Instructor’s Solutions Manual

to

Concepts of Programming Languages

Seventh Edition

R.W. Sebesta
Preface

Changes to the Seventh Edition

The goals, overall structure, and approach of this seventh edition of Concepts of Programming Languages remain the same as those of the six earlier editions. The principal goals are to introduce the main constructs of contemporary programming languages and to provide the reader with the tools necessary for the critical evaluation of existing and future programming languages. An additional goal is to prepare the reader for the study of compiler design, by providing an in-depth discussion of programming language structures, presenting a formal method of describing syntax, and introducing approaches to lexical and syntactic analysis.

The seventh edition evolved from the sixth through several kinds of changes. To maintain the currency of the material, some of the discussion of older programming languages has been replaced by material on newer languages. For example, sections were added to both Chapters 1 and 2 that discuss markup/programming hybrid languages, using XSLT and JSP as examples. A section on program proofs using axiomatic semantics was added, including a new proof. The section on recursive descent parsing in Chapter 4 was strengthened by adding a new parsing routine and including a trace of a complete parse using the recursive descent algorithm. Material has been added in several places to introduce the most interesting features of Java 5.0, including its new iterative statement its enumeration class, and its generics. Finally, minor changes, primarily to improve clarity, were made to a large number of sections of the book.

The Vision

This book describes the fundamental concepts of programming languages by discussing the design issues of the various language constructs, examining the design choices for these constructs in some of the most common languages, and critically comparing design alternatives.

Any serious study of programming languages requires an examination of some related topics, among which are formal methods of describing the syntax and semantics of programming languages, which are covered in Chapter 3. Also, implementation techniques for various language constructs must be considered: Lexical and syntax analysis are discussed in Chapter 4, and implementation of subprogram linkage is covered in Chapter 10. Implementation of some other language constructs is discussed in various other parts of the book.

The following paragraphs outline the contents of the seventh edition.

Chapter Outlines

Chapter 1 begins with a rationale for studying programming languages. It then discusses the criteria used for evaluating programming languages and language constructs. The primary influences on language design, common design tradeoffs, and the basic approaches to implementation are also examined.

Chapter 2 outlines the evolution of most of the important languages discussed in this book. Although no language is described completely, the origins, purposes, and contributions of each are discussed. This historical overview is valuable, because it provides the background necessary to understanding the practical and theoretical basis for contemporary language design. It also motivates further study of language design and evaluation. In addition, because none of the remainder of the book depends on Chapter 2, it can be read on its own, independent of the other chapters.

Chapter 3 describes the primary formal method for describing the syntax of programming language—BNF. This is followed by a description of attribute grammars, which describe both the syntax and static semantics of languages. The difficult task of semantic description is then explored, including brief introductions to the three most common methods: operational, axiomatic, and denotational semantics.

Chapter 4 introduces lexical and syntax analysis. This chapter is targeted to those colleges that no longer require a compiler design course in their curricula. Like Chapter 2, this chapter stands alone and can be read independently of the rest of the book.

Chapters 5 through 14 describe in detail the design issues for the primary constructs of the imperative languages. In each case, the design choices for several example languages are presented and evaluated. Specifically, Chapter 5 covers the many characteristics of variables, Chapter 6 covers data types,
and Chapter 7 explains expressions and assignment statements. Chapter 8 describes control statements, and Chapters 9 and 10 discuss subprograms and their implementation. Chapter 11 examines data abstraction facilities. Chapter 12 provides an in-depth discussion of language features that support object-oriented programming (inheritance and dynamic method binding), Chapter 13 discusses concurrent program units, and Chapter 14 is about exception handling and event handling.

The last two chapters (15 and 16) describe two of the most important alternative programming paradigms: functional programming and logic programming. Chapter 15 presents an introduction to Scheme, including descriptions of some of its primitive functions, special forms, and functional forms, as well as some examples of simple functions written in Scheme. Brief introductions to COMMON LISP, ML, and Haskell are given to illustrate some different kinds of functional language. Chapter 16 introduces logic programming and the logic programming language, Prolog.

To the Instructor

In the junior-level programming language course at the University of Colorado at Colorado Springs, the book is used as follows: We typically cover Chapters 1 and 3 in detail, and though students find it interesting and beneficial reading, Chapter 2 receives little lecture time due to its lack of hard technical content. Because no material in subsequent chapters depends on Chapter 2, as noted earlier, it can be skipped entirely, and because we require a course in compiler design, Chapter 4 is not covered.

Chapters 5 through 9 should be relatively easy for students with extensive programming experience in C++, Java, or C#. Chapters 10 through 14 are more challenging and require more detailed lectures.

Chapters 15 and 16 are entirely new to most students at the junior level. Ideally, language processors for Scheme and Prolog should be available for students required to learn the material in these chapters. Sufficient material is included to allow students to dabble with some simple programs.

Undergraduate courses will probably not be able to cover all of the last two chapters in detail. Graduate courses, however, should be able to completely discuss the material in those chapters by skipping over parts of the early chapters on imperative languages.

Supplemental Materials

The following supplements are available to all readers of this book at www.aw.com/cssupport:

- A set of lecture notes slides. These slides are in the form of Microsoft PowerPoint source files, one for each of the chapters of the book.
- PowerPoint slides of all the figures in the book, should you wish to create your own lecture notes.
- To reinforce learning in the classroom, to assist with the hands-on lab component of this course, and/or to facilitate students in a distance learning situation, access the Companion Website at www.aw.com/sebesta. The web site contains:
  1. Mini-manuals (approximately 100-page tutorials) on a handful of languages. These proceed on the assumption that the student knows how to program in some other language, giving the student enough information to complete the chapter materials in each language. Currently, the site includes manuals for C++, C, Java, and Smalltalk.
  2. Self-grading review exercises. Using the Addison-Wesley software engine, students can complete a series of multiple-choice and fill-in-the-blank exercises to check their understanding of the chapter just read.

Solutions to many of the problem sets are available only to qualified instructors. Please contact your local Addison-Wesley sales representative, or send e-mail to aw.cse@aw.com, for information about how to access them.

Language Processor Availability

Processors for and information about some of the programming languages discussed in this book can be found at the following Web sites:
C#  microsoft.com
Java   java.sun.com
Haskell haskell.org
Scheme www.cs.rice.edu/CS/PLT/packages/drscheme/
Perl   www.perl.com

JavaScript is included in virtually all browsers; PHP is included in virtually all Web servers. All this information is also included on the companion Web site.

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Chapter 1

Problem Set:

3. Some arguments for having a single language for all programming domains are: It would dramatically cut the costs of programming training and compiler purchase and maintenance; it would simplify programmer recruiting and justify the development of numerous language dependent software development aids.

4. Some arguments against having a single language for all programming domains are: The language would necessarily be huge and complex; compilers would be expensive and costly to maintain; the language would probably not be very good for any programming domain, either in compiler efficiency or in the efficiency of the code it generated. More importantly, it would not be easy to use, because regardless of the application area, the language would include many unnecessary and confusing features and constructs (those meant for other application areas). Different users would learn different subsets, making maintenance difficult.

5. One possibility is wordiness. In some languages, a great deal of text is required for even simple complete programs. For example, COBOL is a very wordy language. In Ada, programs require a lot of duplication of declarations. Wordiness is usually considered a disadvantage, because it slows program creation, takes more file space for the source programs, and can cause programs to be more difficult to read.

7. The argument for using the right brace to close all compounds is simplicity—a right brace always terminates a compound. The argument against it is that when you see a right brace in a program, the location of its matching left brace is not always obvious, in part because all multiple-statement control constructs end with a right brace.

8. The reasons why a language would distinguish between uppercase and lowercase in its identifiers are: (1) So that variable identifiers may look different than identifiers that are names for constants, such as the convention of using uppercase for constant names and using lowercase for variable names in C, and (2) so that catenated words as names can have their first letter distinguished, as in TotalWords. (Some think it is better to include a connector, such as underscore.) The primary reason why a language would not distinguish between uppercase and lowercase in identifiers is it makes programs less readable, because words that look very similar are actually completely different, such as SUM and Sum.

10. One of the main arguments is that regardless of the cost of hardware, it is not free. Why write a program that executes slower than is necessary. Furthermore, the difference between a well-written efficient program and one that is poorly written can be a factor of two or three. In many other fields of endeavor, the difference between a good job and a poor job may be 10 or 20 percent. In programming, the difference is much greater.

15. The use of type declaration statements for simple scalar variables may have very little effect on the readability of programs. If a language has no type declarations at all, it may be an aid to readability, because regardless of where a variable is seen in the program text, its type can be determined without looking elsewhere. Unfortunately, most languages that allow implicitly declared variables also include explicit declarations. In a
program in such a language, the declaration of a variable must be found before the reader can determine the type of that variable when it is used in the program.

18. The main disadvantage of using paired delimiters for comments is that it results in diminished reliability. It is easy to inadvertently leave off the final delimiter, which extends the comment to the end of the next comment, effectively removing code from the program. The advantage of paired delimiters is that you can comment out areas of a program. The disadvantage of using only beginning delimiters is that they must be repeated on every line of a block of comments. This can be tedious and therefore error-prone. The advantage is that you cannot make the mistake of forgetting the closing delimiter.

Chapter 2

Problem Set:

6. Because of the simple syntax of LISP, few syntax errors occur in LISP programs. Unmatched parentheses is the most common mistake.

7. The main reason why imperative features were put in LISP was to increase its execution efficiency.

10. The main motivation for the development of PL/I was to provide a single tool for computer centers that must support both scientific and commercial applications. IBM believed that the needs of the two classes of applications were merging, at least to some degree. They felt that the simplest solution for a provider of systems, both hardware and software, was to furnish a single hardware system running a single programming language that served both scientific and commercial applications.

11. IBM was, for the most part, incorrect in its view of the future of the uses of computers, at least as far as languages are concerned. Commercial applications are nearly all done in languages that are specifically designed for them. Likewise for scientific applications. On the other hand, the IBM design of the 360 line of computers was a great success--it still dominates the area of computers between supercomputers and minicomputers. Furthermore, 360 series computers and their descendants have been widely used for both scientific and commercial applications. These applications have been done, in large part, in Fortran and COBOL.

14. The argument for typeless languages is their great flexibility for the programmer. Literally any storage location can be used to store any type value. This is useful for very low-level languages used for systems programming. The drawback is that type checking is impossible, so that it is entirely the programmer's responsibility to insure that expressions and assignments are correct.

18. A good deal of restraint must be used in revising programming languages. The greatest danger is that the revision process will continually add new features, so that the language grows more and more complex. Compounding the problem is the reluctance, because of existing software, to remove obsolete features.
Chapter 3

Instructor's Note:

In the program proof on pages 161-163, there is a statement that may not be clear to all, specifically, \((n + 1) * \ldots * n = 1\). The justification of this statement is as follows:

Consider the following expression:

\[(\text{count} + 1) * (\text{count} + 2) * \ldots * n\]

The former expression states that when \text{count} is equal to \(n\), the value of the later expression is 1. Multiply the later expression by the quotient:

\[(1 * 2 * \ldots * \text{count}) / (1 * 2 * \ldots * \text{count})\]

whose value is 1, to get

\[(1 * 2 * \ldots * \text{count} * (\text{count} + 1) * (\text{count} + 2) * \ldots * n) / (1 * 2 * \ldots * \text{count})\]

The numerator of this expression is \(n!\). The denominator is \(\text{count}!\). If \text{count} is equal to \(n\), the value of the quotient is

\[n! / n!\]

or 1, which is what we were trying to show.

Problem Set:

2a. \(<\text{class_head}> \rightarrow \{<\text{modifier}>\} \text{ class <id> [extends class_name]}\)

\[ [\text{implements <interface_name>} {, <interface_name>}] \]

\(<\text{modifier}> \rightarrow \text{public} | \text{abstract} | \text{final}\)

2c. \(<\text{switch_stmt}> \rightarrow \text{switch ( <expr> ) } \{ \text{case <literal>} : <\text{stmt_list}> \}

\[ \{ \text{case <literal>} : <\text{stmt_list}> \} [\text{default} : <\text{stmt_list}>] \}

3. \(<\text{assign}> \rightarrow <\text{id}> = <\text{expr}>\)

\(<\text{id}> \rightarrow \text{A} | \text{B} | \text{C}\)

\(<\text{expr}> \rightarrow <\text{expr}> * <\text{term}>\)

\[ | <\text{term}>\]

\(<\text{term}> \rightarrow <\text{factor}> + <\text{term}>\)
\[ | \langle \text{factor} \rangle \]
\[ \langle \text{factor} \rangle \rightarrow ( \langle \text{expr} \rangle ) \]
\[ | \langle \text{id} \rangle \]

6.

(a) \( \langle \text{assign} \rangle \Rightarrow \langle \text{id} \rangle = \langle \text{expr} \rangle \)

\[ \Rightarrow A = \langle \text{expr} \rangle \]
\[ \Rightarrow A = \langle \text{id} \rangle \ast \langle \text{expr} \rangle \]
\[ \Rightarrow A = A \ast \langle \text{expr} \rangle \]
\[ \Rightarrow A = A \ast ( \langle \text{expr} \rangle ) \]
\[ \Rightarrow A = A \ast ( \langle \text{id} \rangle \ast \langle \text{expr} \rangle ) \]
\[ \Rightarrow A = A \ast ( \langle \text{id} \rangle \ast \langle \text{expr} \rangle ) \]
\[ \Rightarrow A = A \ast ( B + \langle \text{expr} \rangle ) \]
\[ \Rightarrow A = A \ast ( B + ( \langle \text{id} \rangle \ast \langle \text{expr} \rangle ) ) \]
\[ \Rightarrow A = A \ast ( B + ( C \ast \langle \text{expr} \rangle ) ) \]
\[ \Rightarrow A = A \ast ( B + ( C \ast \langle \text{id} \rangle ) ) \]
\[ \Rightarrow A = A \ast ( B + ( C \ast A ) ) \]
7.

(a) \( \text{<assign>} \Rightarrow \text{id} = \text{<expr>} \)

\[
\Rightarrow A = \text{<expr>}
\]

\[
\Rightarrow A = \text{<term>}
\]

\[
\Rightarrow A = \text{<factor>} \ast \text{<term>}
\]

\[
\Rightarrow A = (\text{<expr>}) \ast \text{<term>}
\]

\[
\Rightarrow A = (\text{<expr>} + \text{<term>}) \ast \text{<term>}
\]

\[
\Rightarrow A = (\text{<term>} + \text{<term>}) \ast \text{<term>}
\]

\[
\Rightarrow A = (\text{<factor>} + \text{<term>}) \ast \text{<term>}
\]
\[ A = (A + B) \times C \]
8. The following two distinct parse tree for the same string prove that the grammar is ambiguous.

9. Assume that the unary operators can precede any operand. Replace the rule

\[ \text{<factor>} \rightarrow \text{<id>} \]

with

\[ \text{<factor>} \rightarrow + \text{<id>} \]
\[ \quad | - \text{<id>} \]

10. One or more a's followed by one or more b's followed by one or more c's.

13. \( S \rightarrow a \ S \ b \ | \ a \ b \)

14.
16. \[ <assign> \rightarrow <id> = <expr> \]
\[ <id> \rightarrow A | B | C \]
\[ <expr> \rightarrow <expr> (+ | -) <expr> \]
\[ | (<expr>) \]
\[ | <id> \]

18.

(a) (Java do-while) We assume that the logic expression is a single relational expression.

\[ \text{loop: (do body)} \]
\[ \text{if <relational_expression> goto out} \]
\[ \text{goto loop} \]
\[ \text{out: ...} \]

(b) (Ada for) for \( I \) in first .. last loop

\[ I = \text{first} \]

\[ \text{loop: if } I < \text{last goto out} \]
\[ \text{...} \]
\[ I = I + 1 \]
\[ \text{goto loop} \]
\[ \text{out: ...} \]

(c) (Fortran Do)

\[ K = \text{start} \]

\[ \text{loop: if } K > \text{end goto out} \]
\[ \text{...} \]
K = K + step

goto loop

out: ...

(e) (C for) for (expr1; expr2; expr3) ...
evaluate(expr1)

loop: control = evaluate(expr2)

if control == 0 goto out

...
evaluate(expr3)

goto loop

out: ...
\[ 2 \times b > 2 - a \]
\[ b > 1 - \frac{a}{2} \]

(d) \[ x = 2 \times y + x - 1 \{ x > 11 \} \]
\[ 2 \times y + x - 1 > 11 \]
\[ 2 \times y + x > 12 \]

20.
(a) \[ a = 2 \times b + 1 \]
\[ b = a - 3 \{ b < 0 \} \]

\[ a - 3 < 0 \]
\[ a < 3 \]

Now, we have:
\[ a = 2 \times b + 1 \{ a < 3 \} \]
\[ 2 \times b + 1 < 3 \]
\[ 2 \times b + 1 < 3 \]
\[ 2 \times b < 2 \]
\[ b < 1 \]

(b) \[ a = 3 \times (2 \times b + a); \]
\[ b = 2 \times a - 1 \{ b > 5 \} \]
\[ 2 \times a - 1 > 5 \]
\[ 2 \times a > 6 \]
\[ a > 3 \]

Now we have:
\[
a = 3 \times (2 \times b + a) \{a > 3\}
3 \times (2 \times b + a) > 3
6 \times b + 3 \times a > 3
2 \times b + a > 1
n > (1 - a) / 2
\]

21a. \(M_{pf}(\text{for var in init\_expr .. final\_expr loop L end loop, s}) \iff\)

if \(\text{VARMAP}(i, s) = \text{undef}\) for var or some i in init\_expr or final\_expr
  then \text{error}
else if \(\text{M}_{c}(\text{init\_expr, s}) > \text{M}_{c}(\text{final\_expr, s})\)
  then s
else \(\text{M}_{l}(\text{while init\_expr - 1 <= final\_expr do L, M}_{a}(\text{var := init\_expr + 1, s}))\)

21b. \(M_{r}(\text{repeat L until B}) \iff\)

if \(\text{M}_{b}(B, s) = \text{undef}\)
  then \text{error}
else if \(\text{M}_{sl}(L, s) = \text{error}\)
  then \text{error}
else if \(\text{M}_{b}(B, s) = \text{true}\)
  then \(\text{M}_{sl}(L, s)\)
else \(\text{M}_{r}(\text{repeat L until B, M}_{sl}(L, s))\)

21c. \(\text{M}_{b}(B, s) \iff\) if \(\text{VARMAP}(i, s) = \text{undef}\) for some i in B
  then \text{error}
else \( B' \), where \( B' \) is the result of evaluating \( B \) after setting each variable \( i \) in \( B \) to \( \text{VARMAP}(i, s) \)

21d. \( M_c((\text{for } (\text{expr}1; \text{expr}2; \text{expr}3) \ L, s)) \) \( \triangleleft \)

if \( \text{VARMAP}(i, s) = \text{undef} \) for some \( i \) in \( \text{expr}1, \text{expr}2, \text{expr}3, \) or \( L \)
then \( \text{error} \)
else if \( M_e(\text{expr}2, M_e(\text{expr}1, s)) = 0 \)
then \( s \)
else \( M_{\text{help}}(\text{expr}2, \text{expr}3, L, s) \)

\( M_{\text{help}}(\text{expr}2, \text{expr}3, L, s) \) \( \triangleleft \)

if \( \text{VARMAP}(i, s) = \text{undef} \) for some \( i \) in \( \text{expr}2, \text{expr}3, \) or \( L \)
then \( \text{error} \)
else
if \( M_{\text{sl}}(L, s) = \text{error} \)
then \( s \)
else \( M_{\text{help}}(\text{expr}2, \text{expr}3, L, M_{\text{sl}}(L, M_e(\text{expr}3, s))) \)

22. The value of an intrinsic attribute is supplied from outside the attribute evaluation process, usually from the lexical analyzer. A value of a synthesized attribute is computed by an attribute evaluation function.

23. Replace the second semantic rule with:

\( <\text{var}>[2].\text{env} \leftarrow <\text{expr}>.\text{env} \)
\( <\text{var}>[3].\text{env} \leftarrow <\text{expr}>.\text{env} \)
\( <\text{expr}>().\text{actual\_type} \leftarrow <\text{var}>[2].\text{actual\_type} \)

predicate: \( <\text{var}>[2].\text{actual\_type} = <\text{var}>[3].\text{actual\_type} \)
Chapter 4

Problem Set:

1.

(a) FIRST(aB) = \{a\}, FIRST(b) = \{b\}, FIRST(cBB) = \{c\}, Passes the test
(b) FIRST(aB) = \{a\}, FIRST(bA) = \{b\}, FIRST(aBb) = \{a\}, Fails the test
(c) FIRST(aaA) = \{a\}, FIRST(b) = \{b\}, FIRST(cAB) = \{c\}, Passes the test

3. $a + b * c$

Call lex /* returns a */
Enter <expr>
Enter <term>
Enter <factor>
Call lex /* returns + */
Exit <factor>
Exit <term>
Call lex /* returns b */
Enter <term>
Enter <factor>
Call lex /* returns * */
Exit <factor>
Call lex /* returns c */
Enter <factor>
Call lex /* returns end-of-input */
Exit <factor>
Exit <term>
Exit <expr>
5.

(a) aaAbb

```
S
  |     |
  a    b
  |     |
  A    |
  |     |
a    A
  |     |
  a    B
  |     |
  b
```

Phrases: aaAbb, aAb, b

Simple phrases: b

Handle: b

(b) bBab

```
S
  |     |
b    a
  |     |
  B    |
  |     |
  A    a
  |     |
  b    b
```

Phrases: bBab, ab

Simple phrases: ab

Handle: ab

7. **Stack** | **Input** | **Action**
---|---|---
0 | id * (id + id) $ | Shift 5
0id5 | * (id + id) $ | Reduce 6 (Use GOTO[0, F])
0F3 | * (id + id) $ | Reduce 4 (Use GOTO[0, T])
0T2 | * (id + id) $ | Reduce 2 (Use GOTO[0, E])
0T2*7 | (id + id) $ | Shift 7
Programming Exercises:

1. Every arc in this graph is assumed to have `addChar` attached. Assume we get here only if `charClass` is SLASH.

   ![Graph Diagram]

   return SLASH_CODE

3. ```
   int getComment() {
       getChar();
       /* The slash state */
   }
```
if (charClass != AST)
    return SLASH_CODE;
else {
/* The com state-end state loop */
do {
    getChar();
/* The com state loop */
while (charClass != AST)
    getChar();
    } while (charClass != SLASH);
    return COMMENT;
}

Chapter 5

Problem Set:

2. The advantage of a typeless language is flexibility; any variable can be used for any type values. The disadvantage is poor reliability due to the ease with which type errors can be made, coupled with the impossibility of type checking detecting them.

3. This is a good idea. It adds immensely to the readability of programs. Furthermore, aliasing can be minimized by enforcing programming standards that disallow access to the array in any executable statements. The alternative to this aliasing would be to pass many parameters, which is a highly inefficient process.

5. Implicit heap-dynamic variables acquire types only when assigned values, which must be at runtime. Therefore, these variables are always dynamically bound to types.

6. Suppose that a Fortran subroutine is used to implement a data structure as an abstraction. In this situation, it is essential that the structure persist between calls to the managing subroutine.

8.

(a) i. Sub1
    ii. Sub1
iii. Main

(b) i. Sub1

ii. Sub1

iii. Sub1

9. Static scoping: $x$ is 5.

Dynamic scoping: $x$ is 10

10. \textbf{Variable} \hspace{1cm} \textbf{Where Declared}

\textbf{In Sub1:}

- A \hspace{1cm} Sub1
- Y \hspace{1cm} Sub1
- Z \hspace{1cm} Sub1
- X \hspace{1cm} Main

\textbf{In Sub2:}

- A \hspace{1cm} Sub2
- B \hspace{1cm} Sub2
- Z \hspace{1cm} Sub2
- Y \hspace{1cm} Sub1
- X \hspace{1cm} Main

\textbf{In Sub3:}

- A \hspace{1cm} Sub3
- X \hspace{1cm} Sub3
- W \hspace{1cm} Sub3
- Y \hspace{1cm} Main
- Z \hspace{1cm} Main

12. Point 1:

- a \hspace{1cm} 1
- b \hspace{1cm} 2
- c \hspace{1cm} 2
- d \hspace{1cm} 2
Point 2:  
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>2</td>
</tr>
<tr>
<td>c</td>
<td>3</td>
</tr>
<tr>
<td>d</td>
<td>3</td>
</tr>
<tr>
<td>e</td>
<td>3</td>
</tr>
</tbody>
</table>

Point 3: same as Point 1

Point 4:  
<p>| | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>a</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>1</td>
</tr>
<tr>
<td>c</td>
<td>1</td>
</tr>
</tbody>
</table>

13. Variable | Where Declared
(a)  
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>d, e, f</td>
<td>fun3</td>
</tr>
<tr>
<td>c</td>
<td>fun2</td>
</tr>
<tr>
<td>b</td>
<td>fun1</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
</tr>
</tbody>
</table>

(b)  
<p>| | |</p>
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<thead>
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<tbody>
<tr>
<td>d, e, f</td>
<td>fun3</td>
</tr>
<tr>
<td>b, c</td>
<td>fun1</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
</tr>
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</table>

(c)  
<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
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</thead>
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<tr>
<td>b, c, d</td>
<td>fun1</td>
</tr>
<tr>
<td>e, f</td>
<td>fun3</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
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</table>

(d)  
<p>| | |</p>
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<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b, c, d</td>
<td>fun1</td>
</tr>
<tr>
<td>e, f</td>
<td>fun3</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
</tr>
</tbody>
</table>

(e)  
<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>c, d, e</td>
<td>fun2</td>
</tr>
<tr>
<td>f</td>
<td>fun3</td>
</tr>
<tr>
<td>b</td>
<td>fun1</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
</tr>
</tbody>
</table>

(f)  
<p>| | |</p>
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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>b, c, d</td>
<td>fun1</td>
</tr>
<tr>
<td>e</td>
<td>fun2</td>
</tr>
<tr>
<td>f</td>
<td>fun3</td>
</tr>
<tr>
<td>a</td>
<td>main</td>
</tr>
</tbody>
</table>
14. | Variable       | Where Declared |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) A, X, W</td>
<td>Sub3</td>
</tr>
<tr>
<td>B, Z</td>
<td>Sub2</td>
</tr>
<tr>
<td>Y</td>
<td>Sub1</td>
</tr>
<tr>
<td>(b) A, X, W</td>
<td>Sub3</td>
</tr>
<tr>
<td>Y, Z</td>
<td>Sub1</td>
</tr>
<tr>
<td>(c) A, Y, Z</td>
<td>Sub1</td>
</tr>
<tr>
<td>X, W</td>
<td>Sub3</td>
</tr>
<tr>
<td>B</td>
<td>Sub2</td>
</tr>
<tr>
<td>(d) A, Y, Z</td>
<td>Sub1</td>
</tr>
<tr>
<td>X, W</td>
<td>Sub3</td>
</tr>
<tr>
<td>(e) A, B, Z</td>
<td>Sub2</td>
</tr>
<tr>
<td>X, W</td>
<td>Sub3</td>
</tr>
<tr>
<td>Y</td>
<td>Sub1</td>
</tr>
<tr>
<td>(f) A, Y, Z</td>
<td>Sub1</td>
</tr>
<tr>
<td>B</td>
<td>Sub2</td>
</tr>
<tr>
<td>X, W</td>
<td>Sub3</td>
</tr>
</tbody>
</table>

**Chapter 6**

*Problem Set:*

1. Boolean variables stored as single bits are very space efficient, but on most computers access to them is slower than if they were stored as bytes.

2. Integer values stored in decimal waste storage in binary memory computers, simply as a result of the fact that it takes four binary bits to store a single decimal digit, but those four bits are capable of storing 16 different values. Therefore, the ability to store six out of every 16 possible values is wasted. Numeric values can be stored efficiently on binary memory computers only in number bases that are multiples of 2. If humans had developed hands with a number of fingers that was a power of 2, these kinds of problems would not occur.

5. When implicit dereferencing of pointers occurs only in certain contexts, it makes the language slightly less orthogonal. The context of the reference to the pointer determines its meaning. This detracts from the readability of the language and makes it slightly more difficult to learn.

7. The only justification for the -> operator in C and C++ is writability. It is slightly easier to write p -> q than (*p).q.
9. The advantage of having a separate construct for unions is that it clearly shows that unions are different from records. The disadvantages are that it requires an additional reserved word and that unions are often separately defined but included in records, thereby complicating the program that uses them.

10. Let the subscript ranges of the three dimensions be named $\text{min}(1), \text{min}(2), \text{min}(3), \text{max}(1), \text{max}(2), \text{and} \text{ max}(3)$. Let the sizes of the subscript ranges be $\text{size}(1), \text{size}(2), \text{and} \text{ size}(3)$. Assume the element size is 1.

Row Major Order:

\[
\text{location}(a[i,j,k]) = (\text{address of } a[\text{min}(1),\text{min}(2),\text{min}(3)]) + ((i-\text{min}(1))*\text{size}(3) + (j-\text{min}(2)))*\text{size}(2) + (k-\text{min}(3))
\]

Column Major Order:

\[
\text{location}(a[i,j,k]) = (\text{address of } a[\text{min}(1),\text{min}(2),\text{min}(3)]) + ((k-\text{min}(3))*\text{size}(1) + (j-\text{min}(2)))*\text{size}(2) + (i-\text{min}(1))
\]

11. The advantage of this scheme is that accesses that are done in order of the rows can be made very fast; once the pointer to a row is gotten, all of the elements of the row can be fetched very quickly. If, however, the elements of a matrix must be accessed in column order, these accesses will be much slower; every access requires the fetch of a row pointer and an address computation from there. Note that this access technique was devised to allow multidimensional array rows to be segments in a virtual storage management technique. Using this method, multidimensional arrays could be stored and manipulated that are much larger than the physical memory of the computer.

15. Implicit heap storage recovery eliminates the creation of dangling pointers through explicit deallocation operations, such as `delete`. The disadvantage of implicit heap storage recovery is the execution time cost of doing the recovery, often when it is not even necessary (there is no shortage of heap storage).

Chapter 7

Problem Set:

1. Suppose `Type1` is a subrange of `Integer`. It may be useful for the difference between `Type1` and `Integer` to be ignored by the compiler in an expression.

7. An expression such as $a + \text{fun}(b)$, as described on page 300.

8. Consider the integer expression $A + B + C$. Suppose the values of $A, B,$ and $C$ are 20,000, 25,000, and -20,000, respectively. Further suppose that the machine has a maximum integer value of 32,767. If the first addition is computed first, it will result in overflow. If the second addition is done first, the whole expression can be correctly computed.
9.
(a) \( ((a \times b)^1 - 1)^2 + c)^3 \)
(b) \( ((a \times (b - 1)^1)^2 / c)^3 \) mod \( d \)\(^4\)
(c) \( ((a - b)^1 / c)^2 \) & \( ((d \times e)^3 / a)^4 - 3)^5 \)\(^6\)
(d) \( ((-a)^1 \) or \( (c = d)^2)^3 \) and \( e \)\(^4\)
(e) \( ((a > b)^1 \) xor \( (c \) or \( (d <= 17)^2)^3 \)\(^4\)
(f) \( (- (a + b)^1)^2 \)

10.
(a) \( (a \times (b - (1 + c)^1)^2)^3 \)
(b) \( (a \times ((b - 1)^2 / (c \) mod \( d)^1)^3 \)\(^4\)
(c) \( ((a - b)^5 / (c \) & \( (d \times (e / (a - 3)^1)^2)^3)^4 \)\(^6\)
(d) \( -(a \) or \( (c = (d \) and \( e)^1)^2)^3 \)\(^4\)
(e) \( (a > (\) xor \( (c \) or \( (d <= 17)^1)^2)^3 \)\(^4\)
(f) \( -(a + b)^1)^2 \)

11. <expr> → <expr> or <e1> | <expr> xor <e1> | <e1>
 <e1> → <e1> and <e2> | <e2>
 <e2> → <e2> = <e3> | <e2> /= <e3> | <e2> < <e3>
         | <e2> <= <e3> | <e2> > <e3> | <e2> >= <e3> | <e3>
 <e3> → <e4>
 <e4> → <e4> + <e5> | <e4> - <e5> | <e4> & <e5> | <e4> mod <e5> | <e5>
 <e5> → <e5> * <e6> | <e5> / <e6> | not <e5> | <e6>
 <e6> → a | b | c | d | e | const | ( <expr> )
12. (a)
12. (b)

\[ \text{expr} \]
\[ \text{e1} \]
\[ \text{e2} \]
\[ \text{e3} \]
\[ \text{e4} \]
\[ \text{e5} \mod \text{e6} \]
\[ \text{e5} \div \text{e6} \]
\[ \text{e5} \times \text{e6} \]
\[ \text{e6} ( \text{expr} ) \]
\[ \text{a} \]
\[ \text{e1} \]
\[ \text{e2} \]
\[ \text{e3} \]
\[ \text{e4} \]
\[ \text{e4} - \text{e5} \]
\[ \text{e5} \]
\[ \text{e6} \]
\[ \text{e6} \]
\[ \text{b} \]
12. (c)
12. (d)

<expr>
  /\  
<expr> and <e1>
   /\  
<e1> or <e2> <e2>
      /\  
<e2> <e2> = <e3> <e4>
         /\  
<e3> <e3> <e4> <e5>
             /\  
- <e4> <e4> <e5> <e6>
                /\  
<e5> <e5> <e6> e

<e6> <e6> d
  /\  
a c
12. (e)

```
<expr>
  <expr> xor <e1>
  <e1> or <e2>
  <e2> or <e2> <= <e3>
  <e2> <= <e3>
  <e3> <= <e3>
  <e3> <= <e4>
  <e3> <= <e4>
  <e4> <= <e5>
  <e4> <= <e5>
  <e5> <= <e6>
  <e5> <= <e6>
  <e6> 17
  <e6> b c d
  a
```
12. (f)

\[ \text{expr} = \text{e1} / \text{e2} / \text{e3} - \text{e4} \]
\[ = \text{e4} + \text{e5} / \text{e6} b \]
\[ a \]

13. (a) (left -> right) \( \text{sum1 is 46; sum2 is 48} \)
    (b) (right -> left) \( \text{sum1 is 48; sum2 is 46} \)

19. (a) 7
    (b) 12

Chapter 8

Problem Set:

1. Three situations in which a combined counting and logical control loops are:
   
   a. A list of values is to be added to a \text{SUM}, but the loop is to be exited if \text{SUM} exceeds some prescribed value.
   
   b. A list of values is to be read into an array, where the reading is to terminate when either a prescribed number of values have been read or some special value is found in the list.
c. The values stored in a linked list are to be moved to an array, where values are to be
moved until the end of the linked list is found or the array is filled, whichever
comes first.

4. Unique closing keywords on compound statements have the advantage of readability
and the disadvantage of complicating the language by increasing the number of
keywords.

8. The primary argument for using Boolean expressions exclusively as control
expressions is the reliability that results from disallowing a wide range of types for this
use. In C, for example, an expression of any type can appear as a control expression, so
typing errors that result in references to variables of incorrect types are not detected by
the compiler as errors.

**Programming Exercises:**

1.  
   (a)  
   \[
   \text{Do } K = (J + 13) / 27, 10 \\
   I = 3 \times (K + 1) - 1 \\
   \text{End Do}
   \]
   
   (b)  
   \[
   \text{for } k \text{ in } (j + 13) / 27..10 \text{ loop} \\[ \\
   i := 3 \times (k + 1) - 1; \\
   \text{end loop;}
   \]
   
   (c)  
   \[
   \text{for } (k = (j + 13) / 27; k \leq 10; i = 3 \times (++k) - 1)
   \]

2.  
   (a)  
   \[
   \text{Do } K = (J + 13.0) / 27.0, 10.0, 1.2 \\
   I = 3.0 \times (K + 1.2) - 1.0 \\
   \text{End Do}
   \]
   
   (b)  
   \[
   \text{while } (k \leq 10.0) \text{ loop} \\[ \\
   i := 3.0 \times (k + 1.2) - 1.0; \\
   k := k + 1.2; \\
   \text{end loop;}
   \]
   
   (c)  
   \[
   \text{for } (k = (j + 13.0) / 27.0; k \leq 10.0; k <= 10.0)
   \]
\[ k = k + 1.2, \quad i = 3.0 \times k - 1 \]

3.

(a) Select Case \((k)\)

Case \((1, 2)\)
\[ J = 2 \times k - 1 \]

Case \((3, 5)\)
\[ J = 3 \times k + 1 \]

Case \((4)\)
\[ J = 4 \times k - 1 \]

Case \((6, 7, 8)\)
\[ J = k - 2 \]

Case Default
Print *, 'Error in Select, K = ', K
End Select

(b) \texttt{case k is}

\begin{align*}
\text{when } 1 \mid 2 & \Rightarrow j := 2 \times k - 1; \\
\text{when } 3 \mid 5 & \Rightarrow j := 3 \times k + 1; \\
\text{when } 4 & \Rightarrow j := 4 \times k - 1; \\
\text{when } 6..8 & \Rightarrow j := k - 2; \\
\text{when others} & \Rightarrow \\
& \text{Put ("Error in case, k =");} \\
& \text{Put (k);} \\
& \text{New_Line;}
\end{align*}

end case;

(c) \texttt{switch (k)}

{ }

\begin{verbatim}
    case 1: case 2:
\end{verbatim}
j = 2 * k - 1;
break;

case 3: case 5:
    j = 3 * k + 1;
break;

case 4:
    j = 4 * k - 1;
break;

case 6: case 7: case 8:
    j = k - 2;
break;

default:
    printf("Error in switch, k =%d\n", k);
}

4. j = -3;
key = j + 2;

for (i = 0; i < 10; i++){
    if (((key == 3) || (key == 2))
        j--;
    else if (key == 0)
        j += 2;
    else j = 0;
    if (j > 0)
        break;
    else j = 3 - i;
}

5. (C)
for (i = 1; i <= n; i++) {
    flag = 1;
    for (j = 1; j <= n; j++)
        if (x[i][j] <> 0) {
            flag = 0;
            break;
        }
    if (flag == 1) {
        printf("First all-zero row is: \d
", i);
        break;
    }
}

(Ada)
for I in 1..N loop
    Flag := true;
    for J in 1..N loop
        if X(I, J) /= 0 then
            Flag := false;
            exit;
        end if;
    end loop;
    if Flag = true then
        Put("First all-zero row is: ");
        Put(I);
        Skip_Line;
        exit;
    }
end if;
end loop;

7.

I, J : Integer;
N : Integer := 100;

I = 0;
J = 17;
while I < N loop
  Sum := Sum + I * J + 3;
  I := I + 1;
  J := J - 1;
end loop;

Chapter 9

Problem Set:

2. The main advantage of this method is the fast accesses to formal parameters in subprograms. The disadvantages are that recursion is rarely useful when values cannot be passed, and also that a number of problems, such as aliasing, occur with the method.

4. This can be done in both Java and C#, using a static (or class) data member for the page number.

5. Assume the calls are not accumulative; that is, they are always called with the initialized values of the variables, so their effects are not accumulative.

\[
\begin{array}{ccc}
  \text{a.} & 2, 1, 3, 5, 7, 9 & \text{b.} & 1, 2, 3, 5, 7, 9 & \text{c.} & 1, 2, 3, 5, 7, 9 \\
  2, 1, 3, 5, 7, 9 & 2, 3, 1, 5, 7, 9 & 2, 3, 1, 5, 7, 9 \\
  2, 1, 3, 5, 7, 9 & 5, 1, 3, 2, 7, 9 & 5, 1, 3, 2, 7, 9 (unless the addresses of the actual parameters are recomputed on return, in which case there will be an index range error.)
\end{array}
\]
6. It is rather weak, but one could argue that having both adds complexity to the language without sufficient increase in writability.

7. (a) 1, 3
   (b) 2, 6
   (c) 2, 6
Chapter 10

Problem Set:

1.

| ari for B | dynamic link | static link | return (to C) |
| ari for C | dynamic link | static link | return (to A) |
| ari for A | dynamic link | static link | return (to BIGSUB) |
| ari for BIGSUB | dynamic link | static link | return |

. .

stack
3.

<table>
<thead>
<tr>
<th></th>
<th>Dynamic Link</th>
<th>Static Link</th>
<th>Return (to C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARI for D</td>
<td>static link</td>
<td>return (to C)</td>
<td>dynamic link</td>
</tr>
<tr>
<td>ARI for C</td>
<td>static link</td>
<td>return (to A)</td>
<td>parameter (flag)</td>
</tr>
<tr>
<td>ARI for A</td>
<td>dynamic link</td>
<td>static link</td>
<td>return (to B)</td>
</tr>
<tr>
<td>ARI for B</td>
<td>dynamic link</td>
<td>static link</td>
<td>return (to A)</td>
</tr>
<tr>
<td>ARI for BIGSUB</td>
<td>dynamic link</td>
<td>static link</td>
<td>return (BIGSUB)</td>
</tr>
</tbody>
</table>

stack
7. One very simple alternative is to assign integer values to all variable names used in the program. Then the integer values could be used in the activation records, and the comparisons would be between integer values, which are much faster than string comparisons.

8. Following the hint stated with the question, the target of every goto in a program could be represented as an address and a nesting_depth, where the nesting_depth is the difference between the nesting level of the procedure that contains the goto and that of the procedure containing the target. Then, when a goto is executed, the static chain is followed by the number of links indicated in the nesting_depth of the goto target. The stack top pointer is reset to the top of the activation record at the end of the chain.

9. Including two static links would reduce the access time to nonlocals that are defined in scopes two steps away to be equal to that for nonlocals that are one step away. Overall, because most nonlocal references are relatively close, this could significantly increase the execution efficiency of many programs.

Chapter 11

Problem Set:

2. The problem with this is that the user is given access to the stack through the returned value of the "top" function. For example, if \( p \) is a pointer to objects of the type stored in the stack, we could have:

\[
p = \text{top}(\text{stack1});
\]

\[
*p = 42;
\]

These statements access the stack directly, which violates the principle of a data abstraction.

4. The problems created by making an abstract data type a pointer are: (a) There are many inherent problems in dealing with pointers (see Chapter 6), (b) comparisons between objects do not work as expected, because they are only pointer comparisons (rather than pointed-to value comparisons), and (c) the implementation of the abstract type cannot control allocation and deallocation of objects of the type (the user can create a pointer to an object with a variable declaration and use it without creating an object).

6. Implicit garbage collection removes the necessity of allowing users to explicitly deallocate objects, thereby eliminating the possibility of user-created dangling pointers.

8. There are several dangers inherent in C’s approach to encapsulation. First, the user is allowed to simply paste the contents of the header file into the application file, which can lead to using subsequently updated implementation files without using the potentially updated header file. This can cause type conflicts between the implementation file and the header file. Another problem with pasting the header file into the implementation file is the loss of documentation of the dependence of the implementation file on the header file.
9. C++ did not eliminate the problems described in Problem 8 because it uses the C linker on its programs.

11. The three ways a C++ client program can reference a name from a namespace defined in a header file are (assuming the namespace name is `MyStack` and the variable is named `topPtr`):

   a. `MyStack::topPtr`

   b. Including the statement:

      ```
      using MyStack::topPtr;
      ```

      in the program.

   c. Including the statement:

      ```
      using namespace MyStack;
      ```

      in the program and referencing `topPtr` by its name.
Chapter 12

Problem Set:

1. In C++, a method can only be dynamically bound if all of its ancestors are marked virtual. By default, all method binding is static. In Java, method binding is dynamic by default. Static binding only occurs if the method is marked final, which means it cannot be overridden.

3. C++ has extensive access controls to its class entities. Individual entities can be marked public, private, or protected, and the derivation process itself can impose further access controls by being private. Ada, on the other hand, has no way to restrict inheritance of entities (other than through child libraries, which this book does not describe), and no access controls for the derivation process.

7. Two problems of abstract data types that are ameliorated by inheritance are: (a) Reuse of abstract data types is much easier, because the modifications of existing types need not be done on the legacy code, and (b) with abstract data types, all types are independent and at the same level, disallowing any logically hierarchical type dependencies.

9. One disadvantage of inheritance is that types cannot be defined to be independent.

11. If a subclass has an is-a relationship with its parent class, a variable of the subclass can appear anywhere a variable of the parent class is allowed to appear.

14. One reason why all Java objects have a common ancestor is so they can all inherit a few universally useful methods.

15. The finalize clause in Java allows a specific action to take place, regardless of whether a try clause succeeds or fails.

Chapter 13

Problem Set:

1. Competition synchronization is not necessary when no actual concurrency takes place simply because there can be no concurrent contention for shared resources. Two nonconcurrent processes cannot arrive at a resource at the same time.

2. When deadlock occurs, assuming that only two program units are causing the deadlock, one of the involved program units should be gracefully terminated, thereby allowed the other to continue.

3. The main problem with busy waiting is that machine cycles are wasted in the process.

4. Deadlock would occur if the release (access) were replaced by a wait (access) in the consumer process, because instead of relinquishing access control, the consumer would wait for control that it already had.

6. Sequence 1: A fetches the value of BUF_SIZE (6)
A adds 2 to the value (8)
A puts 8 in BUF_SIZE
B fetches the value of BUF_SIZE (8)
B subtracts 1 (7)
B put 7 in BUF_SIZE
BUF_SIZE = 7

Sequence 2:  
A fetches the value of BUF_SIZE (6)
B fetches the value of BUF_SIZE (6)
A adds 2 (8)
B subtracts 1 (5)
A puts 8 in BUF_SIZE
B puts 5 in BUF_SIZE
BUF_SIZE = 5

Sequence 3:  
A fetches the value of BUF_SIZE (6)
B fetches the value of BUF_SIZE (6)
A adds 2 (8)
B subtracts 1 (5)
B puts 5 in BUF_SIZE
A puts 8 in BUF_SIZE
BUF_SIZE = 8

Many other sequences are possible, but all produce the values 5, 7, or 8.

10. The safety of cooperation synchronization using semaphores is basically the same as using Ada’s when clauses, although the when clauses are somewhat more readable than semaphores.

Chapter 14

Problem Set:

5. There are several advantages of a linguistic mechanism for handling exceptions, such as that found in Ada, over simply using a flag error parameter in all subprograms. One advantage is that the code to test the flag after every call is eliminated. Such testing makes programs longer and harder to read. Another advantage is that exceptions can be propagated farther than one level of control in a uniform and implicit way. Finally, there is the advantage that all programs use a uniform method for dealing with unusual circumstances, leading to enhanced readability.
6. There are several disadvantages of sending error handling subprograms to other subprograms. One is that it may be necessary to send several error handlers to some subprograms, greatly complicating both the writing and execution of calls. Another is that there is no method of propagating exceptions, meaning that they must all be handled locally. This complicates exception handling, because it requires more attention to handling in more places.

Chapter 15

Problem Set:

6. $y$ returns the given list with leading elements removed up to but not including the first occurrence of the first given parameter.

7. $x$ returns the number of non-NIL atoms in the given list.

Programming Exercises:

5. (DEFINE (deleteall atm lst)

   (COND
     ((NULL? lst) '())
     ((EQ? atm (CAR lst)) (deleteall atm (CDR lst)))
     (ELSE (CONS (CAR lst) (deleteall atm (CDR lst))))
   ))

7. (DEFINE (deleteall atm lst)

   (COND
     ((NULL? lst) '())
     ((NOT (LIST? (CAR lst)))
      (COND
        ((EQ? atm (CAR lst)) (deleteall atm (CDR lst)))
        (ELSE (CONS (CAR lst) (deleteall atm (CDR lst))))
      )
     )
     (ELSE (CONS (deleteall atm (CAR lst)))
   ))
Chapter 16

Problem Set:

1. Ada variables are statically bound to types. Prolog variables are bound to types only when they are bound to values. These bindings take place during execution and are temporary.

2. On a single processor machine, the resolution process takes place on the rule base, one rule at a time, starting with the first rule, and progressing toward the last until a match is found. Because the process on each rule is independent of the process on the other rules, separate processors could concurrently operate on separate rules. When any of the processors finds a match, all resolution processing could terminate.

6. The list processing capabilities of Scheme and Prolog are similar in that they both treat lists as consisting of two parts, head and tail, and in that they use recursion to traverse and process lists.

7. The list processing capabilities of Scheme and Prolog are different in that Scheme relies on the primitive functions CAR, CDR, and CONS to build and dismantle lists, whereas with Prolog these functions are not necessary.

Programming Exercises:

2. intersect([], X, []). intersect([X | R], Y, [X | Z] :- member(X, Y),
\!
intersect(R, Y, Z).

intersect([X | R], Y, Z) :- intersect(R, Y, Z).

Note: this code assumes that the two lists, \( X \) and \( Y \), contain no duplicate elements.

3. union([], X, X).

union([X | R], Y, Z) :- member(X, Y), !, union(R, Y, Z).

union([X | R], Y, [X | Z]) :- union(R, Y, Z).