Returns a scalar, which is 1 if all the elements in the vector `x` are nonzero and 0 otherwise.
`all(A)`	Returns a row vector having the same number of columns as the matrix A and containing ones and zeros, depending on whether or not the corresponding column of A has all nonzero elements.
`any(x)`	Returns a scalar, which is 1 if any of the elements in the vector `x` is nonzero and 0 otherwise.
`any(A)`	Returns a row vector having the same number of columns as A and containing ones and zeros, depending on whether or not the corresponding column of the matrix A contains any nonzero elements.
`finite(A)`	Returns an array of the same dimension as A with ones where the elements of A are finite and zeros elsewhere.

(continued …)

Table 4.3–4 (continued)

Logical function	Definition
`ischar(A)`	Returns a 1 if `A` is a character array and 0 otherwise.
`isempty(A)`	Returns a 1 if `A` is an empty matrix and 0 otherwise.
`isinf(A)`	Returns an array of the same dimension as `A`, with ones where `A` has '`inf`' and zeros elsewhere.
`isnan(A)`	Returns an array of the same dimension as `A` with ones where `A` has '`NaN`' and zeros elsewhere. ('`NaN`' stands for "not a number," which means an undefined result.)

(continued …)

Table 4.3–4 (continued)

`isnumeric(A)`	Returns a 1 if A is a numeric array and 0 otherwise.
`isreal(A)`	Returns a 1 if A has no elements with imaginary parts and 0 otherwise.
`logical(A)`	Converts the elements of the array A into logical values.
`xor(A,B)`	Returns an array the same dimension as A and B; the new array has ones where either A or B is nonzero, but not both, and zeros where A and B are either both nonzero or both zero.

The `find` Function

`find(A)`

Computes an array containing the indices of the nonzero elements of the array A.

`[u,v,w] = find(A)`

Computes the arrays `u` and `v` containing the row and column indices of the nonzero elements of the array A and computes the array `w` containing the values of the nonzero elements. The array `w` may be omitted.

Logical Operators and the `find` Function

Consider the session

```
>>x = [5, -3, 0, 0, 8];y = [2, 4, 0, 5, 7];
>>z = find(x&y)
z =
   1    2    5
```

Note that the find function returns the *indices*, and not the *values*.

(continued …)

Logical Operators and the find Function (continued)

Remember, the find function returns the *indices,* and not the *values*. In the following session, note the difference between the result obtained by `y(x&y)` and the result obtained by `find(x&y)` in the previous slide.

```
>>x = [5, -3, 0, 0, 8];y = [2, 4, 0, 5, 7];
>>values = y(x&y)
values =
   2    4     7
>>how_many = length(values)
how_many =
   3
```


More? See pages 198-199.

The `if` Statement

The `if` statement's basic form is

`if` *logical expression*
    statements
`end`

Every `if` statement must have an accompanying end statement. The end statement marks the end of the *statements* that are to be executed if the *logical expression* is true.

More? See pages 201-202.

The `else` Statement

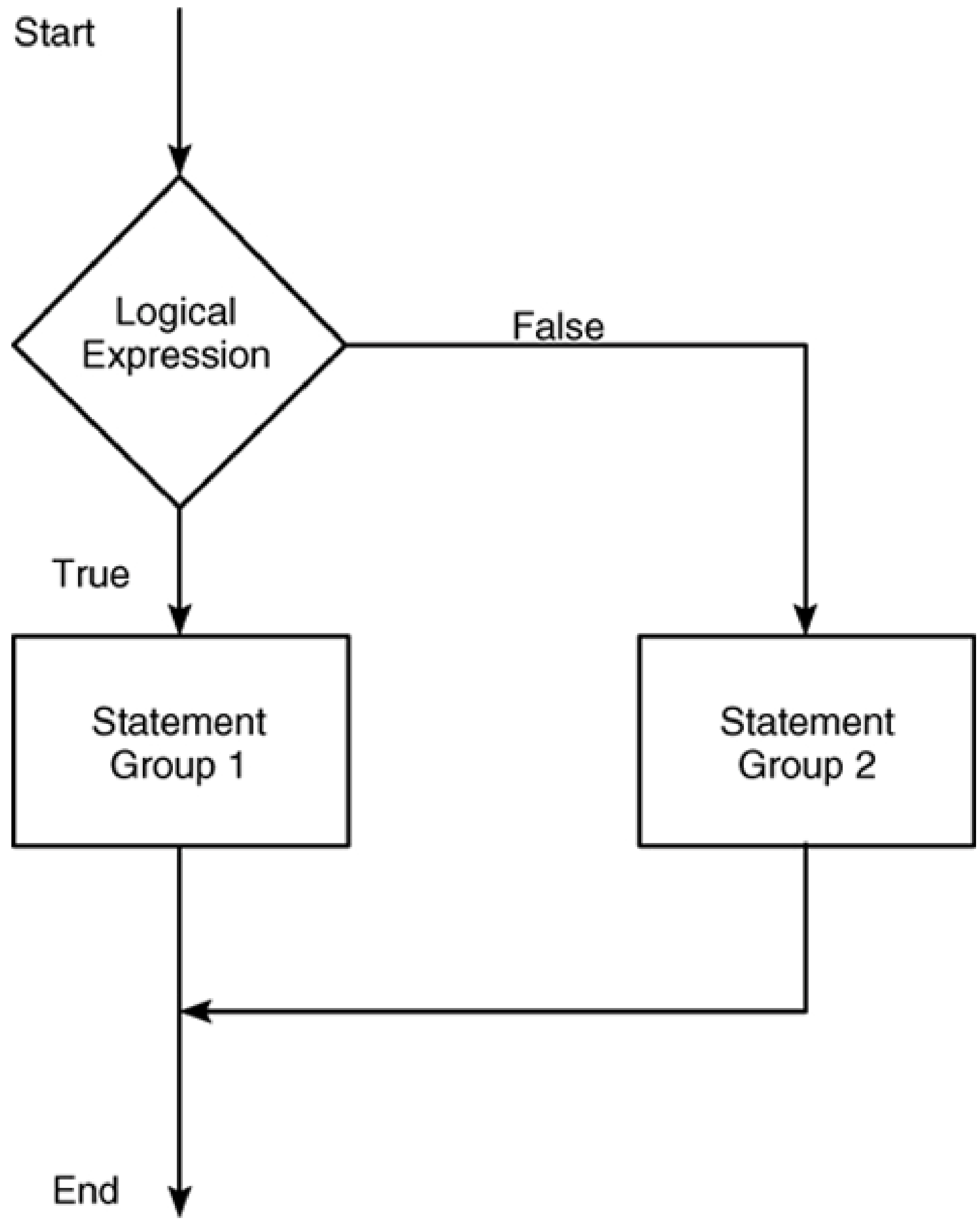
The basic structure for the use of the `else` statement is

`if` *logical expression*
  statement group 1
`else`
  statement group 2
`end`

More? See pages 202-205.

Flowchart of the `else` structure.

Figure 4.4–2



When the test, if *logical expression,* is performed, where the logical expression may be an *array,* the test returns a value of true only if *all* the elements of the logical expression are true!

For example, if we fail to recognize how the test works, the following statements do not perform the way we might expect.

```
x = [4,-9,25];
if x < 0
   disp('Some elements of x are negative.')
else
   y = sqrt(x)
end
```

Because the test `if x < 0` is false, when this program is run it gives the result

```
y =
 2   0 + 3.000i   5
```

Instead, consider what happens if we test for `x` positive.

```
x = [4,-9,25];
if x >= 0
  y = sqrt(x)
else
  disp('Some elements of x are negative.')
end
```

When executed, it produces the following message:

```
Some elements of x are negative.
```

The test `if x < 0` is false, and the test if `x >= 0` also returns a false value because `x >= 0` returns the vector `[1,0,1]`.

The following statements

```
if logical expression 1
   if logical expression 2
     statements
  end
end
```

can be replaced with the more concise program

```
if logical expression 1 & logical expression 2
  statements
end
```

The `elseif` Statement

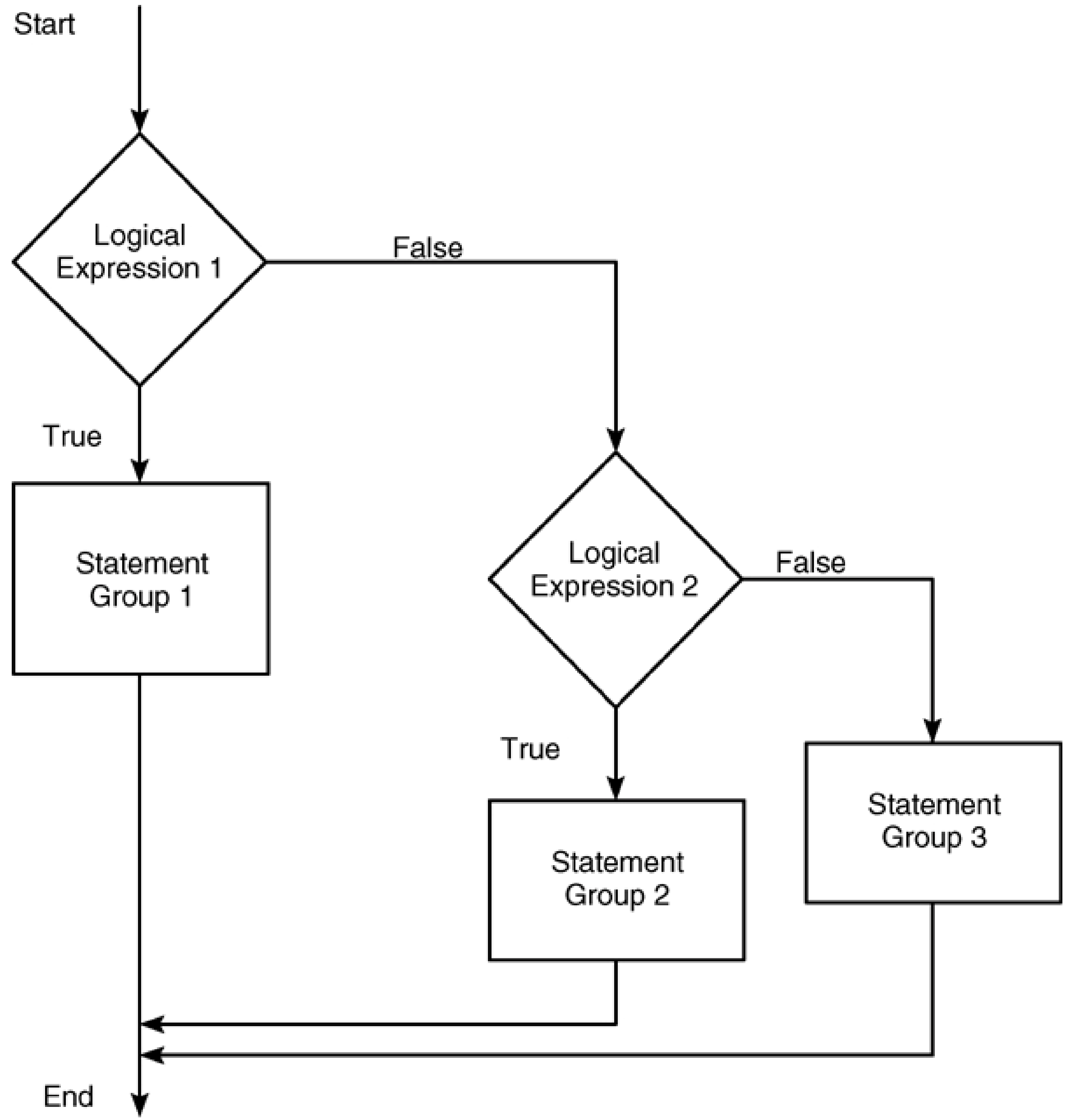
The general form of the `if` statement is

```
if logical expression 1
     statement group 1
elseif logical expression 2
     statement group 2
else
     statement group 3
end
```

The `else` and `elseif` statements may be omitted if not required. However, if both are used, the `else` statement must come after the `elseif` statement to take care of all conditions that might be unaccounted for.

Flowchart for the general `if-elseif-else` structure.

Figure 4.4–3



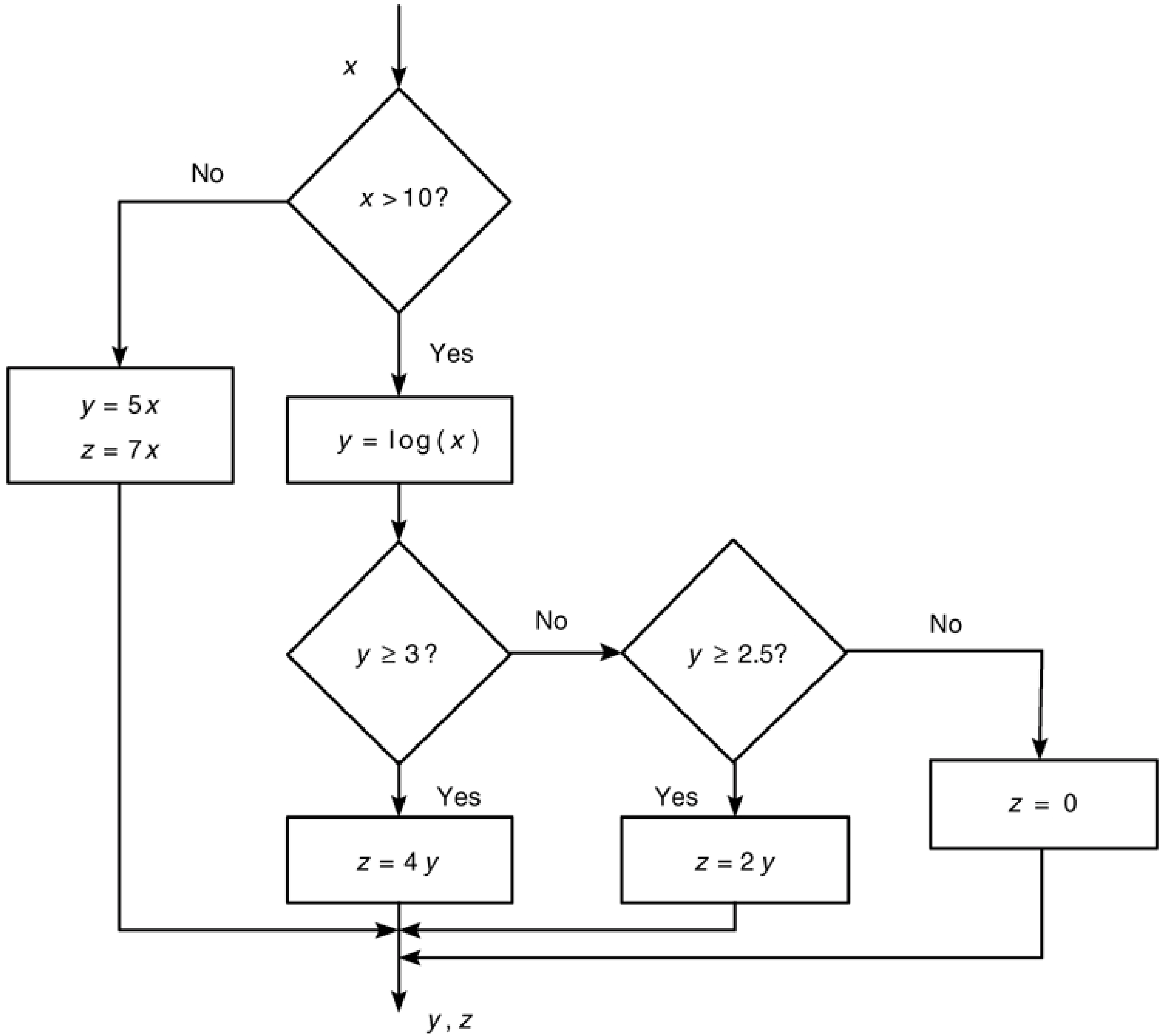
For example, suppose that `y = log(x)` for *x* `> 10`, *y* `= sqrt(`*x*`)` for `0 <= x <= 10`, and `y = exp(x) - 1` for `x < 0`. The following statements will compute y if `x` already has a scalar value.

```
if x > 10
  y = log(x)
elseif x >= 0
  y = sqrt(x)
else
  y = exp(x) - 1
end
```


More? See pages 205-208.

Flowchart illustrating nested `if` statements.

Figure 4.4–4



Strings

A *string* is a variable that contains characters. Strings are useful for creating input prompts and messages and for storing and operating on data such as names and addresses.

To create a string variable, enclose the characters in single quotes. For example, the string variable `name` is created as follows:

```
>>name = ’Leslie Student’
name =
   Leslie Student
```

(continued …)

Strings (continued)

The following string, `number`, is *not* the same as the variable number created by typing `number = 123`.

```
>>number = '123'
number =
    123
```

Strings and the `input` Statement

The prompt program on the next slide uses the `isempty(x)` function, which returns a 1 if the array `x` is empty and 0 otherwise.

It also uses the input function, whose syntax is

`x = input('`*`prompt`*`', '`*`string`*`')`

This function displays the string `prompt` on the screen, waits for input from the keyboard, and returns the entered value in the string variable `x`.

The function returns an empty matrix if you press the **Enter** key without typing anything.

Strings and Conditional Statements

The following prompt program is a script file that allows the user to answer *Yes* by typing either Y or y or by pressing the **Enter** key. Any other response is treated as the answer *No*.

```
response = input('Want to continue? Y/N [Y]: ','s');
if (isempty(response))|(response=='Y')|(response=='y')
  response = 'Y'
else
  response = 'N'
end
```


More? See pages 209-210.

for Loops

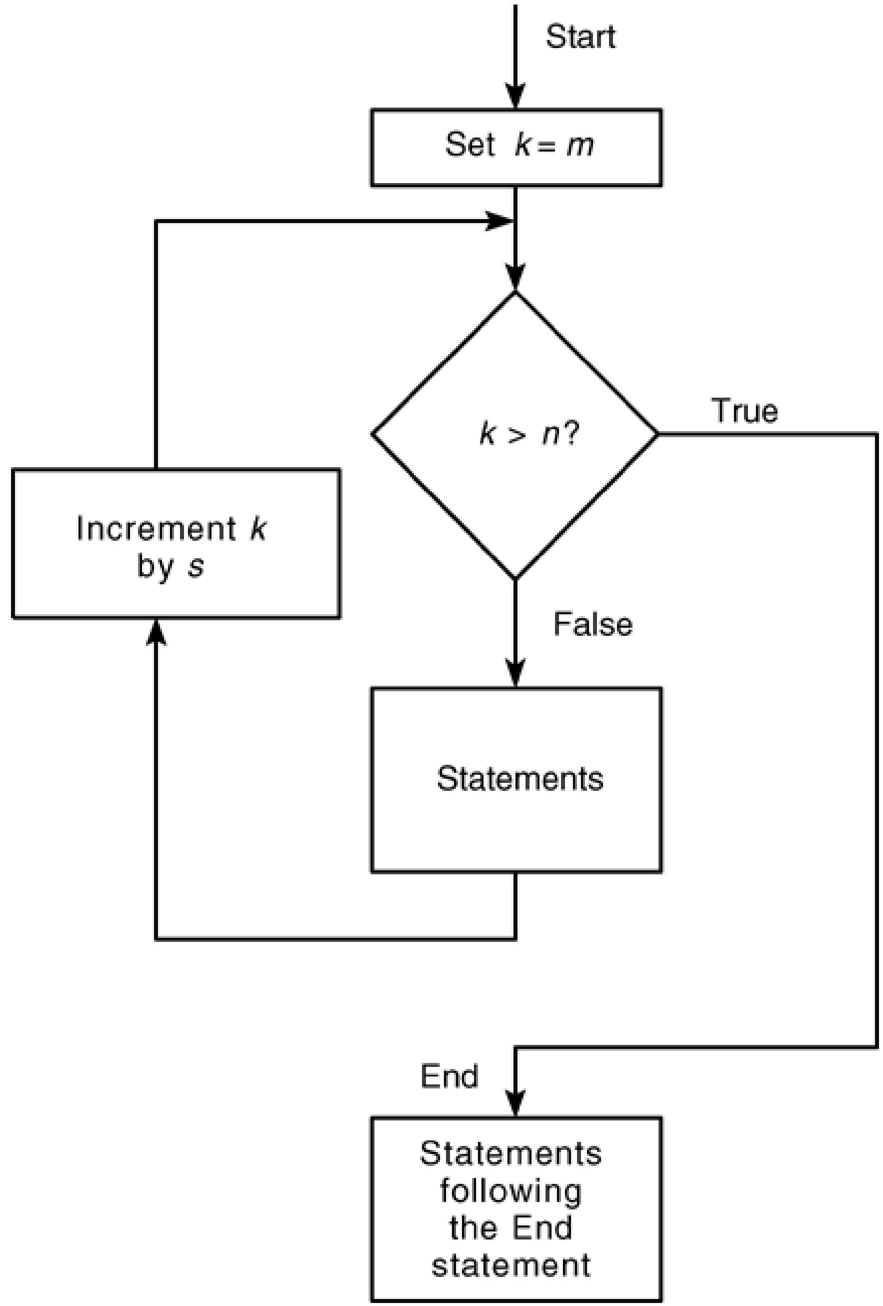
A simple example of a `for` loop is

```
for k = 5:10:35
  x = k^2
end
```

The *loop variable* `k` is initially assigned the value 5, and `x` is calculated from `x = k^2`. Each successive pass through the loop increments `k` by 10 and calculates `x` until `k` exceeds 35. Thus `k` takes on the values 5, 15, 25, and 35, and `x` takes on the values 25, 225, 625, and 1225. The program then continues to execute any statements following the end statement.

Flowchart of a `for` Loop.

Figure 4.5–1



Note the following rules when using for loops with the loop variable expression `k = m:s:n`:

- The step value `s` may be negative.

  Example: `k = 10:-2:4` produces k = 10, 8, 6, 4.
- If `s` is omitted, the step value defaults to 1.
- If `s` is positive, the loop will not be executed if `m` is greater than n.
- If `s` is negative, the loop will not be executed if `m` is less than n.
- If `m` equals n, the loop will be executed only once.
- If the step value `s` is not an integer, round-off errors can cause the loop to execute a different number of passes than intended.

The `continue` Statement

The following code uses a `continue` statement to avoid computing the logarithm of a negative number.

```
x = [10,1000,-10,100];
y = NaN*x;
for k = 1:length(x)
  if x(k) < 0
    continue
  end
  y(k) = log10(x(k));
end
y
```

The result is `y = 1, 3, NaN, 2`.

More? See pages 210-217.

Use of a *Mask*

We can often avoid the use of loops and branching and thus create simpler and faster programs by using a logical array as a *mask* that selects elements of another array. Any elements not selected will remain unchanged.

The following session creates the logical array `C` from the numeric array `A` given previously.

```
>>A = [0, -1, 4; 9, -14, 25; -34, 49, 64];
>>C = (A >= 0);
```

The result is

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

We can use this mask technique to compute the square root of only those elements of A given in the previous program that are no less than 0 and add 50 to those elements that are negative. The program is

```
A = [0, -1, 4; 9, -14, 25; -34, 49, 64];
C = (A >= 0);
A(C) = sqrt(A(C))
A(~C) = A(~C) + 50
```


More? See pages 217-218.

`while` Loops

The `while` loop is used when the looping process terminates because a specified condition is satisfied, and thus the number of passes is not known in advance. A simple example of a while loop is

```
x = 5;
while x < 25
   disp(x)
   x = 2*x - 1;
end
```

The results displayed by the `disp` statement are 5, 9, and 17.

The typical structure of a while loop follows.

```
while logical expression
    statements
end
```

For the `while` loop to function properly, the following two conditions must occur:

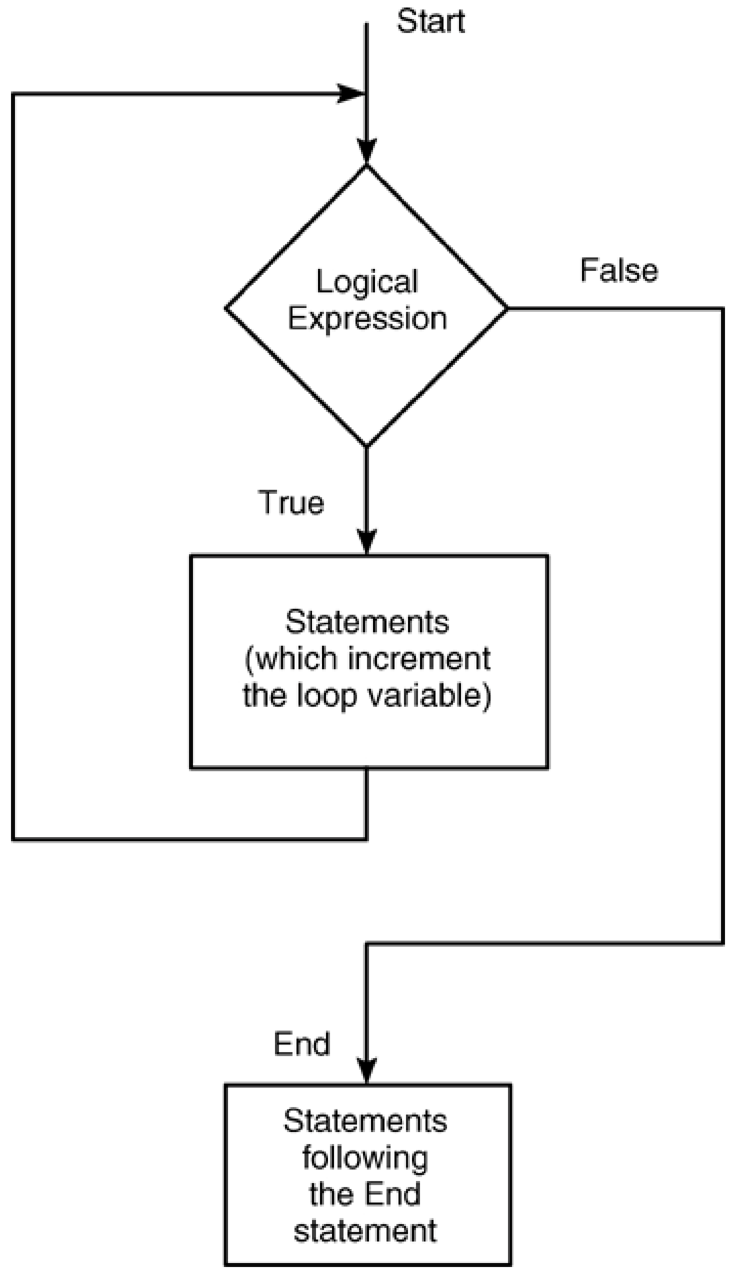
1. The loop variable must have a value before the while statement is executed.

2. The loop variable must be changed somehow by the *statements.*

More? See pages 221-223.

Flowchart of the `while` loop.

Figure 4.5–3



A simple example of a `while` loop is

```
x = 5;k = 0;
while  x < 25
   k = k + 1;
   y(k) = 3*x;
   x = 2*x-1;
end
```

The loop variable `x` is initially assigned the value 5, and it keeps this value until the statement `x = 2*x - 1` is encountered the first time. Its value then changes to 9. Before each pass through the loop, `x` is checked to see if its value is less than 25. If so, the pass is made. If not, the loop is skipped.

Another Example of a `while` Loop

Write a script file to determine how many terms are required for the sum of the series $5k^2 - 2k$, $k = 1, 2, 3, \ldots$ to exceed 10,000. What is the sum for this many terms?

```
total = 0;k = 0;
while total < 1e+4
   k = k + 1;
   total = 5*k^2 - 2*k + total;
end
disp('The number of terms is:')
disp(k)
disp('The sum is:')
disp(total)
```

The sum is 10,203 after 18 terms.

The `switch` Structure

The `switch` structure provides an alternative to using the `if`, `elseif`, and `else` commands. Anything programmed using `switch` can also be programmed using `if` structures.

However, for some applications the `switch` structure is more readable than code using the `if` structure.

Syntax of the switch structure

```
switch input expression
```
(which can be a scalar or string).

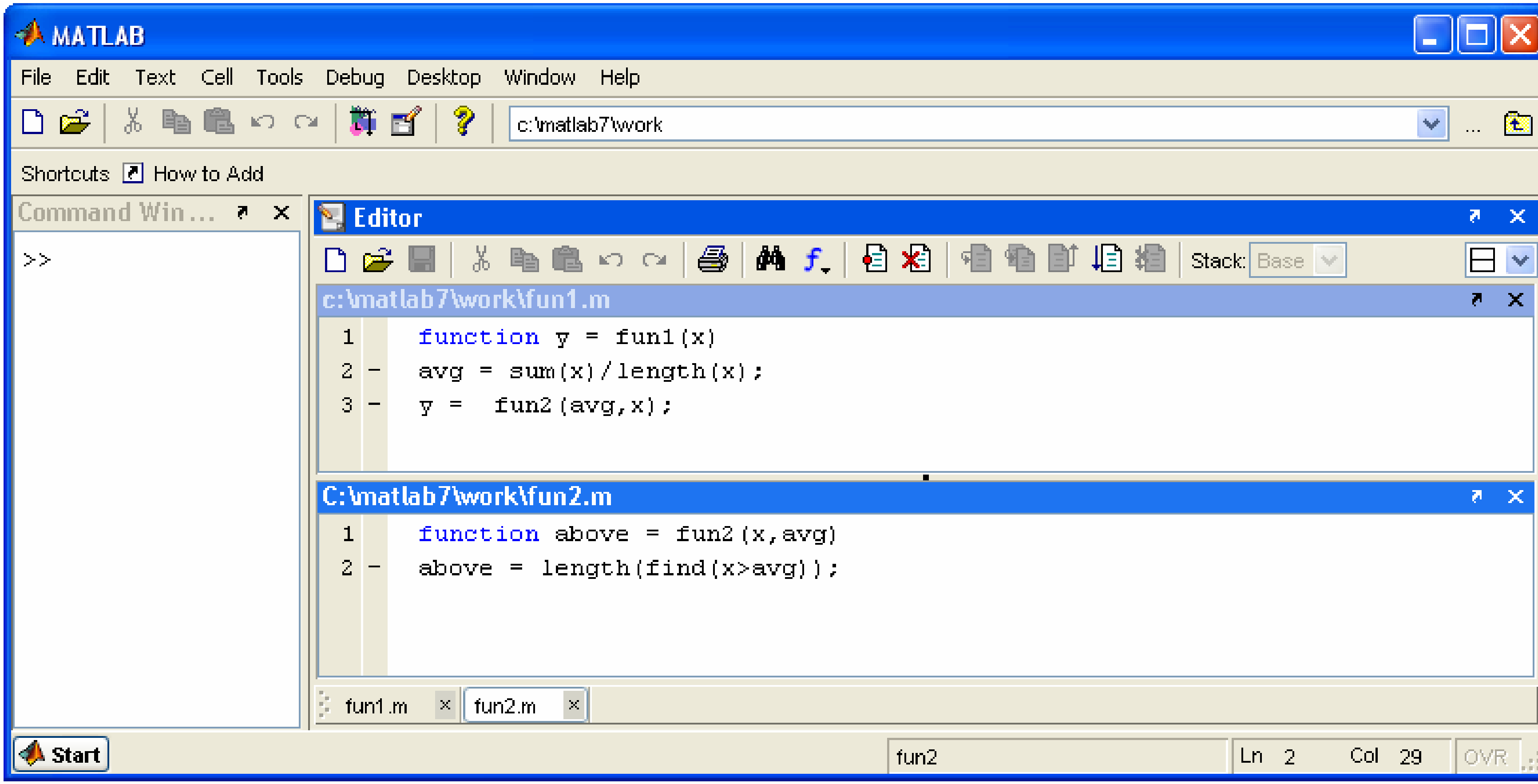
```
   case value1
        statement group 1
   case value2
        statement group 2
   .
   .
   .
   otherwise
        statement group n
end
```

The following switch block displays the point on the compass that corresponds to that angle.

```
switch angle
 case 45
   disp('Northeast')
 case 135
   disp('Southeast')
 case 225
   disp('Southwest')
 case 315
   disp('Northwest')
 otherwise
   disp('Direction Unknown')
end
```

 More? See pages 225-227.

The Editor/Debugger containing two programs to be analyzed. Figure 4.7–1

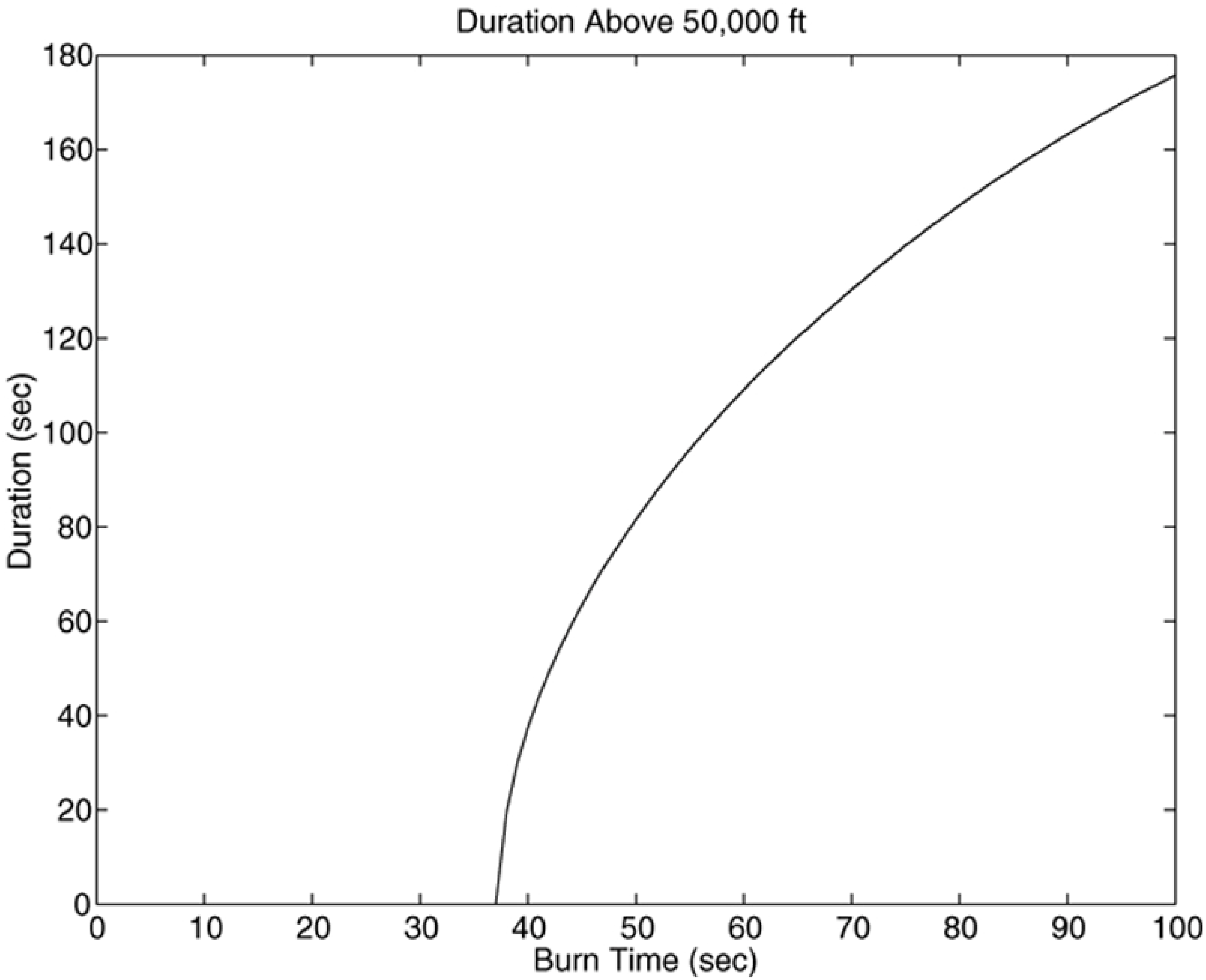


 More? See pages 228-234.

The remaining slides show figures from Chapter 4 and its homework problems.

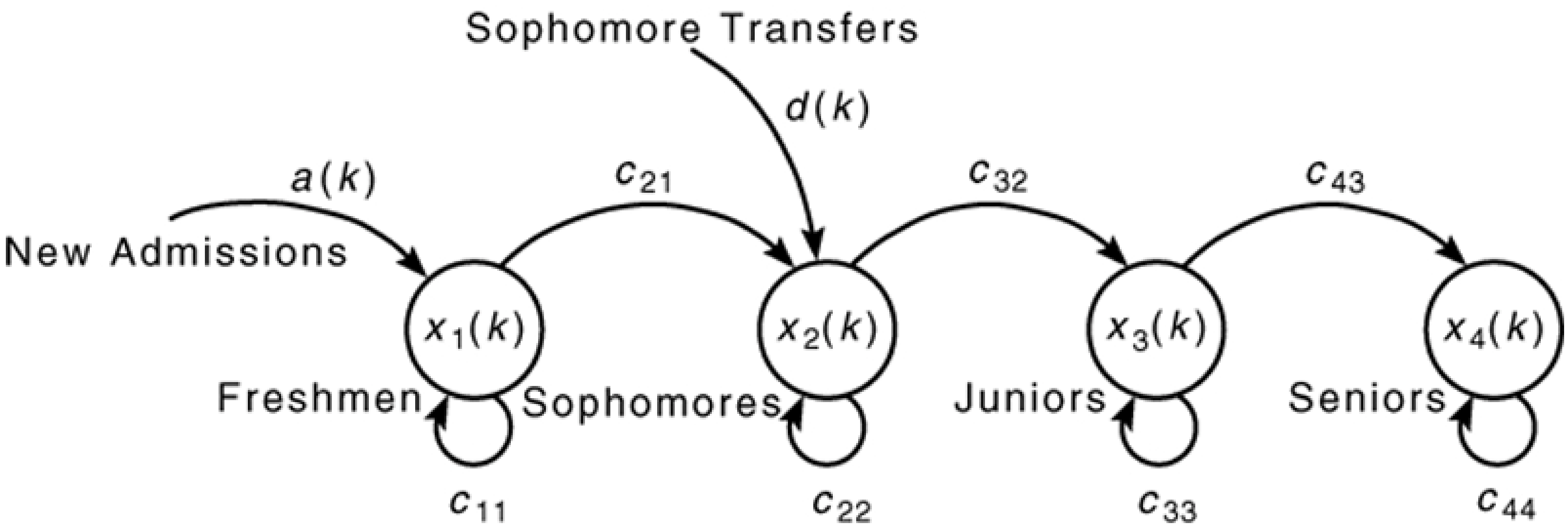
Duration above 50,000 ft as a function of the burn time.

Figure 4.5–2



The state transition diagram for the college enrollment model.

Figure 4.8–1



Class enrollments versus time.

Figure 4.8–2

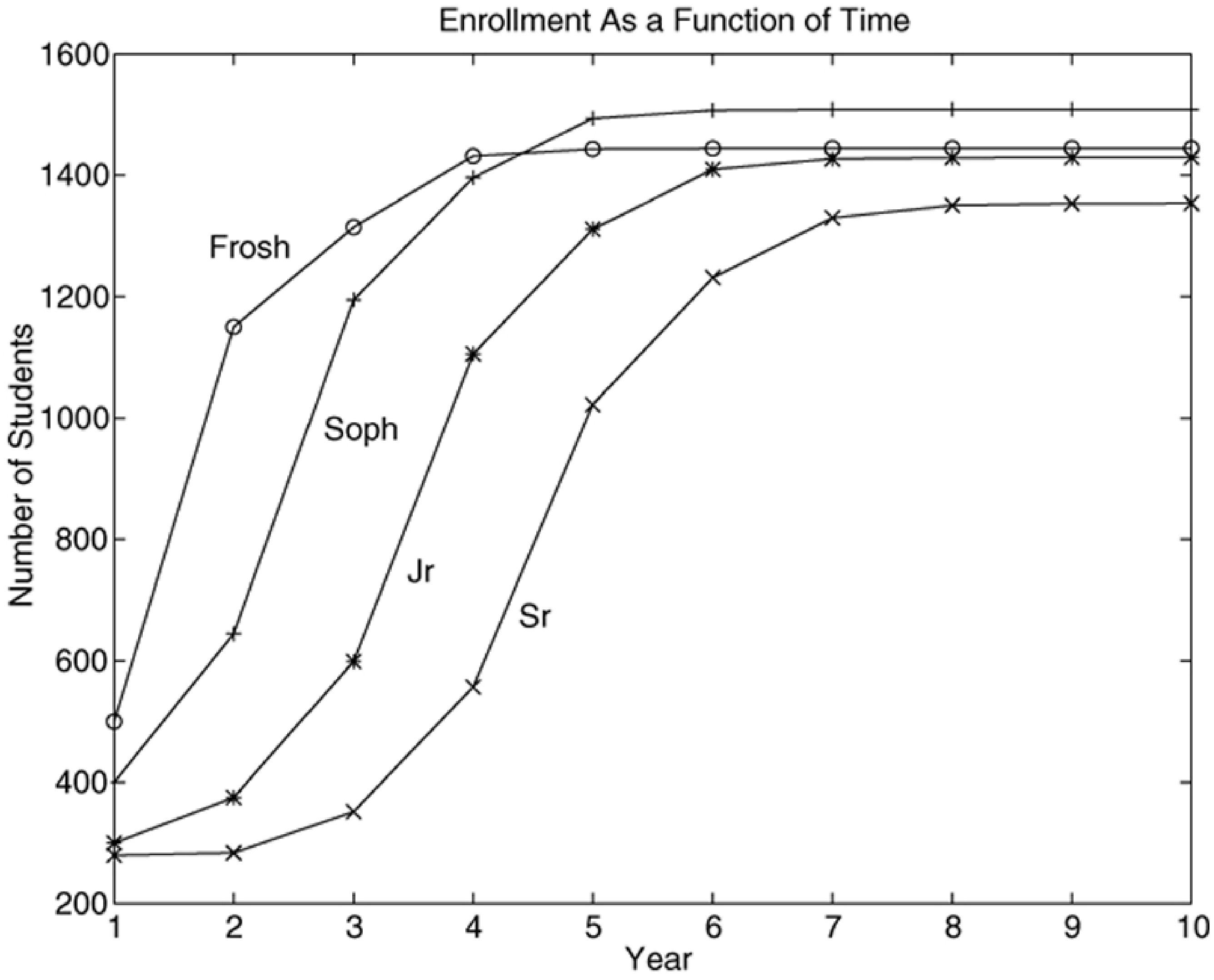
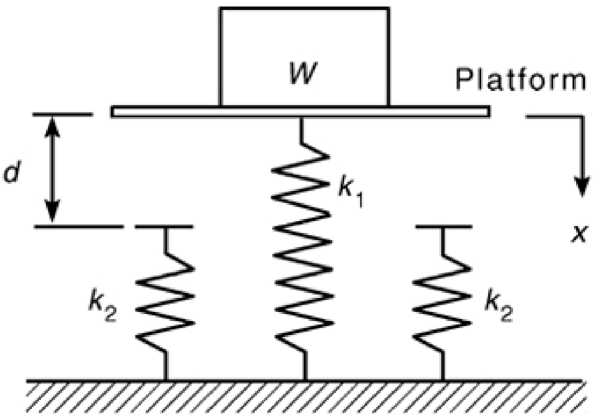
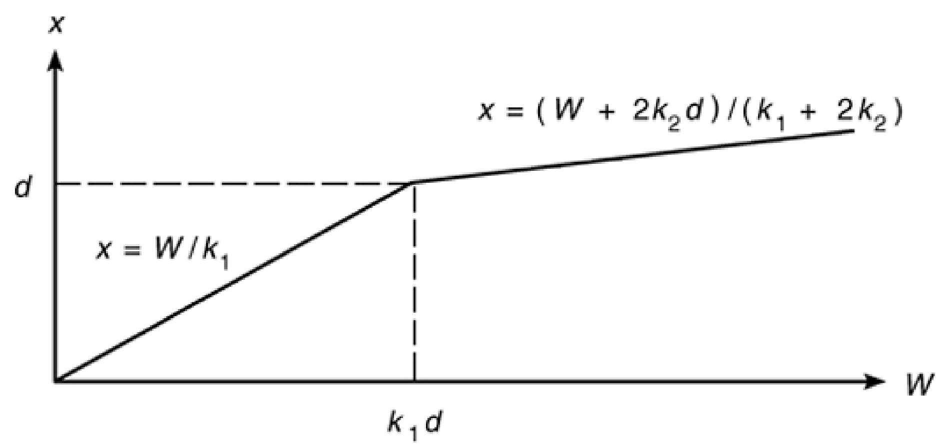


Figure P19

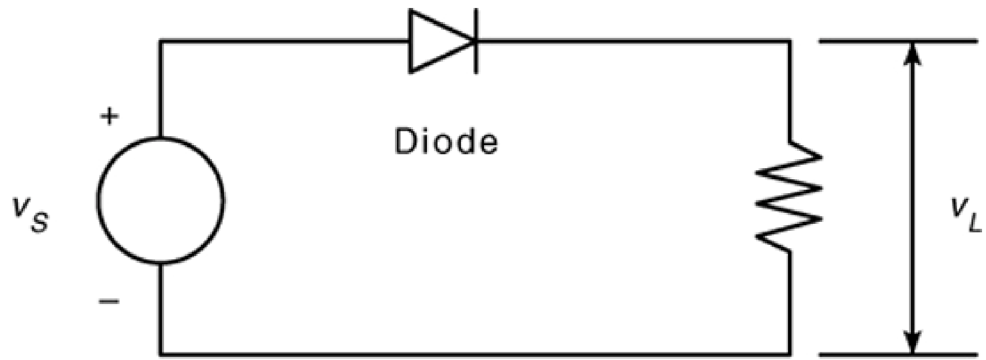


(a)

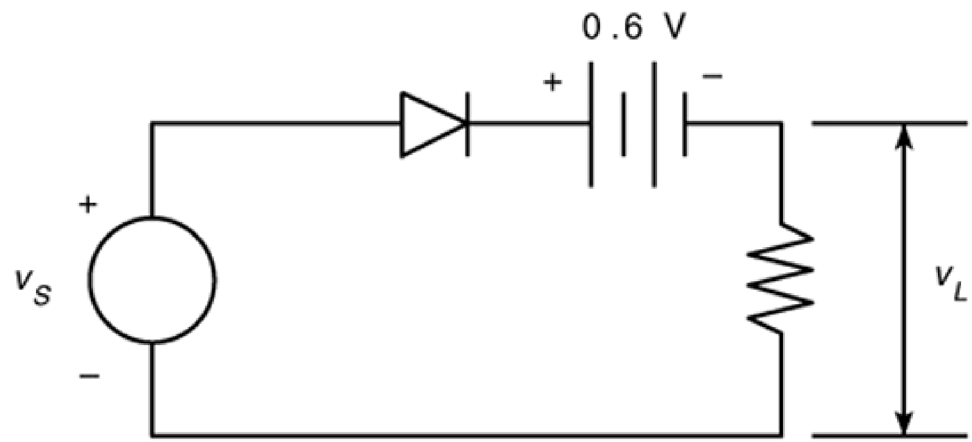


(b)

Figure P24



(a)



(b)

Figure P25

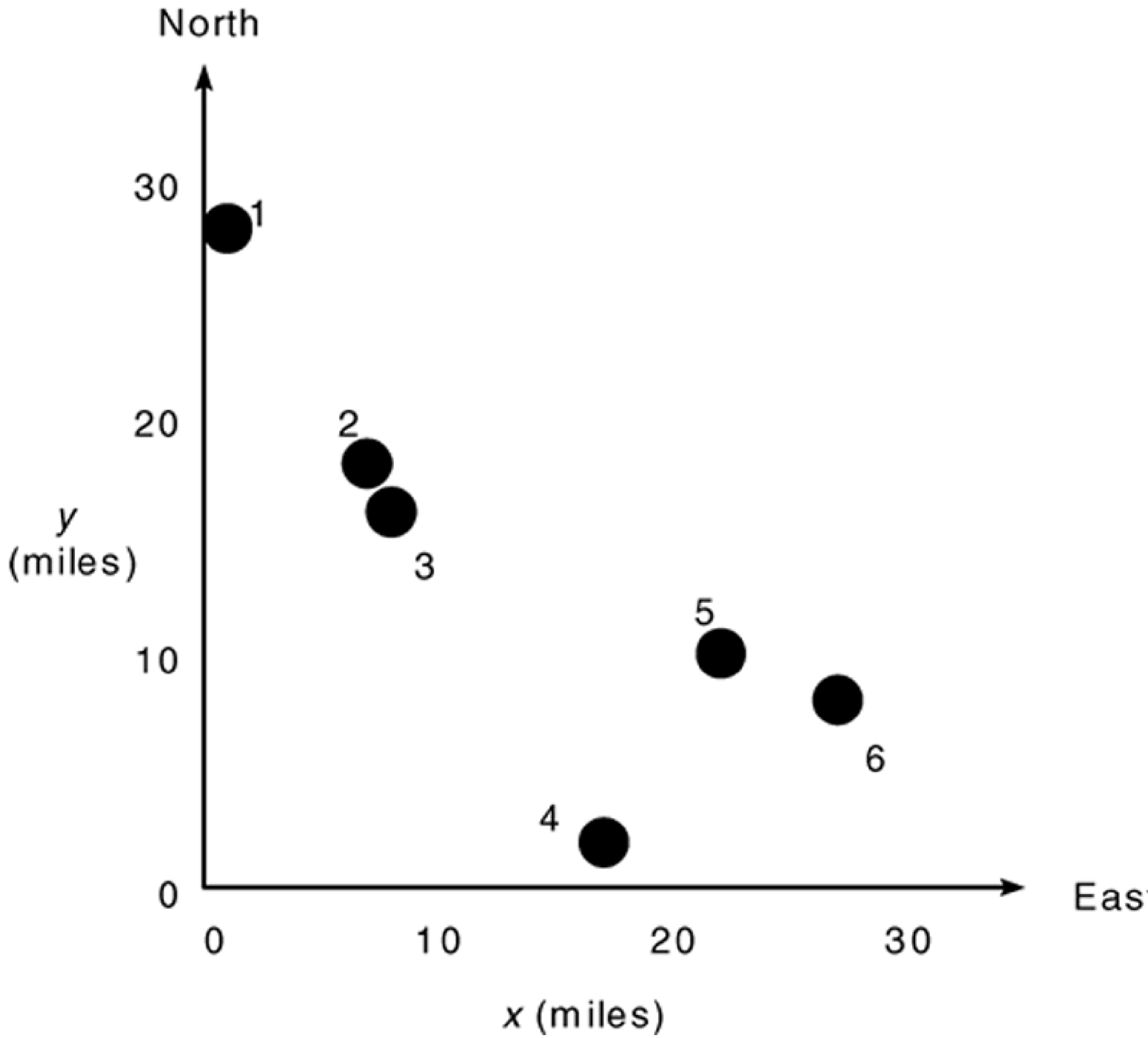


Figure P29

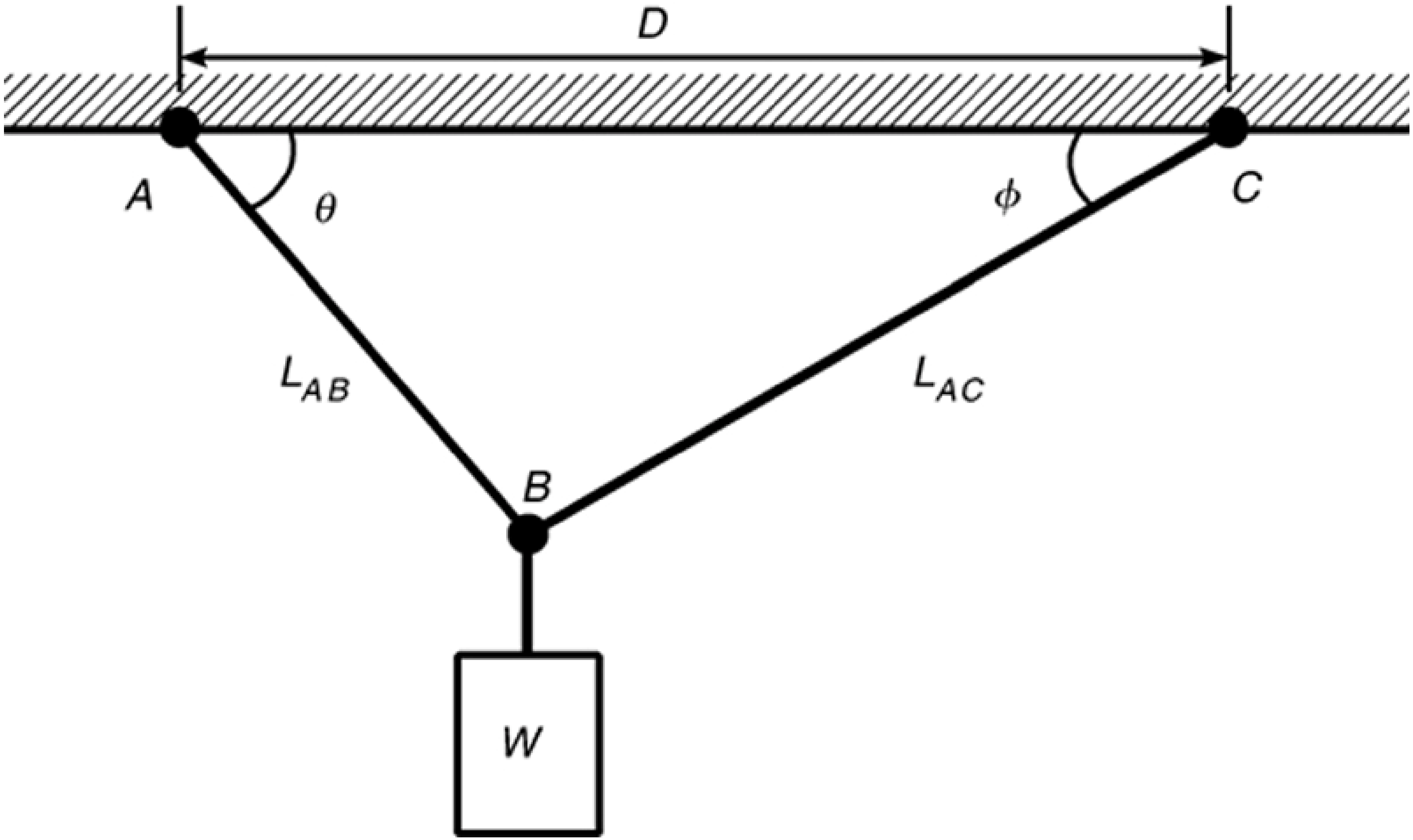
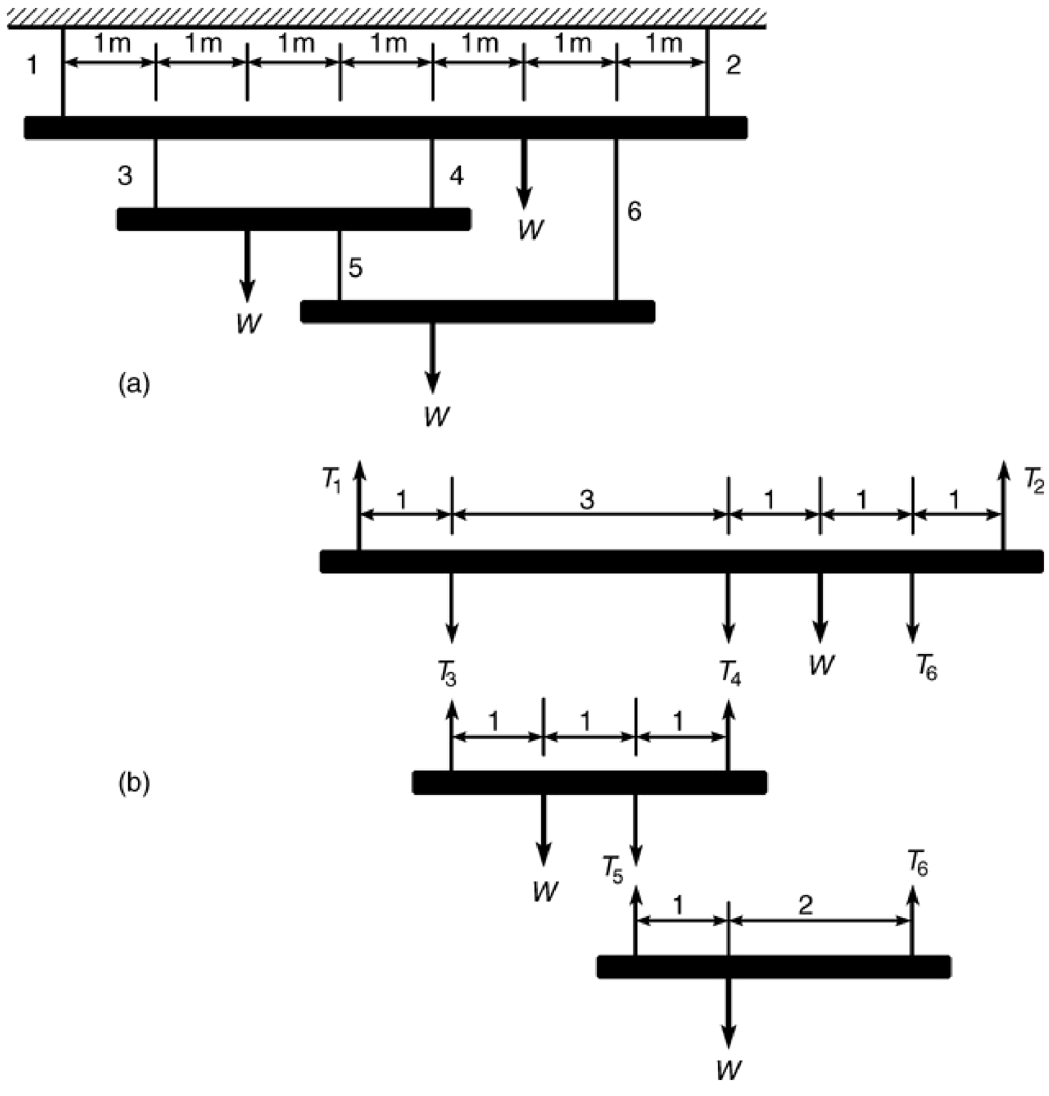


Figure P30



1m
1m
1m
1m
1m
1m
1m
1
2
3
4
6
5
W
W
W
(a)
T1
T2
1
3
1
1
1
T3
T4
W
T6
1
1
1
(b)
W
T5
T6
1
2
W

Figure P31

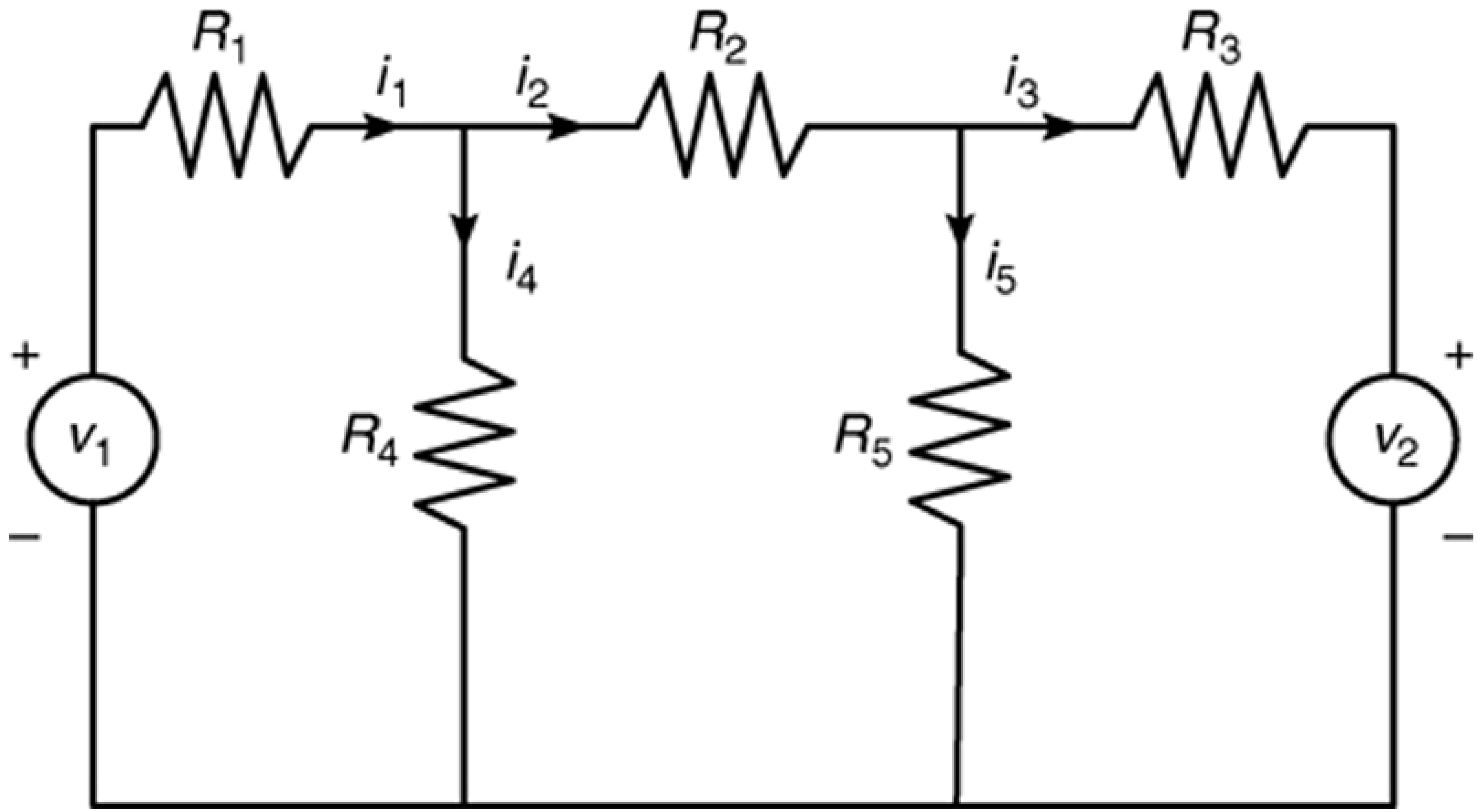


Figure P32