FOURTH EDITION

# Assembler Language with ASSIST and ASSIST/I

**ROSS A. OVERBEEK**
**Argonne National Laboratory**

**W. E. SINGLETARY**
**Northern Illinois University, Emeritus**

This PDF was created with
the written permission
of Dr. Ross A. Overbeek.
Do NOT share this PDF
with others and do NOT
post it on any website or
electronic sharing site.

**PRENTICE HALL**
**Englewood Cliffs, NJ 07632**

**Library of Congress Cataloging in Publication Data**
Overbeek, Ross A.
Assembler language with ASSIST and ASSIST/I / Ross A. Overbeek, W. E. Singletary.—4th ed.
p. cm.
Includes index.
ISBN 0-02-390005-9
1. Assembler language (Computer program language) 2. Assist (Computer program) 3. Assist/I (Computer program) I. Singletary, Wilson E. II. Title.
QA76.73A8093 1991 90-6182
005.13'6—dc20 CIP

William W. Boone of the University of Illinois, Urbana. Bill was the grandfather and father, respectively, of the authors in the field of mathematical logic. We welcome this opportunity to express our appreciation for the influence that he has had on our professional careers.

R. A. O.
W. E. S.

Editor: Ed Moura
Production supervisor: John Travis
Production manager: Pamela Kennedy Oborski
Cover designer: Alex Teshin
Cover illustration by Edith Ge

This book was set in Century Expanded by Graphic Typesetting Service, Inc.

© 1986, 1983, and 1976 by Science Research Associates, Inc.

© 1991 by Prentice-Hall, Inc.
A Simon & Schuster Company
Englewood Cliffs, New Jersey 07632

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Printed in the United States of America
10 9 8 7 6 5 4 3

ISBN 0-5250-8

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

# Preface to the Fourth Edition

In this edition, only minor changes have been made in the body of the text. The main changes have been to add a substantial number of nonprogramming exercises, add some new programming exercises, and make minor alterations to many of the existing exercises. A number of instructors have asked for nonprogramming exercises for which answers were not given in the text. We have added such exercises, and expanded the set for which answers are provided in Appendix G. The reader interested in self-study should check Appendix G to determine which answers are provided. We should also point out that *Exercises for IBM Basic Assembler Language*, second edition, by Kathleen Keil (Macmillan, 1989) offers an excellent selection of nonprogramming exercises.

We have added a number of nonprogramming exercises that require the reader to deduce some fairly minimal information from program dumps. These exercises may seem superfluous, since the ASSIST dumps offer a great deal of extra information. However, we do feel that many basic skills can be sharpened by tracing information in dumps, that in real situations the actual dumps do not reflect the wonderful debugging aids of ASSIST, and that the process of figuring out "what went wrong" can be an enormously pleasurable activity. We hope that these new exercises prove beneficial.

Several instructors have been taken by surprise when they became aware that ASSIST does not support floating-point computations and only a limited macro capability (ASSIST/I does not support *any* ability to define macros). It is certainly true that we planned on a class actually utilizing an IBM (or IBM-compatible) mainframe for exercises involving IO, floating-point, or macros. However, it is also true that a solid introduction to IBM assembler language can easily be attained now by anyone with only an IBM PC.

**We would like to note that ASSIST/I is no longer being commercially marketed, and is now available in the public domain. Anyone with an existing copy is welcome to copy and distribute it. Educational institutions that wish an initial copy that will execute on an IBM PC (or PC-compatible) system should be able to acquire a copy from Macmillan Publishing Company. Anyone who cannot get a copy from a friend should be able to purchase a copy for a very modest fee from Books and Bytes (708-416-0102).**

R. A. O.
W. E. S.

# Preface

The objective of this text is the systematic introduction of a completely operational subset of assembler language. Elements of the language are introduced without the complications inherent in any attempt to cover file manipulation and data processing concepts in a first assembler language course. Concentration on the language alone permits a more thorough and comprehensive initial treatment.

Prior knowledge of flowcharting (including structured flowcharts) and a higher-level language provides a useful background for the material presented in this text but is not essential. No specific knowledge beyond a familiarity with ordinary arithmetic operations is presumed (although an ability to read with comprehension is helpful).

The authors are convinced that any programming language is most effectively taught by doing both of the following:

1. introducing complete programs in a simple subset of the language as early as possible
2. building upon that subset in an orderly and logical manner with the introduction of complete sample programs and exercises at manageable intervals

In order to achieve the text's goal most effectively, it was necessary to choose a method of initially bypassing the complicated I/O features of the language, as well as furnishing more comprehensible debugging tools than those available on production assemblers. The ASSIST student assembler was chosen for the following reasons:

1. ASSIST, at this writing, is the most widely used student assembler. This software package is now being used at more than 350 installations.
2. Only the five pseudo-instructions of ASSIST (XREAD, XPRNT, XDECI, XDECO, and XDUMP) are necessary to achieve the stated objectives. The macros that implement these instructions are included in the ASSIST package and may be used independently with any assembler.
3. Experience has shown that, under ASSIST, student jobs run in about one-fourth the time that these same jobs require under the vendor-supplied, assemble-and-go procedures.

4. Both OS and DOS versions of ASSIST are available to educational and commercial computer installations. An ASSIST software request form is available in the back of the *Instructor's Guide*.

It is the opinion of the authors that, to present a working knowledge of assembler language adequately in a first course, an aid such as ASSIST is an absolute necessity.

Preprints of the original version of this text were classroom-tested in introductory courses at various universities for three years, and the first edition itself has been generally available for more than six years. This experience has shown that the first nine chapters can be adequately covered in a fifteen-week semester. The assigned exercises for such courses have included a selection of nonprogramming assignments and an assigned program from each of the exercise sets in Chapters 2–9. The exercises are an integral part of any formal or self-study course, since programming is a skill that can be acquired only through practice.

This text is not intended to supplant the use of manuals. Many details of assembler language have been omitted to facilitate the exposition and to conserve space. It is highly recommended that the following manuals be used in conjunction with the text:

- IBM System/370 Principles of Operation (GA22-7000)
- Assembler Language (GC33-4010)
- System/370 Reference Summary (GX20-1850)

The reader should be aware that each of these publications has gone through several editions, and care should be exercised to assure that the latest edition of each has been obtained.

The authors acknowledge the many useful suggestions and advice received from Graham M. Campbell and John Mashey, the creators of ASSIST, during the writing of the original text. In addition, the authors are indebted to Charles Hughes, Frank Cable, and Walter Sillars for their careful reading of that text and the many useful suggestions that they offered.

R. A. O.
W. E. S.

# Contents

**Preface to the Fourth Edition** v

**Preface** vi

**Chapter 1 NUMBER SYSTEMS AND COMPUTER STORAGE** 1

1.1 Number Systems 1
1.2 Binary- or Hexadecimal-to-Decimal Conversion 3
1.3 Decimal-to-Binary or -Hexadecimal Conversion 4
1.4 Conversions between Binary and Hexadecimal Representations 6
1.5 Addition and Subtraction of Binary and Hexadecimal Numbers 8
1.6 Main Storage Organization 15
1.7 Binary Representation of Integer Numbers 17
1.8 Overflow 19
1.9 General-Purpose Registers and Relative Addressing 20

**Chapter 2 BASIC CONCEPTS** 25

2.1 The Function of a Program 25
2.2 RR Instructions 26
2.3 RX Instructions 29
2.4 A Complete Program 31
2.5 XDUMP and Implicit Addresses 35
2.6 The Condition Code and Branching 39
2.7 The XREAD and XDECI Instructions 42
2.8 The XPRNT and XDECO Instructions 46
2.9 More Instructions and Examples 52
2.10 Multiplication and Division 58

2.11 Register EQUates and Extended Mnemonics 65
2.12 Literals 67
2.13 The LA Instruction 69

**Chapter 3 LOOPING, SUBROUTINES, AND MORE INSTRUCTIONS 77**

3.1 The STC and IC Instructions 77
3.2 Looping Using the BCT and BCTR Instructions 78
3.3 The BXLE and BXH Instructions 84
3.4 BAL, BALR, and Subroutines 95
3.5 STM and LM Instructions 100
3.6 A-Type Address Constants 101

**Chapter 4 ROUNDING OUT THE ESSENTIALS 109**

4.1 The SPACE, EJECT, and TITLE Instructions 109
4.2 Documentation Standards 126
4.3 Two SI Instructions: MVI and CLI 127
4.4 MVC and CLC: the SS Counterparts of MVI and CLI 130
4.5 Referencing the Location Counter 134
4.6 Uses of the ORG Instruction 136
4.7 Logical Arithmetic and Comparison Instructions 146

**Chapter 5 DECIMAL ARITHMETIC 157**

5.1 Zoned and Packed Decimal Formats 157
5.2 The PACK and UNPK Instructions 160
5.3 The Decimal Instructions AP, SP, and ZAP 163
5.4 The Decimal Instructions MP, DP, and CP 166
5.5 X-Type Constants 168
5.6 The ED Instruction 170
5.7 The SRP Instruction 179
5.8 The CVB and CVD Instructions 181
5.9 The EDMK Instruction 183
5.10 The Edit Algorithm 197

**Chapter 6 EXTERNAL SUBROUTINES AND DSECTs 203**

6.1 Functions of the Assembler and Loader 203
6.2 An Introduction to External Subroutines 205

6.3 Coding and Invoking External Subroutines 206
6.4 Linkages between BAL and High-Level Languages 223
6.5 Dummy Sections (DSECTs) 224

**Chapter 7 INPUT/OUTPUT UNDER OS AND DOS 231**

7.1 Introduction 231
7.2 Sequential Files 231
7.3 Tape Files 233
7.4 Disk Files 234
7.5 An Overview of the Queued Sequential Access Method (QSAM) 236
7.6 Invoking QSAM Services in an OS Environment 237
7.7 Invoking QSAM Services in a DOS Environment 252

**Chapter 8 ADVANCED TECHNIQUES 267**

8.1 Constants, Literals, and the DC and DS Statements 267
8.2 The AND, OR, and EXCLUSIVE OR Instructions 275
8.3 The TM Instruction 283
8.4 The Shift Instructions 285
8.5 Halfword Instructions 293
8.6 The MVCL, CLCL, and EX Instructions 298
8.7 The TR Instruction 302
8.8 The TRT Instruction 305
8.9 The CLM, ICM, and STCM Instructions 312
8.10 The SPM Instruction 321
8.11 The MVN, MVZ, and MVO Instructions 322

**Chapter 9 MACROS AND CONDITIONAL ASSEMBLY 345**

9.1 Symbolic Parameters and Macros 345
9.2 Conditional Assembly 349
9.3 Arithmetic SET Symbols 360
9.4 Binary SET Symbols 366
9.5 Character SET Symbols 369
9.6 The MNOTE and MEXIT Instructions 371
9.7 Operand Sublists 375
9.8 Keyword Macro Definitions 377
9.9 Additional Uses of Conditional ASSEMBLY 388

**Chapter 10 FLOATING-POINT ARITHMETIC** **391**

10.1 Introduction 391
10.2 Floating-Point Number Representations 392
10.3 E- and D-Type DC and DS Statements 395
10.4 Conversions between Decimal and Floating-Point Numbers 396
10.5 Normalization and Floating-Point Registers 397
10.6 The Floating-Point Load and Store Instructions 398
10.7 The Floating-Point Add, Subtract, and Compare Instructions 400
10.8 The Floating-Point Multiply, Divide, and Halve Instructions 402
10.9 Sign Control 406
10.10 Unnormalized Add and Subtract Instructions 406
10.11 Extended-Precision Arithmetic and Rounding 407
10.12 Floating-Point Arithmetic Exceptions 409
10.13 The Input and Output of Floating-Point Numbers 410

**Chapter 11 DEBUGGING A PROGRAM** **417**

11.1 Introduction 417
11.2 Verification Techniques 418
11.3 Working from a Dump 421
11.4 Summary 426

**Chapter 12 STRUCTURED PROGRAMMING** **429**

12.1 Introduction 429
12.2 Loops—the Do-While Construct 432
12.3 Processing Alternatives—the If Construct 435
12.4 How to Formulate an Algorithm—Stepwise Refinement 441
12.5 A Structured Program with Pseudo-Code 447
12.6 Writing Structured Programs Using Macros to Implement the Structures 449

**Chapter 13 A CURSORY TOUR OF ASSIST/I** **457**

13.1 Introduction 457
13.2 Getting Started with ASSIST/I 457
13.3 Basic Functions of the Text Editor 463

**Chapter 14 EFFECTIVE USE OF ASSIST/I** 469

14.1 Introduction 469
14.2 Use of XREAD and XPRNT under ASSIST/I 469
14.3 Getting Printed Output 471
14.4 Interactive Debugging with ASSIST/I 473
14.5 Advanced Features of the Editor—the Quick Commands 479
14.6 More on the Editor—Block and File Commands 482

**Chapter 15 ASSIST/I USERS' MANUAL** 485

15.1 Editing Programs 485
15.2 ASSIST/I Pseudo-Instructions 492
15.3 The $ENTRY 497
15.4 Running Programs 498
15.5 Making Final Runs 498
15.6 Printing Programs and Listings 499
15.7 Using the ASSIST/I Debugger 499
15.8 Altering ASSIST/I Options 504

Appendix A Illustration of Subroutines 507
Appendix B Table of Extended Mnemonics 516
Appendix C Converting Hexadecimal to Punched Card Codes 517
Appendix D Errors and Their Causes 525
Appendix E Interrupts and the Supervisor 533
Appendix F Listing of Structured Programming Macros 542
Appendix G Answers to Nonprogramming Exercises 555

**INDEX** 560

# 1

# Number Systems and Computer Storage

## 1.1 NUMBER SYSTEMS

The system commonly used for representing numbers is the decimal number system. This is the familiar positional number system in which any natural number may be uniquely represented by use of the ten symbols 0, 1, 2, . . . , 9. In this system these ten symbols, also referred to as decimal digits, represent the numbers zero, one, two, . . . , nine, respectively. A unique representation of any natural number $m$ can be given in the form

$$d_n d_{n-1} d_{n-2} \ldots d_1 d_0$$

where $m \geqslant 0$. The same natural number $m$ can also be represented in the form

$$d_n \times 10^n + d_{n-1} \times 10^{n-1} + d_{n-2} \times 10^{n-2} + \ldots + d_1 \times 10^1 + d_0 \times 10^0$$

For example, the number one hundred twenty-three may be represented by

$$123$$

or by

$$1 \times 10^2 + 2 \times 10^1 + 3 \times 10^0$$

The decimal number system is also called the base ten system since ten digits are utilized in the number representations in this system. There is, however, nothing sacred about the base ten since the notion of a positional number system can be easily generalized to any given base $b$ where $b$ is a natural number greater than or equal to two. Consider the following examples:

- *Example 1.* The number one hundred twenty-three is to be represented in the base two or binary number system. The symbols 0 and 1 are chosen to represent zero and one, just as ten symbols were selected in the base ten system to represent zero, one, two, . . . , nine. Then, since

$$123 = 1 \times 2^6 + 1 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$$

the number one hundred twenty-three would be represented in the binary system by

1111011

- *Example 2.* The number one hundred twenty-three is to be represented in the base sixteen, or hexadecimal, number system. The symbols 0, 1, 2, . . . , 9, A, B, C, D, E, F are chosen to represent the numbers zero, one, two, . . . , nine, ten, . . . , fifteen. Then, since

$$123 = 7 \times 16^1 + 11 \times 16^0$$

the number one hundred twenty-three would be represented in the hexadecimal system by 7B.

Table 1-1 gives the representations of the numbers zero through thirty-two in each of these three number systems.

**Table 1-1**

| *Decimal* | *Hexa-decimal* | *Binary* | *Decimal* | *Hexa-decimal* | *Binary* |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 17 | 11 | 10001 |
| 1 | 1 | 1 | 18 | 12 | 10010 |
| 2 | 2 | 10 | 19 | 13 | 10011 |
| 3 | 3 | 11 | 20 | 14 | 10100 |
| 4 | 4 | 100 | 21 | 15 | 10101 |
| 5 | 5 | 101 | 22 | 16 | 10110 |
| 6 | 6 | 110 | 23 | 17 | 10111 |
| 7 | 7 | 111 | 24 | 18 | 11000 |
| 8 | 8 | 1000 | 25 | 19 | 11001 |
| 9 | 9 | 1001 | 26 | 1A | 11010 |
| 10 | A | 1010 | 27 | 1B | 11011 |
| 11 | B | 1011 | 28 | 1C | 11100 |
| 12 | C | 1100 | 29 | 1D | 11101 |
| 13 | D | 1101 | 30 | 1E | 11110 |
| 14 | E | 1110 | 31 | 1F | 11111 |
| 15 | F | 1111 | 32 | 20 | 100000 |
| 16 | 10 | 10000 | | | |

The decimal, hexadecimal, and binary number systems have particular significance to an assembler language programmer. It is essential, for reasons that will become apparent later, that the programmer have the ability

to convert a representation of a number given in any one of these three systems to a representation in either of the other two systems. Sections 1.2, 1.3, and 1.4 are devoted to a presentation of algorithms that may be used to perform these conversions.

In the remainder of this book, wherever a number representation appears and it would not otherwise be clear from the context which of the three number systems is intended, a subscript will be appended to the representation to indicate the appropriate base. As an example, consider 1011, which could represent eleven, one thousand eleven, or four thousand one hundred thirteen, depending upon the choice of the number base.

The following expressions should be clear to the reader:

$$1011_2 = 11_{10}$$
$$1011_{16} = 4113_{10}$$

## 1.2 BINARY- OR HEXADECIMAL-TO-DECIMAL CONVERSION

Let

$$a_n a_{n-1} \ldots a_2 a_1 a_0$$

be the representation of a number $m$ in base $b$. Then, the decimal representation of $m$ is given by the sum

$$d_n b^n + d_{n-1} b^{n-1} + \ldots d_2 b^2 + d_1 b^1 + d_0 b^0$$

where each $d_i$ is the decimal equivalent of the corresponding $a_i$.

The following examples illustrate the effect of applying the above algorithm to number representations in the binary system:

a. $1011011_2 = 1 \times 2^0 + 1 \times 2^1 + 0 \times 2^2 + 1 \times 2^3 + 1 \times 2^4 + 0 \times 2^5 + 1 \times 2^6$
$= 1 \times 1 + 1 \times 2 + 0 \times 4 + 1 \times 8 + 1 \times 16 + 0 \times 32 + 1 \times 64$
$= 91$

b. $1011_2 = 1 \times 2^0 + 1 \times 2^1 + 0 \times 2^2 + 1 \times 2^3$
$= 11$

c. $110_2 = 0 \times 2^0 + 1 \times 2^1 + 1 \times 2^2$
$= 6$

d. $10110111_2 = 1 \times 2^0 + 1 \times 2^1 + 1 \times 2^2 + 0 \times 2^3 + 1 \times 2^4 + 1 \times 2^5 + 0 \times 2^6 + 1 \times 2^7$
$= 183$

**Exercises**

Convert the following numbers in binary representations to their equivalent decimal representations.

| | | | |
|---|---|---|---|
| **1. a.** 11 | **c** 11110 | **e.** 111 | **g.** 101110111 |
| **b.** 10111 | **d.** 111011 | **f.** 1111 | **h.** 0111 |
| **2. a.** 101 | **c.** 01010 | **e.** 1110 | **g.** 11011101 |
| **b.** 1101 | **d.** 110011 | **f.** 0011 | **h.** 100110011 |

The following examples illustrate the effect of applying the conversion algorithm to number representations in the hexadecimal system:

a. $613_{16} = 3 \times 16^0 + 1 \times 16^1 + 6 \times 16^2$
$= 3 \times 1 + 1 \times 16 + 6 \times 256$
$= 1555$

b. $A61 = 1 \times 16^0 + 6 \times 16^1 + A \times 16^2$
$= 1 \times 1 + 6 \times 16 + 10 \times 256$
$= 2657$

c. $BE = E \times 16^0 + B \times 16^1$
$= 14 \times 1 + 11 \times 16$
$= 190$

**Exercises**

Convert the following hexadecimal representations to decimal representations.

| | | | |
|---|---|---|---|
| **1. a.** F | **c.** BD2 | **e.** CEF | **g.** F1 |
| **b.** A1 | **d.** 1000 | **f.** EF | **h.** 126 |
| **2. a.** D | **c.** B13 | **e.** 100 | **g.** BA9 |
| **b.** B7 | **d.** E42 | **f.** 10D | **h.** ABCD |

## 1.3 DECIMAL-TO-BINARY OR -HEXADECIMAL CONVERSION

To obtain the representation of a number $n$ in a given base $b$ from the representation of $n$ in the decimal system, the following algorithm may be applied:

*Step 1.* Divide $n$ by $b$, giving a quotient $q$ and remainder $r$.
*Step 2.* Write the representation of $r$ in the base $b$ as the rightmost digit or as the digit to the immediate left of the one last written.
*Step 3.* If $q$ is zero, stop. Otherwise set $n$ equal to $q$ and go to Step 1.

The following example illustrates the effect of applying this algorithm to convert decimal to hexadecimal representations:

Assume that the given decimal representation is 123.

*Step 1.* Divide 123 by 16, giving $q = 7$ and $r = 11$.
*Step 2.* Since $r = 11 = B_{16}$, B is written as the rightmost digit in the hexadecimal representation.
*Step 3.* Since $q = 7$, set $n = 7$ and proceed to Step 1.

*Step 1.* Divide 7 by 16, giving $q = 0$ and $r = 7$.
*Step 2.* Since $r = 7 = 7_{16}$, write 7 to the immediate left of the digit previously written, giving 7B.
*Step 3.* Since $q = 0$, stop. The desired hexadecimal representation is 7B.

Figure 1-1 graphically illustrates the application of the conversion algorithm in the example just given.

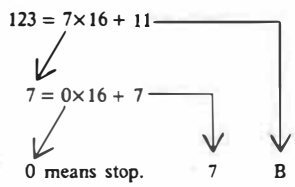



**Figure 1-1**

Hence $123 = 7B_{16}$

In a similar way the calculations performed in converting the decimal representation 123 to binary representation are illustrated in Figure 1-2.

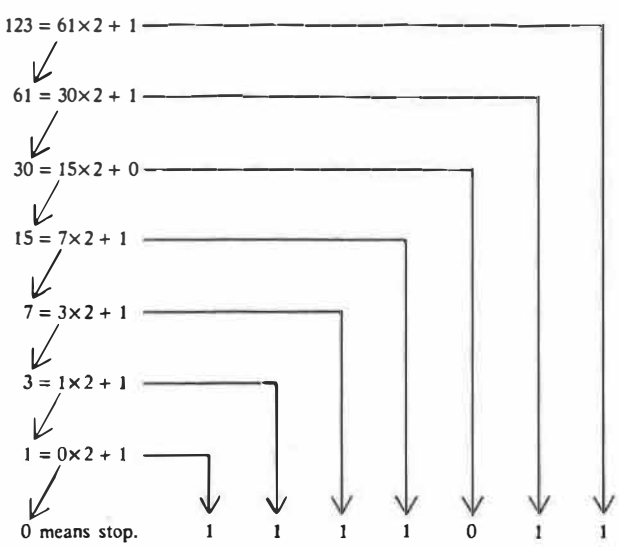



**Figure 1-2**

Hence $123 = 1111011_2$

Appendix C provides a convenient table to assist in conversions between the decimal and hexadecimal number systems.

**Exercises**

**1.** Convert the following decimal representations to hexadecimal representations.

**a.** 124 **b.** 42 **c.** 4000 **d.** 432

**2.** Convert the representations given above to binary representations.

**3.** Convert the following decimal representations to hexadecimal representations.

**a.** 116 **b.** 87 **c.** 1873 **d.** 6728

**4.** Convert the decimal representations given in problem 3 to binary representations.

## 1.4 CONVERSIONS BETWEEN BINARY AND HEXADECIMAL REPRESENTATIONS

Because 16 digits are required in the hexadecimal system and $16 = 2^4$, a very simple algorithm exists for converting binary representations to hexadecimal representations, and vice versa.

The algorithm for converting from binary to hexadecimal may be stated as follows:

*Step 1.* Starting at the right of a binary representation $n$, separate the digits into groups of four. If there are fewer than four digits in the last (leftmost) group, add as many zeros as may be necessary to the left of the leftmost digit to fill out the group. For example, if $n = 101101$, the digits should be separated into two groups depicted as follows: 10 1101. Since the leftmost group does not contain four digits, two leading zeros are added to give 0010 1101.

*Step 2.* Convert each group of four binary digits to a hexadecimal digit. The result is the hexadecimal representation of $n$.

The following examples should serve to clarify the use of this algorithm:

• *Example 1.* $n = 101101$

10 1101

Adding zeros to fill out the leftmost group yields

0010 1101

Then converting these groups of binary digits to hexadecimal representation yields

2 D

Hence $101101_2 = 2D_{16}$

- *Example 2.* $n = 101011101$
  The algorithmic process may be represented as follows:

| | | |
|---|---|---|
| 1 | 0101 | 1101 |
| 0001 | 0101 | 1101 |
| 1 | 5 | D |

Hence $101011101_2 = 15D_{16}$

- *Example 3.* $n = 111111$
  This yields

| | |
|---|---|
| 11 | 1111 |
| 0011 | 1111 |
| 3 | F |

Hence $111111_2 = 3F_{16}$

To convert from hexadecimal representations to binary, the above algorithm is simply reversed; that is, each hexadecimal digit is represented by a group of four binary digits and then any leading zeros are dropped.

Consider the following examples of this process:

- *Example 1.* $n = 12BC$
  The conversion process is illustrated as follows:

| | | | |
|---|---|---|---|
| 1 | 2 | B | C |
| 0001 | 0010 | 1011 | 1100 |

Hence $12BC_{16} = 1001010111100_2$

- *Example 2.* $n = FB2$
  This yields

| | | |
|---|---|---|
| F | B | 2 |
| 1111 | 1011 | 0010 |

Hence $FB2_{16} = 111110110010_2$

- *Example 3.* $n = 1080$
  This yields

| | | | |
|---|---|---|---|
| 1 | 0 | 8 | 0 |
| 0001 | 0000 | 1000 | 0000 |

Hence $1080_{16} = 1000010000000_2$

**Exercises**

**1.** Convert the following hexadecimal representations to corresponding binary representations.

**a.** E **c.** B976 **e.** FFAB
**b.** 10CD **d.** 4210 **f.** ABCD

**2.** Convert the following binary representations to corresponding hexadecimal representations.

**a.** 101101111 **c.** 1010 **e.** 10111101111
**b.** 101010101 **d.** 11110001 **f.** 1011110011100010

**3.** Convert the following hexadecimal representations to corresponding binary representations.

**a.** B **c.** D7BA **e.** 9AF7
**b.** 11 **d.** 77 **f.** F18B

**4.** Convert the following binary representations to corresponding hexadecimal representations.

**a.** 1101 **c.** 110111 **e.** 10000011
**b.** 101010 **d.** 1111111 **f.** 110011000

In the remainder of this text, we shall follow the convention of referring to representations of numbers in the binary, decimal, and hexadecimal systems simply as binary, decimal, or hexadecimal numbers.

## 1.5 ADDITION AND SUBTRACTION OF BINARY AND HEXADECIMAL NUMBERS

The algorithms for the addition and subtraction of integer numbers in positional number systems are independent of the base in which the numbers are represented. These algorithms do, however, require that the table for addition of digits in the appropriate base be known. You are, no doubt, so familiar with the addition table for decimal digits that you automatically think of 8 plus 8 as 16, or 6 plus a carry (which we will write as 6 + c).

The algorithm for the addition of integer numbers, assuming that both addends are positive, is as follows:

*Step 1.* Write the two addends one above the other with the rightmost digits of these numbers aligned.

*Step 2.* Add the two rightmost digits; if a 1 appears above these digits, indicating a carry, add 1 to the result. Write the integer portion of this result to the immediate left of the last recorded digit in the sum;

if a carry is part of the result, write a 1 above the next higher order pair of digits. (If one or both of the digits do not exist, assume a value of 0 for the missing digits.)

*Step 3.* Delete the rightmost digits of the two addends. If the digits of the addends are exhausted, stop; otherwise, go to Step 2.

To illustrate the use of this algorithm, suppose that the numbers 743 and 864 in the familiar decimal number system are to be added. The result of applying the algorithm is graphically depicted in Figure 1-3.

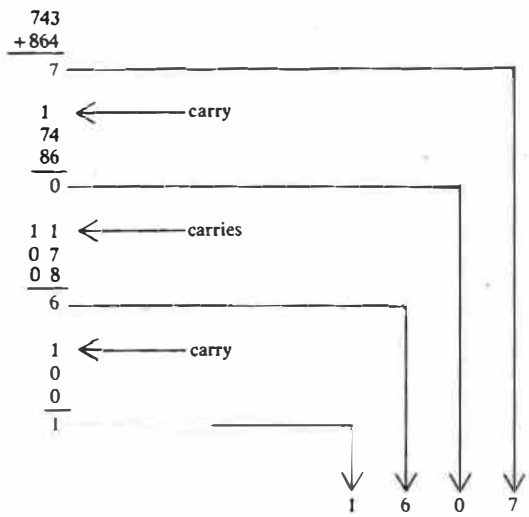



**Figure 1-3**

Collecting the results yields

$$\begin{array}{r} 11 \\ 743 \\ +\,864 \\ \hline 1607 \end{array} \longleftarrow \text{carries}$$

Table 1-2 presents the addition of binary digits. This table is easy to remember since there are only two digits involved.

**Table 1-2**

| + | 0 | 1 |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 1 | 0+c |

The result of using this table and the addition algorithm to find the sum of 10110 and 1011 is graphically depicted in Figure 1-4.

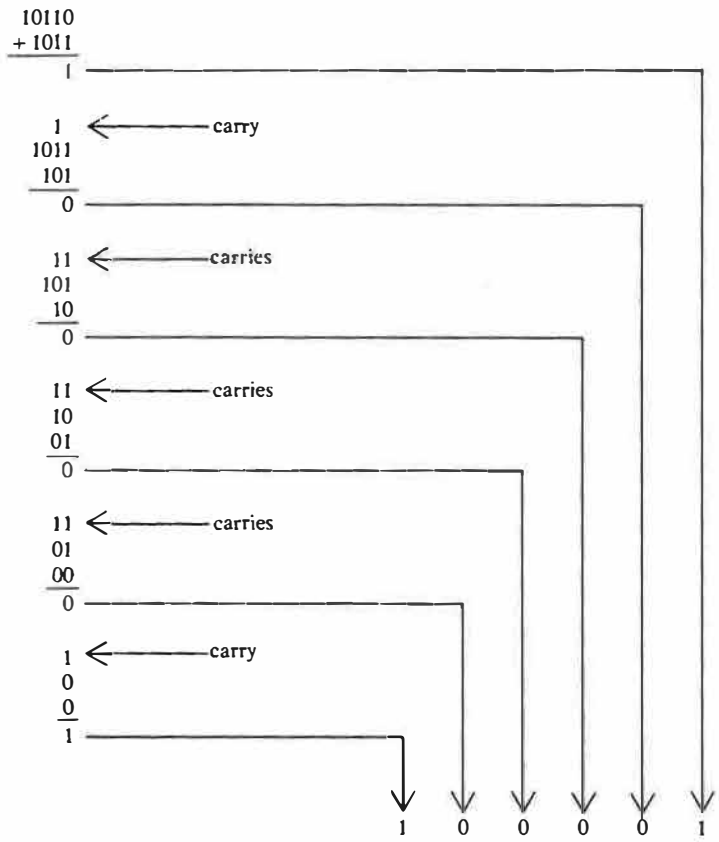



**Figure 1-4**

Collecting these results, we have

$$\begin{array}{r} 1111 \\ 10110 \\ +\,1011 \\ \hline 100001 \end{array} \longleftarrow \text{carries}$$

With little or no practice you should easily master the art of adding binary numbers as indicated in the collected result without writing down the intermediate steps. This is the same way that you add decimal numbers. More practice is required in the case of hexadecimal numbers because the addition table (Table 1-3) is much more complex. Figure 1-5 graphically depicts the addition of the hexadecimal numbers 9A05 and FCDE.

**Table 1-3**

| + | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c |
| 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c |
| 3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c |
| 4 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c |
| 5 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c |
| 6 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c |
| 7 | 7 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c |
| 8 | 8 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c |
| 9 | 9 | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c |
| A | A | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c |
| B | B | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c | A+c |
| C | C | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c | A+c | B+c |
| D | D | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c | A+c | B+c | C+c |
| E | E | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c | A+c | B+c | C+c | D+c |
| F | F | 0+c | 1+c | 2+c | 3+c | 4+c | 5+c | 6+c | 7+c | 8+c | 9+c | A+c | B+c | C+c | D+c | E+c |

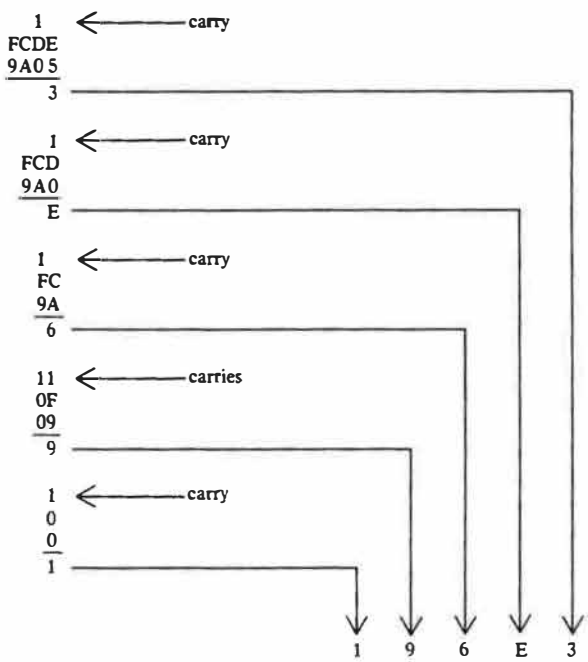



**Figure 1-5**

Collecting the results yields

```
11  1   ←—— carries
 FCDE
 9A05
196E3
```

Subtraction is the inverse of addition. The addition tables given may, therefore, be utilized in performing subtraction. In the subtraction algorithm presented below it will be assumed that the subtrahend (the number to be subtracted) is less than or equal to the minuend (the number from which the subtrahend is to be subtracted), and, further, that both of these numbers are positive. (These should prove to be nonessential restrictions when a programmer is required, in practice, to perform subtraction on binary or hexadecimal numbers.)

The subtraction algorithm is as follows:

*Step 1.* Write the minuend above the subtrahend with the rightmost digits of these numbers aligned.

*Step 2.* *(a)* If the rightmost digit in the minuend is greater than or equal to the corresponding digit in the subtrahend, subtract the digit in the subtrahend from the corresponding digit in the minuend and write the result to the immediate left of the last recorded digit in the difference; otherwise

*(b)* If the rightmost digit $d$ in the minuend is less than the corresponding digit in the subtrahend, replace $d$ by $d + c$, decrease the next-higher-order nonzero digit in the minuend by 1, replace any intervening zero digits in the minuend by the digit corresponding in value to the base minus 1. Then subtract the rightmost digit in the subtrahend from $d + c$ and write the result to the immediate left of the last recorded digit in the difference.

*Step 3.* Delete the rightmost digits in the minuend and subtrahend. If the digits of these two numbers are exhausted, stop; otherwise, go to Step 2.

To use the addition table for the subtraction of two digits, first locate the digit in the subtrahend in the column of digits to the left of the table. Then locate the digit $d$ in the minuend (or $d + c$) in the row corresponding to this digit. Finally, proceed vertically up the corresponding column to find the difference in the row of digits at the top of the table.

The result of using this algorithm to subtract 10011 from 111000 is graphically depicted in Figure 1-6.

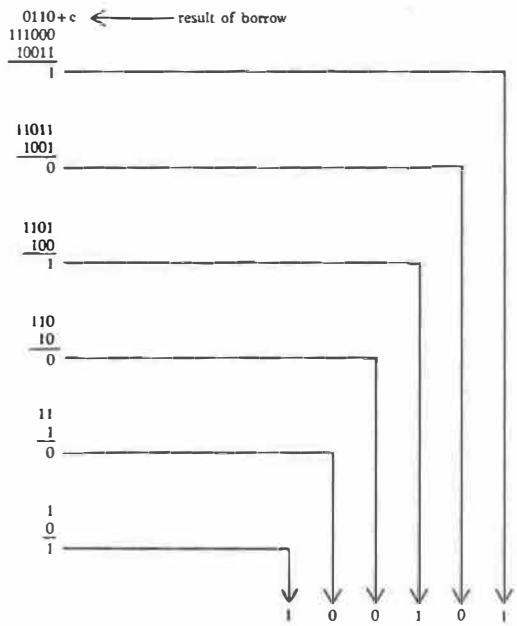



**Figure 1-6**

Collecting the results yields

```
  0110+ c ←—— result of borrow
111000
 10011
------
100101
```

Using the algorithm to subtract 9AE5 from FCDE results in Figure 1-7.

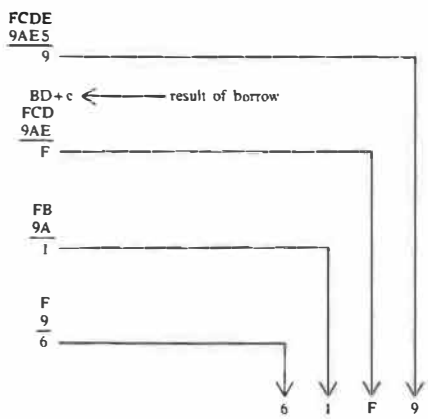



**Figure 1-7**

Collecting the results yields

```
  BD + c ←—— result of borrow
 FCDE
 9AE5
 ----
 61F9
```

As in the case of addition, you should find that you can easily perform subtraction as indicated in the collected results without actually carrying out the intermediate steps.

## Exercises

**1.** Add the following binary numbers.

**a.** 10110 + 1101 **b.** 110011 + 100111 **c.** 10110 + 10110

**2.** Subtract the following binary numbers.

**a.** 11101 − 1001 **b.** 10011 − 1011 **c.** 110001 − 10010

**3.** Add the following hexadecimal numbers.

**a.** FB28 + 3254 **b.** 82CD + 1982 **c.** E2C + A31 **d.** 1423 + 19A0

**4.** Subtract the following hexadecimal numbers.

**a.** FCDE − 985A **b.** 89A3 − 6494 **c.** 642E − 150F **d.** FFFF − EADF

**5.** Add the following binary numbers.

**a.** 11001 + 101 **b.** 11111 + 1011 **c.** 10101 + 11111

**6.** Subtract the following binary numbers.

**a.** 11111 − 1101 **b.** 10000 − 1110 **c.** 11001 − 10110

**7.** Add the following hexadecimal numbers.

**a.** FA17 + 3397 **b.** 11111 + 7EEBF **c.** EBB3 + AE7F **d.** FF15 + 88AF

**8.** Subtract the following hexadecimal numbers.

| | | | |
|---|---|---|---|
| **a.** FFA9 | **b.** 16FC | **c.** 6658 | **d.** EEFA |
| − 7BB | − FFF | − 5700 | − DFFF |

## 1.6 MAIN STORAGE ORGANIZATION

A computer is a high-speed electronic machine designed to store, manipulate, and retrieve data. The area in which data is stored is called the *main storage* of the computer. To understand how data is manipulated by a computer, it is first necessary to understand the manner in which this data is represented in storage. The following discussion deals with the representation of numeric data in the main storage of the computer.

Storage may be thought of as a long sequence of on-off switches called *binary digits* or *bits*. Typical current computer memories contain between $2^{19}$ and $2^{30}$ bits. These bits are organized into groups of eight contiguous bits, and each such group is called a *byte*. Bytes are assigned consecutive increasing hexadecimal numbers starting with the number 0. Thus, storage may be pictorially represented as

| | | | |
|---|---|---|---|
| bbbbbbbb | bbbbbbbb | bbbbbbbb | . . . |
| byte 0 | byte 1 | byte 2 | . . . |

where each of the b's represents a bit and the number assigned to a given byte is called the absolute *address* of that byte. In order to relate the on-off switches to binary digits, it is standard convention to represent a switch that is on by a 1 and a switch that is off by a 0. Hence, the condition of each byte may be identified with an eight-digit binary number at any given moment. For example, if it is assumed that all of the switches in the first two bytes of storage are on, the condition of storage may be pictorially represented as

| | | |
|---|---|---|
| 11111111 | 11111111 | . . . |
| byte 0 | byte 1 | . . . |

where byte 0 and byte 1 each contain the binary number corresponding to the decimal number 255. Because of the natural correspondence between binary and hexadecimal numbers, the condition of a byte can be represented by a two-digit hexadecimal number. Hence, the condition of storage given in the last example may be represented as

| | | |
|---|---|---|
| FF | FF | . . . |
| byte 0 | byte 1 | . . . |

The byte is the fundamental unit of main storage in the sense that any position or address in storage which it is possible to specify is referred to by the address of the byte at that position. It is often necessary to reference *fields* that contain several bytes. The address of such a field is considered to be the address of the first (pictorially, the leftmost) byte in the field.

Aside from the bits and bytes there are several other units of storage which are of particular importance. If all of the bytes in storage are thought of as being grouped into consecutive nonoverlapping pairs beginning with byte zero, the resulting pairs of bytes are referred to as *halfwords*. This relationship of the bytes in storage to halfwords may be pictorially represented as follows:

| | | | | | |
|---|---|---|---|---|---|
| B0 B1 | B2 B3 | B4 B5 | B6 B7 | B8 B9 | etc. |
| H | H | H | H | H | |

From the above discussion, it should be particularly noted that each address that is an even number is the address of a halfword, and only even numbers are halfword addresses. For this reason, each even address is called a *halfword boundary*. Thus, it is valid to speak of the halfword beginning at address A8, but it is incorrect to speak of the halfword beginning at address A9.

In a manner analogous to that which pertains to halfwords, storage is also thought of as being organized into groups of four bytes, called *fullwords*, and groups of eight bytes, called *doublewords*. By analogy, each fullword must begin at an address that is evenly divisible by four, and each doubleword must begin at an address that is evenly divisible by eight.

This relationship between bytes, halfwords, fullwords, and doublewords may be pictorially represented as shown in Figure 1-8.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| byte 0 | byte 1 | byte 2 | byte 3 | byte 4 | byte 5 | byte 6 | byte 7 |
| HALFWORD beginning at 0 | | HALFWORD beginning at 2 | | HALFWORD beginning at 4 | | HALFWORD beginning at 6 | |
| FULLWORD beginning at 0 | | | | FULLWORD beginning at 4 | | | |
| DOUBLEWORD beginning at 0 | | | | | | | |

**Figure 1-8**

## 1.7 BINARY REPRESENTATION OF INTEGER NUMBERS

The capacity to perform integer arithmetic is a requirement common to all high-speed electronic digital computers. This requirement imposes the need to devise a method for representing both positive and negative integers in binary form. Several preliminary concepts must be introduced before the representation of integers in binary form in the computer is discussed.

Let $n$ be the binary representation of any integer. Then the *one's complement* of $n$ is the result of replacing each 0 in this representation with a 1 and replacing each 1 with a 0. For example, the binary representation of 9 is

1001

and the one's complement of this representation is

0110

If $n$ is the binary representation of any integer, then the *two's complement* of $n$ is formed by doing both of the following:

1. Find the one's complement of $n$.
2. Add 1 to this result.

For example, if the integer representations are in four digits, the two's complement of 5 may be found as follows:

| | |
|---|---|
| 0101 | binary representation of 5 |
| 1010 | one's complement of 5 |
| +1 | |
| 1011 | two's complement of 5 |

The 32-bit fullword is the unit of storage that was chosen in IBM computers for representing integer numbers. The fullword is, therefore, a particularly important unit of storage, since most arithmetic operations performed in these machines involve fullword operands. The method used for encoding integer numbers in fullwords is as follows:

1. Any integer in the range 0 to $2^{31} - 1$ (that is, 0 to 2,147,483,647) is represented in a fullword in its exact binary representation. Note that each 32-bit binary number in this range has a value of 0 in the leftmost bit position. This bit is called the *sign bit*, and all positive integer representations are characterized by having a sign bit value of 0.
2. Any integer in the range $-1$ to $-2^{31} + 1$ is encoded by taking the two's complement of the encoded form of its absolute value. A representation

of $-2^{31}$ is also allowed, but this representation (a 1 followed by 31 0's) is not the two's complement of the representation of any positive integer. The sign bit in the encoded form of each negative integer has a value of 1.

As an example, the encoded form of $+1$ is

00000000 00000000 00000000 00000001

The reader should verify that the encoded form of $-1$ is

11111111 11111111 11111111 11111111

There are two integers with encoded forms that are identical to their two's complements. These integers are 0 and $-2^{31}$.

Some rather remarkable things are true of the binary representations of integers in this scheme:

- The two's complement of the representation of a negative integer (with the exception of $-2^{31}$) is the representation of the absolute value of that integer.
- When binary addition is performed on the representations of integer numbers (whether the signs are mixed or not), the result has the correct value in the sign bit (provided that the result is in the range $-2^{31}$ to $2^{31} - 1$).

Integer addition is performed by simply performing the usual binary addition. Integer subtraction is performed by first taking the two's complement of the subtrahend and then adding the result to the minuend. There is no need for the sign bits of the integer representations of the numbers involved in these operations to be checked before the operations are performed, for the sign bit of the result will be correct as noted above.

To conserve space and since 32-bit binary numbers are all but impossible to read at a glance, the printouts of the conditions of memory locations are always given in hexadecimal form. (Remember that one hexadecimal digit represents four binary digits.) The printed forms of the representations of 1 and $-1$ are, therefore,

00000001

and

FFFFFFFF

In the rest of this text, the conditions of storage locations will be indicated by the hexadecimal representations of the existing binary conditions.

**Exercises**

Give the fullword representations of the following numbers (as eight-digit hexadecimal numbers).

| | | |
|---|---|---|
| **1. a.** 1 | **c.** −1 | **e.** 8412 |
| **b.** 248 | **d.** −10 | **f.** −8412 |
| **2. a.** 17 | **c.** −2 | **e.** 5352 |
| **b.** 267 | **d.** −321 | **f.** −5352 |

## 1.8 OVERFLOW

Overflow occurs when operations are performed on the representations of integer numbers with the effect that the carry into the sign bit of the result differs from the carry out of that position. As examples, consider the following addition operations on integers coded in five-bit binary numbers:

```
                    0 carry out of the sign bit
+8   01000
+9   01001
     -----
     10001
                    1 carry into the sign bit

                    1 carry out of the sign bit
-8   11000
-9   10111
     ------
     101111
                    0 carry into the sign bit
```

Note that in each case the result exceeds the range of numbers that can be encoded in five binary bits. The reader should verify that only numbers in the range $-2^4$ to $2^4-1$ can be encoded in five binary bits and that both 17 and −17 are out of this range.

In essence, overflow occurs when the result is outside the range that can be accommodated by the encoding scheme being used. The possibility of overflow in other situations will be covered when these situations are discussed.

## Exercises

Which of the following operations will result in overflow (assuming the result is to be stored in a fullword)?

1. **a.** complement $42_{16}$
   **b.** complement 0
   **c.** complement $-80000000_{16}$
   **d.** add 4 to $75800000_{16}$
   **e.** subtract $7FFFFFFF_{16}$ from $-4$
   **f.** add C to $7FFFFFF4_{16}$
   **g.** subtract 4 from $-7FFFFFF0_{16}$

2. **a.** complement 87
   **b.** complement FFFFFFFF
   **c.** complement 7FFFFFFC
   **d.** subtract 5 from 8000000F
   **e.** subtract 8 from 7FFFFFFC
   **f.** subtract 8 from 80000000
   **g.** add 17 to 7FFFFFFC

## 1.9 GENERAL-PURPOSE REGISTERS AND RELATIVE ADDRESSING

In Section 1.6, main storage was introduced as a hardware unit into which data could be stored in the form of binary numbers. Modern IBM computers also contain 16 general-purpose registers as units for storing and manipulating data. Each register is a 32-bit storage unit whose contents can be altered or accessed in much less time than it would take to alter or access a field in main storage. The relatively slow speed of accessing and altering storage, as compared to the extremely fast access time for the registers, is a result of the cost involved. Because of the difference in response time, the registers are often used as storage for frequently referenced data items or as operands in arithmetic operations.

In Section 2.2, we will describe the ways of doing arithmetic on numbers stored in registers and also the facilities for causing 32-bit words to be transferred to a register from a field in storage or vice versa. The 16 registers are numbered 0, 1, 2, . . . , 15 and will be referred to as R0, R1, . . . , R15 throughout this text.

One particularly important use of registers involves the concept of addressing. As previously stated, every byte of storage has associated with it an absolute address, and every field is addressed by the address of its leftmost byte. Whenever a program is run, it must be stored somewhere in main storage. Thus each instruction and each item of data in the program will have an absolute address. When, in a program, reference is made to a data item or to an instruction, the computer must have an absolute address to find what is referred to.

A difficulty arises immediately: The writer of a program does not know where in storage his program will be stored when it is run and therefore

does not know any of the relevant absolute addresses. Some other means has to be provided for referring to data or instructions within the program.

The means that is provided is called *base-displacement addressing* or *explicit addressing*. The idea is that within a program the relative positions of any two statements are fixed, such that if the absolute address of any one statement in the program were known, then the address of any other statement could be calculated. To do this, one would compute the distance between the statement whose absolute address is known and the one whose address is to be found. Such a distance, measured as a number of bytes, is called a *displacement*.

But how, you ask, can the absolute address of even one statement in the program be known? The way this comes about will be covered in later chapters. For now, it is sufficient to know that, when a program is executed (not before), such an address will be contained in at least one of the general-purpose registers. A register that holds an absolute address, from which the addresses of other statements can be calculated, is called a *base register*.

The standard way, then, to refer to any data item or instruction in a program is to specify a base register and a displacement. When the instruction containing the reference is executed, the sum of the displacement and the absolute address in the base register will be calculated to obtain the absolute address of the item or instruction. For example, if the displacement specified were 4, the base register specified were R1, and R1 contained 0000007C, the absolute address formed would be 000080. (The 32-bit contents of a register will always be shown in their hexadecimal representation.)

Base-displacement addresses are often specified in the format

D(B)

where D is the displacement, expressed as a decimal number in the range 0 to 4095
B is the number of the base register

For example,

4(1) 20(13) 0(11)

are base-displacement addresses. In the first example, $4_{10} = 4_{16}$ is added to the contents of R1. In the second example, $20_{10}$ is converted to $14_{16}$ and added to the contents of R13. In the third example, the contents of R11 give the desired address without modification.

Occasionally, it is convenient to express an address as the sum of a displacement, the contents of a base register, and the contents of a second register as well. The additional register is called an *index register;* the format for an address that includes an index register is

D(X,B)

where D and B have the same meaning as above
X is the number of the index register

For example,

4(7,1)

is a D(X,B) address, using R7 as the index register, R1 as the base register, and 4 as the displacement. If R1 contains 0000007C and R7 contains 00000010, the address calculated will be the sum of the contents of the two registers plus the displacement, or 000090.

In the next chapter, we will introduce the machine instructions in which D(B) or D(X,B) addresses may be used. Such an address is always used as part of a particular instruction; it never stands alone. Moreover, the rules for the particular instruction always specify which of the two addressing formats should be used.

There are three details that qualify the above remarks:

1. When the contents of an index register or a base register are used to calculate an address, only the value represented by the rightmost 24 bits of the register is used in the calculation. Thus, for the purpose of calculating an address, the value added from a register must always be in the range 000000 to FFFFFF. As an example, suppose that R1 contained FFFFFFFF (the encoding of −1). Then the effective address derived from 0(R1) is not negative; rather it is FFFFFF, an extremely large absolute address.
2. In either the D(B) or the D(X,B) address format, the registers may be omitted. This means that when a D(B) address is required, the programmer may use either of the following forms:

| *Form* | *Example* |
|---|---|
| D(B) | 42(15) |
| D | 42 |

Similarly, when a D(X,B) address is required, the programmer may use:

| *Form* | *Example* |
|---|---|
| D(X,B) | 42(1,14) |
| D(X) | 42(1) |
| D(,B) | 42(,14) |
| D | 42 |

Note that if only one register is specified in the D(X,B) address format, the presence or absence of a comma determines whether the register given is considered an index register or a base register.

When registers are omitted from a D(B) or D(X,B) address, the calculation of the corresponding absolute address is performed by using 0 in place of the contents of the omitted registers. Thus, either 42(14) or

42(,14) is converted to an absolute address by adding the binary equivalent of decimal 42 to the binary number represented by the rightmost three bytes of the contents of R14.

3. R0 should not ordinarily be used as an index register or as a base register. If R0 is specified in an address, it will be taken to mean that the corresponding register has been omitted. (As an example, both 4(,15) and 4(0,15) refer to the same absolute address.)

## Exercises

For the following two exercises, assume

| | |
|---|---|
| 0008AB40 | is in R0 |
| 0000004C | is in R1 |
| FC08AB44 | is in R2 |

**1.** Determine which of the following are valid addresses of the form D(B). For those that are valid, calculate the corresponding absolute address.

| | | | |
|---|---|---|---|
| **a.** 404(1) | **c.** 16(1) | **e.** 18(0) | **g.** 13(1,2) |
| **b.** 404(2) | **d.** 16(,1) | **f.** 18 | **h.** 13(2,1) |

**2.** Determine which of the following are valid relative addresses of the form D(X,B). For those that are valid, calculate the corresponding absolute address.

| | | | |
|---|---|---|---|
| **a.** 64(1,2) | **c.** 2(,0) | **e.** 13(,1) | **g.** 13(1,2) |
| **b.** 64(1,0) | **d.** 13(1,) | **f.** 48(0,2,1) | **h.** 13(2,1) |

For the following two exercises, assume

| | |
|---|---|
| 0007F144 | is in R0 |
| 00000028 | is in R1 |
| EC088840 | is in R7 |

**3.** Determine which of the following are valid D(B) addresses. For those that are valid, calculate the corresponding absolute address.

| | | | |
|---|---|---|---|
| **a.** 312(7) | **c.** 12(,0) | **e.** 110(0) | **g.** 14(1,7) |
| **b.** 312(1,7) | **d.** 12(1) | **f.** 2400 | **h.** 5032(1) |

**4.** Determine which of the following are valid D(X,B) addresses. For those that are valid, calculate the corresponding absolute address.

| | | | |
|---|---|---|---|
| **a.** 56(0,1) | **c.** 8(,7) | **e.** 11(1,7) | **g.** (1,7) |
| **b.** 0(0,1,7) | **d.** 6(7,0) | **f.** 4000(1) | **h.** 11(0,0) |

# 2

# Basic Concepts

## 2.1 THE FUNCTION OF A PROGRAM

The modern electronic digital computer is a remarkable device; it can perform literally millions of operations per second. If these operations occur in the proper sequence, meaningful results will be obtained that might have been totally inaccessible otherwise. The function of a program is to direct the order in which operations are executed within the computer. The creation of programs that correctly direct the sequence of operations is, therefore, of fundamental importance if computers are to be successfully utilized. Most of the remainder of this text will be devoted to a detailed description of the process of producing such programs.

The language described in this text is a symbolic language called *Basic Assembler Language*; this is the assembler language developed for use on IBM mainframe computers, beginning with the Model 360 class of machines. The task of the programmer is to produce a source program written in this language. The computer cannot directly carry out or execute assembler-language instructions. Each of these instructions must be translated into a machine-language instruction before the computer can begin to perform the task that the program was intended to accomplish. The machine-language instructions that the computer can execute directly are strings of binary digits that are difficult for a human to decipher. A program consisting entirely of machine-language instructions is called an *object program*.

After an assembler-language program has been prepared, a few additional instructions in *Job Control Language* (*JCL*) are added to the program, and the resulting program is presented to the computer through an input device, such as a card reader or a terminal. The JCL instructions invoke a program called an *assembler*, which translates the source program instructions into machine-language instructions and thus produces an object program.

During the translation, or assembly, of the source program, a listing is produced that displays the source-language instructions along with the machine-language instructions that are generated. If incorrectly formatted assembler-language instructions are encountered in the assembly process, error messages are printed in the listing and execution of the program is

aborted after the assembly process is completed. However, if no syntax errors are detected, the object program is loaded into the main storage of the computer and execution of the program begins.

The fact that a source program contains no syntax errors is certainly no guarantee that the resulting object program will perform the task for which it was intended. The program may still contain logical errors that the assembler had no means of detecting. To correct such errors, the programmer must understand exactly what is involved in encoding assembler-language instructions into machine language. The rules for performing this translation are covered in succeeding chapters; for now, all that must be grasped is that the assembler will produce an object program.

Suppose that a program has been successfully assembled and loaded in storage. The actual execution of the program is sketchily depicted by the following algorithm:

*Step 1.* Initially, the absolute address of the first instruction of the program to be executed is inserted into a special pointer called the *Program Status Word* (*PSW*).

*Step 2.* The machine retrieves from storage the instruction that is pointed to by the PSW.

*Step 3.* The machine then updates the contents of the PSW to point to the next instruction.

*Step 4.* The machine executes the operation indicated by the previously retrieved instruction. If the instruction did not cause a branch to occur (a branch is caused by a basic operation analogous to a GO TO statement in a higher-level language), then go to Step 2. Otherwise, put the absolute address that is to be branched to into the PSW, and go to Step 2.

The above procedure leaves a variety of questions unanswered. (For example, how does the machine halt?) It does, however, capture the essence of the way in which a program governs the operations of a machine. Later you will be able to visualize the details of the process more clearly.

## 2.2 RR INSTRUCTIONS

The process of encoding instructions can be clarified by considering some specific instructions in their symbolic and encoded forms. Instructions are encoded according to five distinct formats—RR, RX, RS, SI, and SS. The set of instructions encoded in the RR format is referred to as the RR *instructions*. In this section, the RR format will be covered in detail; discussions of the other formats will be deferred to later sections.

An RR instruction is most often used to cause an operation involving two registers. As a concrete example, consider the format of the Add Register instruction:

AR r1,r2 (*Add Register*)

Execution of this instruction causes the contents of r2 to be added to the contents of r1; the contents of r2 are unaltered, unless r2 is r1. If an overflow occurs in the process of addition, a fixed-point overflow condition will exist; this will normally cause termination of the program, and a message will be printed indicating that an error has occurred.

For example, execution of the instruction

AR 14,0

causes the number contained in R0 (the number may be positive or negative) to be added to the contents of R14, with the result replacing the original contents of R14.

In the preceding discussion of the symbolic format of the AR instruction, the form that would be used by a programmer was presented. As previously mentioned, the symbolic form must be translated into an encoded form before the instruction is actually executed. The encoded form of any RR instruction is a 16-bit binary number that will occupy a halfword of storage in the machine when the program is executed. The encoded instruction can, therefore, be represented as a four-digit hexadecimal number. The precise format of an encoded RR instruction is

$$h_0h_0h_{r1}h_{r2}*$$

where $h_0h_0$ is a two-digit operation code specifying the purpose of the instruction

$h_{r1}$ is the number of the register (0-F) that is to be used as the first operand

$h_{r2}$ is the number of the register that is to be used as the second operand

The operation code (op code) for an AR instruction is 1A. Therefore, the encoding of

AR 14,0

is 1AE0. The 1A means that the encoded instruction is an AR, the E indicates that the first operand is R14, and the 0 indicates that R0 is the second operand.

*Here, as in all instruction formats displayed in this work, each h represents one hexadecimal digit. Thus, $h_0h_0$ is a one-byte operation code.

Before ending this discussion of RR instructions, we shall introduce the Subtract Register and Load Register instructions.

```
SR      r1,r2          (Subtract Register)
```

Execution of this instruction causes the number represented by the contents of r2 to be subtracted from the number represented by the contents of r1. Just as for an AR, the result replaces the contents of r1; r2 is unaltered, unless r2 is r1. Fixed-point overflow can occur.

```
LR      r1,r2          (Load Register)
```

Execution of this instruction causes the replacement of the original contents of r1 by the contents of r2, while the contents of r2 remain unaltered. Thus, execution of the instruction

```
LR      5,10
```

causes the contents of R10 to be copied into R5.

Additional RR instructions will be introduced throughout the remainder of this text. However, the first few examples will employ only these three RR instructions and several RX instructions, which are introduced in Section 2.3.

## Exercises

**1.** Utilize the table of op codes in Appendix C to encode the following RR instructions.

**a.** AR 1,15 **c.** AR 14,3 **e.** AR 15,14
**b.** SR 2,10 **d.** SR 0,0

**2.** Write the symbolic equivalent of the following encoded RR instructions.

**a.** 1820 **b.** 1AFE **c.** 1BCC **d.** 1834

**3.** Suppose that

R0 contains 001A2F0B
R1 contains FFFFA21C
R6 contains 000019EF

Then show the contents of all three registers after each of the following instructions.

**a.** LR 6,0 **c.** AR 1,6 **e.** SR 1,1
**b.** SR 6,0 **d.** SR 1,6

**4.** Utilize the table of op codes in Appendix C to encode the following RR instructions.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **a.** | AR | 0,12 | **c.** | AR | 15,13 | **e.** | SR | 10,9 |
| **b.** | SR | 13,1 | **d.** | SR | 15,15 | **f.** | LR | 12,9 |

**5.** Write the symbolic equivalent of the following RR instructions.

**a.** 1BBB **b.** 18C1 **c.** 1A0F **d.** 1834

**6.** Suppose that

R0 contains 00088804
R1 contains FFFFFF00
R8 contains 00001874

Then show the contents of all three registers after each of the following instructions.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **a.** | LR | 0,8 | **c.** | AR | 8,1 | **e.** | SR | 0,0 |
| **b.** | SR | 0,1 | **d.** | SR | 1,0 | **f.** | LR | 8,8 |

## 2.3 RX INSTRUCTIONS

RX instructions usually cause an operation that involves a register and main storage to be performed. For example, consider the Load instruction:

L r,D(X,B) (*Load*)

Execution of this instruction causes the fullword in storage starting at the effective address derived from D(X,B) to be loaded into r. The original contents of r are replaced, while the fullword in storage remains unaltered. Three errors might occur during the execution of a Load instruction:*

1. If the absolute address calculated from D(X,B) is not a multiple of 4 (not a fullword boundary), a *specification exception* occurs.
2. If D(X,B) is an address greater than any actual storage address, an *addressing exception* will occur. This exception can happen only if either the X or the B register contains an excessively large number.
3. If D(X,B) is the actual address of an area, but the address is not within the area of storage allocated to the program, a *protection error* will occur.

*The discussion of errors here, as elsewhere in this text, has been kept to a minimum to avoid detracting from the essentials. A more comprehensive summary of the errors and their causes is included in Appendix D.

The encoded form of an RX instruction occupies two halfwords and conforms to the following format:

$$h_0h_0h_rh_X \qquad h_Bh_Dh_Dh_D$$

| | | |
|---|---|---|
| where | $h_0h_0$ | is the op code indicating the particular instruction |
| | $h_r$ | is the number of the register used as the first operand |
| | $h_X$ | is the number of the index register (0 if omitted) |
| | $h_B$ | is the number of the base register (0 if omitted) |
| | $h_Dh_Dh_D$ | is the displacement |

Thus, since the op code of L is 58,

```
L        2,12(1,10)
```

is encoded as 5821 A00C. Note that the displacement used in a relative address must be in the range 0 to 4095 simply because $FFF_{16} = 4095_{10}$ is the largest three-digit hexadecimal number (and only three digits are provided in the encoded form of the instruction).

The ST instruction performs the inverse of the operation of the L instruction:

```
ST       r,D(X,B)                    (Store)
```

Execution of this instruction causes the contents of r to replace the fullword at the location determined by D(X,B); the condition of r remains unaltered. The absolute address corresponding to D(X,B) must, therefore, be on a fullword boundary. The same exceptions (errors) that can occur for an L instruction can also occur for an ST instruction.

## Exercises

**1.** Utilize the table of op codes in Appendix C to encode the following RX instructions.

| | | |
|---|---|---|
| **a.** L 15,0(3,2) | **c.** L 15,0(2) | **e.** L 15,24 |
| **b.** L 15,0(,2) | **d.** ST 2,20(14,13) | **f.** ST 6,4(8) |

**2.** Decode the following RX instructions.

| | | |
|---|---|---|
| **a.** 5801 500C | **c.** 5811 801C | **e.** 5023 D00C |
| **b.** 5010 0004 | **d.** 5845 E004 | |

**3.** Suppose that

R2 contains 000ABC10
R3 contains 0000000B
R4 contains 000C1F11

Calculate the absolute address of areas in storage that would be referenced by the execution of each of the following instructions and determine whether a specification error would result.

**a.** L 0,16(2)
**b.** ST 1,16(4)
**c.** ST 15,20(3,4)
**d.** L 8,0(2,4)

**4.** Utilize the table of op codes in Appendix C to encode the following RX instructions.

**a.** L 14,12(1,3)
**b.** ST 1,12(11,12)
**c.** L 13,0(15)
**d.** ST 12,12(13)
**e.** L 1,14(,2)
**f.** ST 0,128

**5.** Decode the following RX instructions.

**a.** 5811 C008
**b.** 5020 2020
**c.** 5000 D00C
**d.** 5823 E028
**e.** 58FF 1000
**f.** 50E1 7008

**6.** Suppose that

R0 contains 0000FF0C
R1 contains 0000000D
R2 contains 000CCC08

Calculate the absolute address of areas in storage that would be referenced by the following instructions and determine whether a specification error would result.

**a.** L 1,4(2)
**b.** ST 12,12(0)
**c.** ST 13,16(1,2)
**d.** L 10,3(1,2)

---

## 2.4 A COMPLETE PROGRAM

In previous sections, the distinction between the symbolic and encoded (or machine) forms of instructions was presented. For example, 1A32 is the encoded form of the symbolic instruction

AR 3,2

Given a choice, a programmer would naturally choose to write programs using the symbolic instructions. The role of an *assembler program* is to accept as input a source program written using symbolic notations and to encode the instructions into *executable format*. The precise format used to represent a symbolic instruction that can be submitted to the assembler is as follows:

1. A label may start in column 1. A label is a string of from one to eight characters such that:
   a. The first character is either a letter from A to Z, a $, a #, or an @.
   b. Each of the characters following may be any of the above or any one of the decimal digits (0, 1, 2, . . . , 9).

   Thus,

   ```
   WORD1
   LOOP
   MYROUTNE
   BRANCH01
   ```

   are valid labels. (The uses of labels will be introduced in Section 2.5.)
2. A mnemonic for the operation code, such as AR for Add Register, starts in column 10. (Appendix C contains a list of valid op codes and the corresponding mnemonics.)
3. The operands start in column 16.
4. Any comment that the user wishes to append to the instruction can occur after allowing at least one blank following the last character of the operands. The only restriction on the comment is that it cannot extend past column 71 of the input record.

The following example of a symbolic instruction, with indications of where the fields would appear, illustrates the above points:

```
1         10      16
LOADUP    L       1,0(2,3)    LOAD THE WORD INTO R1
```

Up to this point, the only symbolic instructions that have been discussed are those that are to be encoded into executable instructions. There are, however, several instructions, called *assembler instructions*, that are not used to generate machine instructions. Rather, these instructions are used to communicate to the assembler information about how the user's program is to be processed and to direct the generation of constants and storage areas. The following assembler instructions are of particular importance:

1. The CSECT instruction is used to begin a program and must appear before any executable instructions in the program. The format of the CSECT instruction is

   ```
   label        CSECT
   ```

2. The end of a program is signified by an END statement. The END statement has as an operand the label of the place in the program where execution of the program should begin. Normally this label is the label of the CSECT statement. For example, the CSECT and END statements would typically occur as

```
MYPROG   CSECT
         .
         .
         .
         END  MYPROG
```

3. A DC statement is used to define constants. The only form of a DC statement that is needed at this point is

   ```
   label      DC      mF'n'
   ```

   where m is a nonnegative decimal integer (duplication factor)
   n is a decimal integer

   If m is omitted, it is assumed to be 1. The effect of this DC statement is to cause m consecutive fullwords, each containing the number n, to be generated. Thus,

   ```
   TWO        DC      F'2'
   ```

   causes one fullword containing 00000002 to be generated and makes it accessible to the program by its symbolic name TWO. DC statements can appear anywhere between the CSECT and END statements in the program. The fullwords that are generated as the result of such DC statements will always begin on fullword boundaries.

4. A DS statement is used to set aside areas of storage for fullwords that require no initial values. The format of the DS statement is

   ```
   label      DS      mF
   ```

   The above statement causes the assembler to set aside the next m fullwords as a storage area. An area of n bytes, which may or may not begin on a fullword boundary, can be set aside by use of a DS statement in the following format:

   ```
   label      DS      CLn
   ```

   Here, CLn stands for Character, Length n. Again, if more than one such area is required, a duplication factor can be used. For example, the statement

   ```
   label      DS      mCLn
   ```

   causes m fields, each of which has a length of n bytes, to be set aside.

Before looking at a sample program, two additional details should be mentioned:

- When execution of a program begins, R15 will always contain the absolute address of the beginning of the program. For now, this can be assumed to mean that R15 contains the address of the first generated instruction in

the program. This fact is significant since it allows all relative addresses to be created using R15 as a base register.

- When execution of a program begins, R14 contains the absolute address of the routine that should be branched to when execution of the program has been completed. That is, when execution of a program terminates, a branch to the address in R14 should be effected. This is referred to as *exiting* from the program. Although branching instructions are not covered until later in this text, the format of the branch instruction that causes the exit is

```
label        BCR      B'1111',14
```

The reader should now be capable of understanding Program 2-1. Since input and output of data and branching have not yet been discussed, this program necessarily performs an extremely simple task. It does, however, illustrate many of the points we have covered and deserves careful consideration.

**Program 2-1**

```
ADD2     CSECT
* THIS PROGRAM ADDS TWO NUMBERS TOGETHER THAT ARE TAKEN
* FROM THE 5TH AND 6TH WORDS OF THE PROGRAM.  THE SUM
* IS STORED IN THE 7TH WORD OF THE PROGRAM.
         L      1,16(,15)      LOAD 1ST NUMBER INTO R1
         L      2,20(15)       LOAD 2ND NUMBER INTO R2
         AR     1,2            ADD R2 TO R1
         ST     1,24(15)       STORE RESULT FROM R1 INTO
*                                 7TH WORD IN PROGRAM
         BCR    B'1111',14     EXIT FROM PROGRAM
         DC     F'4'
         DC     F'6'
         DS     F
         END    ADD2
```

Since this is the first program presented in this text, it seems appropriate to cover aspects of it in detail.

- The statement ADD2 CSECT is an example of how a program should begin. The name ADD2 is arbitrary; however, it is a good idea to choose a name related to the purpose of the program.
- The next three statements are comments. Any input record with an asterisk in column 1 is a comment and does not generate any code. The comment itself can be anywhere from column 2 through column 71. A paragraph giving the purpose of the program and any general information that a reviewing programmer might find helpful should always preface a program.

- The actual instructions in this program that will be translated into executable code are

```
L       1,16(,15)
L       2,20(15)
AR      1,2
ST      1,24(15)
BCR     B'1111',14
```

The assembler will convert these into machine code and produce a listing of the following form:

| LOC | OBJ CODE | SOURCE | STATEMENT |
|---|---|---|---|
| 000000 | 5810 F010 | L | 1,16(,15) |
| 000004 | 582F 0014 | L | 2,20(15) |
| 000008 | 1A12 | AR | 1,2 |
| 00000A | 501F 0018 | ST | 1,24(15) |
| 00000E | 07FE | BCR | B'1111',14 |

In the first instruction, R15 is used as a base register. In the other RX instructions no base register is used, and R15 is used as an index register. When only one of the two registers is specified in a D(X,B) address, it makes no operational difference in the execution of the program whether it is used as the X or the B register.

- The constants are generated starting at location 000010 and the listing produced from the DC and DS statements is

```
000010    00000004    DC  F'4'
000014    00000006    DC  F'6'
000018                DS  F
```

Note that the DS statement generates no object code.

- The END statement marks the end of the program and contains the label of the starting point as the operand. Normally, this is the label that is used in the CSECT statement.

## 2.5 XDUMP AND IMPLICIT ADDRESSES

Several improvements could be made in the program presented in Section 2.4 (Program 2-1). The most obvious one is that the result of the addition should be displayed. The techniques for handling input/output (I/O) will, for the most part, be deferred to later sections of this chapter. Until that material is covered, the XDUMP instruction will be used to display answers.

The XDUMP statement is a *pseudo-instruction* that may be utilized when the ASSIST assembler is used to perform the encoding of symbolic instructions. The format of the XDUMP instruction is

```
label        XDUMP  area,length
```

The first operand must be the D(X,B) address of an area to be displayed on the printed output. The second operand indicates the number of bytes of storage to be displayed. The execution of an XDUMP instruction will normally cause the contents of the indicated area, along with some explanatory information, to be displayed in the printed output.* If the two operands are omitted, however, the contents of the 16 registers will be displayed rather than the contents of an area in storage. Thus, the instruction

```
XDUMP  12(15),4
```

will cause a four-byte area in storage, starting at the address given by 12(15), to be displayed in the printed output. On the other hand, the instruction

```
XDUMP
```

causes the contents of the registers to be printed out.

The main use of the XDUMP instruction is as a debugging tool, to locate errors in a program. The reader will quickly learn the utility of this tool as a mechanism for tracing the progress of execution through a program and for verifying the results produced by sections of a program. For now it may also be used to display the final output of programs.

In Program 2-1, it was necessary that the programmer calculate all of the relative addresses used in the program. In a large program, it would be extremely tedious to perform these calculations. This motivates the use of a different form of relative addressing, called implicit addressing. An *implicit address* is an address that the assembler will be required to convert to an explicit address.

The two most common forms of implicit addresses used with RX instructions are

```
label
```

and

```
label(r)
```

where label is the label of a field in the program
r is a register number

*Actually, an XDUMP instruction with an operand will cause a number of 32-byte lines of storage to be printed. Each of these lines will begin with an address that is a multiple of 32 ($20_{16}$). The number of lines printed will be the least number that contains all of the bytes specified by the operand.

When only a label is used, the implicit address refers to the field with the given label. Thus, the code

```
        L       1,WORD
        .
        .
        .
WORD    DS      F
```

illustrates the use of the first form of an implicit address. If a register is used in an implicit address, the effective address is the address calculated by adding the contents of the register to the address of the indicated field. Hence, assuming that R10 contains one of the eight values 0, 4, 8, . . . , 28, the code

```
        L       1,WORDS(10)
        .
        .
        .
WORDS   DS      8F
```

causes one of the eight words generated by the instruction

```
WORDS   DS      8F
```

to be loaded into R1; which word is determined by the contents of R10. In this case, R10 plays the role of an index register (i.e., it is used as an index into a sequence of fields).

Implicit addresses of the following forms may also be used:

label ± n
label ± n(r)

where n is a decimal integer
r is the number of a register

For example,

AREA + 10(2)

represents the address found by adding the contents of R2 to the address of the tenth byte past AREA.

As previously mentioned, when an implicit address is used, the assembler must convert it to the corresponding explicit address. Thus, the following information must be available to the assembler:

1. which register should be used as a base register
2. what absolute address will be in the base register

For example, in Program 2-1 the fact that R15 contains the absolute address of ADD2 when program execution begins must be available to the assembler. This information can be conveyed to the assembler by the USING statement, which is of the form

USING label,reg

where label is the label of a field
reg is the number of a register which may be assumed to contain the absolute address of that field during the execution of the program

These concepts are far from trivial. The reader is urged to consider Program 2-2 carefully. This rewritten version of ADD2 utilizes both XDUMP and implicit addressing and presents a significant enhancement of the version given in Program 2-1.

**Program 2-2**

```
ADD2     CSECT
         USING ADD2,15
         L     1,WORD1        LOAD THE CONTENTS OF WORD1 INTO R1
         L     2,WORD2        LOAD THE CONTENTS OF WORD2 INTO R2
         AR    1,2            GET THE SUM OF THE TWO WORDS; AND
         ST    1,WORD3        STORE THE SUM INTO WORD3
         XDUMP WORD3,4        DUMP OUT THE ANSWER
         BCR   B'1111',14     EXIT FROM THE PROGRAM
WORD1    DC    F'4'
WORD2    DC    F'6'
WORD3    OS    F
         END   ADD2
```

Note the following two improvements:

- The USING statement tells the assembler that, when it converts implicit addresses (labels) to explicit base-displacement form, it may use R15 as the base register and it may assume that, when the program is executed, R15 will contain the absolute address of ADD2.
- XDUMP causes the sum stored in WORD3 to be displayed in the printed output.

## Exercises

**1.** Type in the latest version of ADD2 and run it. Carefully examine the output (both the assembler listing and the printing caused by the XDUMP).

Remove the BCR instruction, which caused the exit from the program. Rerun the program and note the following: After executing XDUMP, an attempt was made to execute the instruction represented by WORD1. Since

the first byte of WORD1 is 00, an error occurred (00 is not a valid op code). This caused a "dump." A dump gives a portrayal of storage as it was when the error occurred. You should become familiar with the contents of a dump, since dumps will recur throughout your experience as a programmer.

**2.** Write a program containing two constants, one equal to 10 and one equal to 20. The program should calculate 10 minus 20 and XDUMP the answer. Run the program and verify the results.

---

## 2.6 THE CONDITION CODE AND BRANCHING

Of the executable instructions covered so far (ST, L, AR, SR, LR, XDUMP), AR and SR are unique in that they alter the setting of the condition code (CC). The condition code is a two-bit number. Certain instructions set the value of the CC to particular values, reflecting the outcome of the instructions. For example, the execution of an AR or SR instruction will set the CC as depicted in the following table:

| *CC* | *Meaning* |
|---|---|
| 0 | The result of the operation was 0. |
| 1 | The result was < 0. |
| 2 | The result was > 0. |
| 3 | Overflow occurred. |

Thus, if R1 contained 00001AFC and R2 contained 001247AE, execution of the instruction

```
AR      1,2
```

would cause the CC to be set to 2, indicating a positive result in R1.

The CC is actually part of a 64-bit unit called the Program Status Word (PSW). In Section 2.1, we pointed out that the PSW always contains the address of the next instruction to be executed. An examination of the format of the PSW (see Appendix C) will reveal that the CC occupies bits 34 and 35 (counting from the left, starting with 0) and that the address of the next instruction is kept in bits 40–63.

A programmer may take advantage of the CC by using it to determine the flow of execution through the program. This facility is brought about through the use of the Branch on Condition (BC) instruction, which causes a branch to be taken or not taken depending on the value of the CC. If the branch is taken, the next instruction executed will be at the address to be

branched to, *not* the instruction immediately following the BC instruction. Otherwise, the BC instruction has no effect, and the instruction immediately following it will be the next instruction executed. The format of the BC instruction is

```
label        BC        B'mask',addr
```

The second operand gives the address, in D(X,B)* form, where execution is continued if the branch is taken. The first operand is used to designate the settings of the CC that will cause the branch to occur. There are four possible settings of the CC—0,1,2, and 3. The mask is a four-bit binary number; each bit starting from the left corresponds to one of the possible values of the CC. When a BC instruction is executed, the branch will be taken only if a 1-bit number in the mask corresponds to the current setting of the CC. Thus, execution of the instruction

```
BC        B'1011',LOOP
```

will cause a branch to LOOP, if the setting of the CC is 0, 2, or 3. Note that a mask of 1111 will cause the branch to occur under all conditions. For example, execution of the instruction

```
BC        B'1111',READ
```

would cause an unconditional branch to the instruction with the label READ.

The encoded format of the BC instruction is

$$h_0h_0h_mh_X \quad h_Bh_Dh_Dh_D$$

| | | |
|---|---|---|
| where | $h_0h_0$ | is the op code 47 |
| | $h_m$ | is the mask |
| | $h_Xh_Bh_Dh_Dh_D$ | is the normal encoding of a D(X,B) address for an RX instruction |

Thus, the instruction

```
BC        B'0001',12(3,4)
```

would be encoded as 4713 400C by the assembler. Program 2-3 illustrates the use of the BC instruction. It is assumed that the programmer will fill in his own values for W1 and W2 if he should choose to type in and run this program.

*Whenever a D(X,B) or D(B) address is specified as an operand, an implicit address may be used instead of the explicit form.

**Program 2-3**

```
* THIS PROGRAM PRINTS THE LARGER OF TWO NUMBERS.
* THE NUMBERS ARE IN W1 and W2.
MAX      CSECT
         USING MAX,15       R15 POINTS TO HEAD OF PROG
         L     1,W1         LOAD THE FIRST WORD
         L     2,W2         GET THE SECOND WORD INTO R2
         SR    1,2          R1 WILL NOW BE POS IF W1 IS HIGH
         BC    B'0010',ONE  BRANCH IF W1 IS HIGH
         XDUMP W2,4         PRINT OUT W2
         BC    B'1111',GO   BRANCH TO EXIT
ONE      XDUMP W1,4         PRINT OUT W1
GO       BCR   B'1111',14   EXIT
W1       DC    F'any value'
W2       DC    F'any value'
         END   MAX
```

In Program 2-3, a branch to ONE will be taken if the CC is 2 after the execution of the SR instruction. Hence, the branch to ONE will occur only if the result of the subtraction is positive, which corresponds to the case in which the word W1 contains a number greater than the number stored in W2.

Like many RX instructions, the BC instruction has an RR counterpart. The BCR (Branch on Condition Register) is coded as follows:

BCR B'mask',r

where mask is the same as in the BC instruction
r is the number of the register that contains the address to be branched to

Thus,

BCR B'1111',14

is an unconditional branch to the address in R14. Since R14 always contains the exit address when a program begins execution, the

BCR B'1111',14

instruction is used to cause the normal termination of a program.

## Exercise

Write a program similar to Program 2-3 in which the user puts any desired value into the three words W1, W2, and W3; the program finds the smallest of the three words and utilizes an XDUMP instruction to display the result.

## 2.7 THE XREAD AND XDECI INSTRUCTIONS

In the following discussion, we assume that the maximum length of an input record to be entered by the XREAD is 80 characters. This is due to the historical fact that, during the period in which IBM assembler became widely used, punched cards were the medium in which programs were encoded. Indeed, a majority of the example programs discussed in this book were first tested using versions of the programs punched into 80-column cards. The practice of using punched cards made terms like "source deck" (to refer to the cards that contained the symbolic version of a program) both natural and common. Therefore, you will find occasional references to punched cards throughout this book, and we trust it will be obvious that, in todays context, each of these references is to "an 80-character input record."

Input records are normally of some fixed size. In this book, most input records contain up to 80 characters of data. When these characters are read into storage, each will occupy one byte. There are 256 legitimate values that can be stored in one character of an input record. Each of these possible values is converted into a unique image, when the record is read into storage. When punched cards were used as input, there were 256 unique patterns of punches for each column, each of which corresponded to hexadecimal values from 00 through FF. Most input records contain only "readable characters," which translate into a subset of the possible 256 values. The correspondence between "readable characters," hexadecimal values that are produced in storage, and how these were encoded in punched cards is given in Appendix C. A small part of Appendix C is given in Table 2-1.

**Table 2-1**

| *Punches* | *Representing* | *Image in Storage* |
|---|---|---|
| none | blank | 40 |
| 11-4 | * | 5C |
| 12-1 | A | C1 |
| 12-2 | B | C2 |
| 0 | 0 | F0 |
| 1 | 1 | F1 |
| 2 | 2 | F2 |
| 3 | 3 | F3 |
| 4 | 4 | F4 |
| 5 | 5 | F5 |
| 6 | 6 | F6 |
| 7 | 7 | F7 |
| 8 | 8 | F8 |
| 9 | 9 | F9 |

- *Example.* If an input record containing 1234 in the first four characters is read into an area called CARD, what would be in the first four bytes of CARD?

The first byte of CARD will contain the value that corresponds to a 1. Since that is F1, the first byte of CARD is F1. The second will be F2; the third, F3; and the fourth, F4. Thus, the first four bytes of CARD would contain F1F2F3F4.

## Exercises

**1.** If a record containing **122A3 in the first seven characters is read into an area called INPUT, what will the first seven bytes of INPUT look like after the card is read in?

**2.** Using Appendix C, determine what the following characters would look like in storage:

$ @ # X and Z

---

The XREAD instruction is a pseudo-instruction that can be used to read an input record into an area of storage. The format of the XREAD instruction is

```
label      XREAD  area,length
```

where area is the address, in D(X,B) form, of the area into which the input should be read

length is the number of characters to be read. The length should be 80 or less. If it is less than 80, the remaining characters of the input record will be ignored.

The settings of the CC after the execution of an XREAD instruction convey the following information:

| CC | Meaning |
|---|---|
| 0 | The record was read successfully. |
| 1 | No record could be read. This is called an end-of-file or EOF condition. |
| 2 | — (The CC is never set to this value.)* |
| 3 | — |

*A dash is used consistently throughout this text to indicate condition code settings that cannot occur.

## Exercise

The following program reads in a set of records. After each record is read, the area containing the image of the record is XDUMPed. When EOF occurs, an exit is taken. Comment, type in, and run the program. Use two or more records as input, and enter a variety of characters into each record. Carefully study the XDUMPs to verify that the images are what you would expect.

```
READ    CSECT
        USING   READ,15
LOOP    XREAD   IN,80
        BCR     B'0100',14
        XDUMP   IN,80
        BC      B'1111',LOOP
IN      DS      CL80
        END     READ
```

The data that is typed into an input record and read into storage appears in what is called *character format*. In particular, the character representations of the decimal digits are F0, F1, F2, . . . , F9. Suppose that a record containing 4 in column 1, 3 in column 3, and blanks elsewhere has been read into storage. In storage the image of the record would be

F440F3404040 . . .

Suppose further that it is required to add the numbers represented by the first and third bytes. There are two immediate problems:

- F4 and F3 cannot be added together in their character representations. They must first be converted to the corresponding binary numbers.
- The binary numbers must be inserted into registers, since the addition is to be done with an AR instruction.

The XDECI is a pseudo-instruction provided for converting numbers in their character representation in storage to their corresponding binary representation in a register. The format for the XDECI instruction is

```
label    XDECI   r,addr
```

where r — is the number of the register into which the binary form of the number will be inserted

addr — is the D(X,B) address of the number in its character format

Execution of an XDECI instruction has the following effects:

1. Beginning at the location given by addr, memory is scanned for the first character that is not a blank.

2. If the first character found is anything other than a decimal digit or a plus or minus sign, R1 is set to the address of that character and the condition code is set to 3 (overflow) to show that no decimal number could be converted. The contents of r are not changed, and nothing more is done.

3. If the first character is a plus or minus sign or a decimal digit, from one to nine decimal digits are scanned, and the number is converted to binary and placed in r.

4. R1 is set to the address of the first nondigit after the string of decimal digits. Thus, r should not usually be 1. This permits the user to scan for any number of decimal values. The values should be separated by blanks.

5. If ten or more decimal digits are found before a blank separator, R1 is set to the address of the first character that is not a decimal digit, the CC is set to 3, and r is left unchanged. A plus or minus sign alone causes a similar action, with R1 set to the address of the character following the sign character.

Note that execution of the XDECI alters R1. Therefore, a programmer cannot expect to save a value in R1 if he issues an XDECI.

The CC is set by XDECI as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The number converted was 0. |
| 1 | The number converted was < 0. |
| 2 | The number converted was > 0. |
| 3 | An attempt was made to convert an invalid number. |

It should be pointed out that the scan performed by the execution of an XDECI instruction will continue, perhaps beyond the field to be scanned, until a nonblank character is encountered. Thus, if the image of an input record is to be scanned, it is advisable to mark the end of the image with a nonblank character other than a decimal digit, so that the condition code may be checked to determine when the end of the image has been reached. For example, this could be done as follows:

```
CARD     DS     CL80
         DC     C'*'
```

Program 2-4 reads in input records with two numbers on each record. The difference between the numbers is calculated and XDUMPed.

**Exercise**

Write a program to sum a set of numbers. The program is to read input records and take one number from each record. When end-of-file occurs, the program should XDUMP the answer and then terminate.

## 2.8 THE XPRNT AND XDECO INSTRUCTIONS

In Section 2.7, the character format of data was introduced. The DC statement, which has been used previously to generate fullword binary constants, can also be used to generate character constants. The format of the appropriate DC statement is

```
label      DC      mCLn'character string'
```

| | | |
|---|---|---|
| where | m | is a duplication factor (a nonnegative integer) |
| | Ln | gives the length of the constant to be generated |
| | character string | is a string of characters |

**Program 2-4**

```
*****************************************************************
*
* THIS PROGRAM READS NUMBERS (TWO PER CARD) AND XDUMPS OUT THE
* DIFFERENCE OF THE TWO NUMBERS.
*
*****************************************************************
*
DIFF     CSECT
         USING DIFF,15
*
         XREAD CARD,80            READ THE FIRST CARD
*
LOOP     BC    B'0100',EXIT       BRANCH IF EOF HAS OCCURRED
*
         XDECI 2,CARD             GET THE FIRST NUMBER ON THE CARD
         BC    B'0001',GETNXT     SKIP THIS CARD ON A BAD VALUE
         XDECI 3,0(1)             NOW GET THE SECOND NUMBER
         BC    B'0001',GETNXT     SKIP THIS CARD ON A BAD VALUE
*
         SR    2,3                GET THE DIFFERENCE
*
         ST    2,WORD             SAVE AND XDUMP THE DIFFERENCE
         XDUMP WORD,4
*
GETNXT   XREAD CARD,80            TRY TO READ THE NEXT CARD
         BC    B'1111',LOOP       GO BACK UP TO TEST FOR EOF
*
EXIT     BCR   B'1111',14         EXIT FROM THE PROGRAM
*
CARD     DS    CL80               CARD INPUT AREA
WORD     DS    F                  PUT THE DIFFERENCE HERE
         END   DIFF
```

For example, the instruction

```
F1        DC        2CL3'A  B'
```

causes two consecutive three-byte fields to be generated, each containing C140C2 (the hexadecimal representation). The following additional rules apply to this use of the DC statement:

1. If the duplication factor is omitted, it is assumed to be 1. Hence,

   ```
   DC        1CL3'*A*'
   ```

   and

   ```
   DC        CL3'*A*'
   ```

   generate the same thing.

2. If the length that is specified is greater than that required to hold the character string, blanks will be padded on the right. Thus,

   ```
   DC        CL6'*A*'
   ```

   would generate 5CC15C404040. If the specified length does not allow enough bytes to represent all of the characters in the character string, the rightmost characters will be truncated. For example,

   ```
   DC        CL2'*A*'
   ```

   would generate the two-byte field 5CC1. If the length is unspecified, a field just large enough to represent the character string will be generated. Therefore,

   ```
   DC        2C'ABC'
   ```

   and

   ```
   DC        2CL3'ABC'
   ```

   each generate two three-byte fields.

3. There are two special characters, ' and &, that are unique in the following respect: To generate a string containing either an ' or an &, two adjacent occurrences of the character must occur in the character string, rather than a single occurrence. Thus,

   ```
   DC        C' A' 'B'
   ```

   generates the three-byte field C17DC2, and

```
        DC      C'&&'
```

generates just one byte containing 50.

The following examples should help to clarify the above comments:

| | *Coded* | *Generated* |
|---|---|---|
| DC | CL1'0' | F0 |
| DC | CL2'0' | F040 |
| DC | 2CL2'89' | F8F9F8F9 |
| DC | C'WORD' | E6D6D9C4 |
| DC | C'&&AB"C' | 50C1C27DC3 |
| DC | CL3'ABCD' | C1C2C3 |

## Exercises

Show what the following DC statements generate. (Use the hexadecimal representation of the contents of the generated fields.)

```
1.      F1      DC      CL5'A'
                DC      2C'A'
                DC      3CL2'B'
                DC      C'1'''
        F49     DC      C'&&0'
                DC      CL4'$$WORD'

2.      FIRST   DC      CL4'ABC'
                DC      2C'1A'
                DC      3CL5'&&$$'
        LAST    DC      CL3'HELLO, WORLD'
```

Just as data that is read in from a record is stored in character format, so too is data that is to be printed. There are two steps involved in printing a line:

1. The line to be printed must be constructed in an area of storage. The actual characters that will appear in the printed line begin in the second byte of the area. The initial byte is reserved for a carriage control character, a byte that controls the positioning of the printed line on a page. The codes that can be used in the first byte and their meanings are

| | |
|---|---|
| blank | Single-space before printing. |
| 0 | Double-space before printing. |
| 1 | Skip to the head of the next page before printing. |

The entire print line (including the carriage control byte) must contain 133 characters or less, because there are only 132 print positions on most printers.

2. After the print line has been constructed, an XPRNT instruction can be used to print the line. The format of the XPRNT instruction is

```
label     XPRNT addr,length
```

where addr is the D(X,B) address of the print line in storage
length is the number of bytes to be taken from storage in constructing the record to be sent to the printer

Program 2-5 illustrates the use of the XPRNT instruction. The program reads any number of records, printing one line per record. The first line will be printed at the top of a page, and all successive lines will be double-spaced.

**Program 2-5**

```
*****************************************************************
*
* THIS PROGRAM SIMPLY READS AND PRINTS CARDS UNTIL EOF OCCURS.
*
*****************************************************************
*
PRINT    CSECT
         USING PRINT,15
*
         XREAD CARD1,80          READ THE FIRST CARD
*
         BC    B'0100',EXIT      EXIT ON EMPTY FILE
*
         XPRNT CC1,81            PRINT THE FIRST CARD
*
         XREAD CARD2,80          NOW READ THE SECOND CARD
*
LOOP     BC    B'0100',EXIT      BRANCH ON EOF
*
         XPRNT CC2,81            PRINT THE CARD
*
         XREAD CARD2,80          TRY TO READ THE NEXT CARD
         BC    B'1111',LOOP      GO BACK TO TEST FOR EOF
*
EXIT     BCR   B'1111',14        LEAVE THE PROGRAM
*
* IT'S A GOOD PRACTICE TO HAVE JUST 1 EXIT POINT FROM A PROGRAM.
* THAT'S WHY WE ALWAYS BRANCH TO EXIT.
*
CC1      DC    C'1'              CAUSE SKIP TO TOP OF PAGE
CARD1    DS    CL80              INPUT AREA FOR FIRST CARD
*
CC2      DC    C'0'              DOUBLE SPACE THE REST
CARD2    DS    CL80              ALL BUT FIRST CARD GET READ HERE
*
         END   PRINT
```

Simply knowing how to print strings of characters is not enough to permit the results of computations to be displayed. Previously, the problem of converting numbers from character to binary format was solved by the introduction of the XDECI instruction. The inverse problem must now be addressed.

Suppose that a result has been developed in a register and one wishes to display this result on a printer. This involves taking the number from the register, converting it from its binary representation to its character representation, and placing the result into the storage area of the print line. All of this can be done quite simply by use of the XDECO instruction

```
label        XDECO  reg,addr
```

Execution of this pseudo-instruction causes the number in the register given as the first operand to be converted to a 12-byte character representation and stored at the D(X,B) address given by the second operand. The contents of the register are unaltered. For example, execution of the instruction

```
XDECO  10,ANSWER
```

causes the binary number in R10 to be converted to its character format and the result to be stored in 12 bytes of storage, starting at ANSWER. The contents of R10 are unaltered.

The number will be right-justified in the 12-byte field, with leading blanks. A minus sign will be printed to the left of the first significant digit if the number is negative. Program 2-6 illustrates the use of XDECO. It reads two numbers from each card and prints the sum of those two numbers.

**Program 2-6**

```
*****************************************************************
*
* THIS PROGRAM READS DATA CARDS, EACH OF WHICH CONTAINS TWO
* NUMBERS.  THE SUM OF THE TWO NUMBERS IS PRINTED.
*
*****************************************************************
*
SUMUP    CSECT
         USING SUMUP,15
*
         XPRNT HEADING,28          PRINT A PAGE HEADING
*
         XREAD CARD,80             READ THE FIRST CARD
*
CHECKEOF BC    B'0100',EXIT        BRANCH ON EOF
*
         XDECI 2,CARD              WE ASSUME THAT BOTH NUMBERS
         XDECI 3,0(1)              ARE VALID
*
         AR    2,3                 CALCULATE THE SUM
*
         XDECO 2,OUTPUT            PUT PRINTABLE FORM INTO PRINT LINE
```

**Program 2-6 (continued)**

```
*
         XPRNT CRG,13              PRINT THE SUM (SINGLE SPACED)
*
         XREAD CARD,80             TRY TO READ THE NEXT CARD
         BC    B'1111',CHECKEOF    GO CHECK FOR EOF
*
EXIT     BCR   B'1111',14          LEAVE THE PROGRAM
*
CARD     DS    CL80                CARD INPUT AREA
*
CRG      DC    C' '                SINGLE SPACE CARRIAGE CONTROL
OUTPUT   DS    CL12                OUTPUT THE SUM HERE
*
HEADING  DC    C'1THIS IS THE OUTPUT OF SUMUP'
         END   SUMUP
```

## Exercises

**1.** Write a program to read in a set of numbers (one number per record) and print the sum of the numbers. A header should be printed at the top of the page, each number should be printed (one per line), and the result should be printed on the last line.

**2.** Write a program similar to the one described in the previous exercise. The only difference should be that the first input record contains the number of records that follow it. For example, if

$$\begin{array}{r} 4 \\ \left.\begin{array}{r} 2 \\ -4 \\ 8 \\ 1 \end{array}\right\} \end{array} \begin{array}{l} \text{Number of input records} \\ \text{Data records} \end{array}$$

were the input, the answer would be 7.

**3.** Write a program to compute the alternating sum/difference of an arbitrary number of values, where termination of data is indicated by an input value less than 0. Do not include the value of this trailer in your computation. For example, if the input data were

$$\begin{array}{r} \left.\begin{array}{r} 26 \\ 43 \\ 71 \\ 122 \end{array}\right\} \\ -6 \end{array} \begin{array}{l} \text{Data records} \\ \text{Sentinel (trailer) card} \end{array}$$

the answer would be $26 - 43 + 71 - 122 = -68$.

4. Write a program to find the total gross weight of a set of trucks. The program should read any number of records, each of which contains the gross weight of one truck. The records should be echo checked (XPRNTed) as they are read. The total gross weight should be printed with an appropriate label.

---

## 2.9 MORE INSTRUCTIONS AND EXAMPLES

Many RR instructions have RX counterparts that execute equivalent operations except that they require a word in main storage as the second operand. For example, the LR and L instructions perform similar tasks: The LR causes the second operand to be taken from a register, while the L accesses a fullword from storage.

The RX counterpart of AR is

```
A        r,D(X,B)        (Add)
```

Execution of this instruction causes the fullword starting at the address given by D(X,B) to be added to the contents of the register given by r. The contents of the fullword in storage are unaltered, and the result replaces the contents of r. For example, execution of the instruction

```
A        2,WORD
```

causes the contents of WORD to be added to the contents of R2. If D(X,B) resolves to other than a multiple of 4 (i.e., a fullword boundary), a specification error may result. If D(X,B) indicates a word outside the boundaries of the program, either a protection or addressing error may occur. If the result of the addition is too large or small to fit into r, a fixed-point overflow occurs.

The S instruction

```
S        r,D(X,B)        (Subtract)
```

corresponds to the SR instruction, just as the A instruction corresponds to the AR instruction. The description of the S is the same as for the A except that the second operand is subtracted from the contents of r.

The next two instructions to be discussed, the CR and C instructions, can be used to compare two numbers. The effect of either of these instructions is limited to the setting of the condition code.

```
CR       r1,r2           (Compare Register)
```

As a consequence of the execution of this instruction, the condition code is set according to the following rules:

| *CC* | *Meaning* |
|---|---|
| 0 | The contents of r1 and r2 are equal. |
| 1 | The number in r1 < the number in r2. |
| 2 | The number in r1 > the number in r2. |
| 3 | — |

No errors can occur.

C r,D(X,B) (*Compare*)

This RX instruction has the same function as the CR instruction except that the fullword starting at D(X,B) is used for the second operand. Protection, addressing, or specification errors can occur, as in the other RX instructions.

Program 2-7 illustrates the use of the A and CR instructions. The program reads a set of numbers and prints the following:

- the number of numbers read
- the smallest number read
- the largest number read

**Program 2-7**

```
*****************************************************************
*
* THIS PROGRAM READS AN INPUT STREAM OF CARDS, EACH OF WHICH
* CONTAINS A SINGLE NUMBER.  THE PROGRAM PRINTS THE SMALLEST VALUE,
* THE LARGEST VALUE, AND THE NUMBER OF VALUES IN THE STREAM.  IF
* THERE ARE NO INPUT CARDS, OR IF THE FIRST CARD DOESN'T HAVE A
* VALID NUMBER ON IT, AN ERROR MESSAGE IS PRINTED AND THE PROGRAM
* EXITS.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  TRY TO READ THE FIRST CARD.  IF SUCCESSFUL, GO TO STEP 3.
*
*   STEP 2.  PRINT AN "EMPTY INPUT" MESSAGE AND GO TO STEP 12
*            TO EXIT FROM THE PROGRAM.
*
*   STEP 3.  TRY TO GET THE NUMBER OFF THE CARD.  IF SUCCESSFUL,
*            GO TO STEP 5.
*
*   STEP 4.  PRINT "INVALID 1ST NUMBER" MESSAGE AND GO TO STEP 12
*            TO EXIT FROM THE PROGRAM.
*
*   STEP 5.  USE THE FIRST VALUE AS THE INITIAL "SMALLEST SO FAR"
*            AND THE INITIAL "LARGEST SO FAR" VALUES.  ALSO, SET
*            THE COUNT OF VALUES READ TO 1.
*
*   STEP 6.  READ THE SECOND CARD.
*
*   STEP 7.  TEST FOR EOF (END CONDITION FOR THE LOOP).  WHEN EOF
*            OCCURS, BRANCH TO STEP 11 TO PRINT THE RESULTS.
*
*   STEP 8.  TRY TO GET THE NUMBER FROM THE CARD.  IF YOU CAN,
*            COUNT IT, AND PROCEED TO STEP 9.  ELSE, GO TO
*            STEP 10 TO READ THE NEXT CARD.
```

**Program 2-7 (continued)**

```
*
*   STEP 9.  IF THE VALUE IS LOWER THAN THE "SMALLEST SO FAR",
*            USE IT AS THE NEW VALUE FOR "SMALLEST SO FAR".
*            SIMILARLY, IF IT'S LARGER THAN THE "LARGEST SO
*            FAR", IT IS USED AS THE NEW VALUE.
*
*   STEP 10. TRY TO READ THE NEXT CARD AND GO BACK TO THE
*            TOP OF THE LOOP (STEP 7).
*
*   STEP 11. PRINT THE 3 VALUES (COUNT, SMALLEST, AND LARGEST).
*
*   STEP 12. EXIT FROM THE PROGRAM.
*
*************************************************************************
*
MIN@MAX  CSECT
         USING MIN@MAX,15
*
***<STEP 1>    READ THE FIRST CARD
*
         XREAD CARD,80
         BC    B'1011',GOTCARD    BRANCH IF THERE WAS A CARD
*
***<STEP 2>    PRINT "EMPTY INPUT" MESSAGE
*
         XPRNT EMPTYMSG,16
         BC    B'1111',EXIT
*
***<STEP 3>    TRY TO GET THE NUMBER OFF THE FIRST CARD
*
GOTCARD  XDECI 2,CARD
         BC    B'1110',GOT1ST     BRANCH IF IT WAS VALID
*
***<STEP 4>    PRINT "INVALID 1ST NUMBER" MESSAGE
*
         XPRNT BAD1ST,23
         BC    B'1111',EXIT
*
***<STEP 5>    INITIALIZE MIN, MAX, AND COUNT
*
GOT1ST   LR    3,2                R3 WILL HOLD MAXIMUM VALUE SO FAR
         LR    4,2                R4 WILL HOLD MINIMUM VALUE SO FAR
         L     5,ONE              R5 COUNTS THE NUMBER VALID CARDS
*
***<STEP 6>    READ THE SECOND CARD
*
         XREAD CARD,80
*
***<STEP 7>    LOOP UNTIL EOF OCCURS
*
CHKEOF   BC    B'0100',EOF
*
***<STEP 8>    IF THE NUMBER IS INVALID, JUST SKIP IT; ELSE, COUNT IT
*
         XDECI 2,CARD
         BC    B'0001',READNXT
         A     5,ONE              COUNT IT (SINCE IT WAS VALID)
*
***<STEP 9>    SET NEW MAX OR MIN, IF NECESSARY
*
         CR    2,3                CHECK FOR NEW MAX
         BC    B'1100',CHKMIN     BRANCH IF <= OLD MAX
*
         LR    3,2                ELSE, SET NEW MAX
         BC    B'1111',READNXT    AND GO READ NEXT VALUE
*
CHKMIN   CR    2,4                CHECK FOR NEW MIN
         BC    B'1010',READNXT    BRANCH IF NOT < OLD MIN
*
         LR    4,2
```

**Program 2-7 (continued)**

```
*
***<STEP 10>   TRY TO READ THE NEXT CARD
*
READNXT  XREAD CARD,80
         BC    B'1111',CHKEOF      BRANCH BACK TO CHECK EOF
*
***<STEP 11>   PRINT THE RESULTS
*
EOF      XDECO 5,#READ             PUT # READ INTO PRINT LINE
         XPRNT LINE1,28            AND PRINT IT
*
         XDECO 3,SMALLEST          PUT MINIMUM INTO PRINT LINE
         XPRNT LINE2,29            AND PRINT IT
*
         XDECO 4,LARGEST           PUT MAXIMUM INTO PRINT LINE
         XPRNT LINE3,28            AND PRINT IT
*
***<STEP 12>   EXIT
*
EXIT     BCR   B'1111',14
*
*****************************************************************
*
CARD     DS    CL80                CARD INPUT AREA
*
EMPTYMSG DC    C'1*** EMPTY INPUT'
*
BAD1ST   DC    C'1*** INVALID 1ST NUMBER'
*
ONE      DC    F'1'
*
LINE1    DC    C'1# OF CARDS READ'
#READ    DS    CL12
*
LINE2    DC    C'OSMALLEST VALUE ='
SMALLEST DS    CL12
*
LINE3    DC    C'OLARGEST VALUE ='
LARGEST  DS    CL12
*
         END   MIN@MAX
```

The following instructions (LCR, LNR, LPR, and LTR) are similar to the LR instruction. Of these four instructions, the LTR will probably prove most useful.

Execution of the instruction

LCR r1,r2 (*Load Complement*)

causes the complement of r2 to be loaded into r1. If r2 contains the number $n$ before the instruction is executed, r2 will remain unchanged (unless r2 and r1 are the same register) and r1 will contain $-n$ after execution. The CC is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | r1 contains 0. |
| 1 | r1 contains a negative number. |
| 2 | r1 contains a positive number. |
| 3 | Overflow occurred. |

Execution of the RR instruction

LNR r1,r2 (*Load Negative*)

causes the negative of the absolute value of the contents of r2 to replace the contents of r1. The contents of r2 are unaltered (unless r1 is r2). The CC is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | r1 contains 0. |
| 1 | r1 contains a negative number. |
| 2 | — |
| 3 | — |

Execution of the RR instruction

LPR r1,r2 (*Load Positive*)

causes the absolute value of the contents of r2 to replace the contents of r1. The contents of r2 are unaltered (unless r1 is r2). Fixed-point overflow will occur if r2 contains the maximum negative number (80000000). The CC is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | r1 contains 0. |
| 1 | — |
| 2 | r1 contains a positive number. |
| 3 | Overflow occurred. |

Execution of the RR instruction

LTR r1,r2 (*Load and Test*)

causes the contents of r2 to be loaded into r1 and sets the condition code. The contents of r2 are unaltered. Thus, this instruction is the same as LR except for the setting of the CC. The CC is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | r1 contains 0. |
| 1 | r1 contains a negative number. |
| 2 | r1 contains a positive number. |
| 3 | — |

LTR is the instruction that should be used to check whether a register contains zero. For example, in order to branch to a routine called ZERO in

the case where R12 contains zero, the following two instructions should be used:

```
LTR     12,12          SET THE CC
BC      B'1000',ZERO
```

Since R12 is loaded into itself, the only effect of the LTR is to set the CC.

Program 2-8 utilizes the LPR instruction to take the absolute value of a number. It reads in a set of numbers (one number per input record) and computes three sums—the sum of the absolute values of all the numbers, the sum of the positive numbers, and the sum of the negative numbers.

**Program 2-8**

```
*****************************************************************
*
* THIS PROGRAM READS IN A DECK OF CARDS, EACH OF WHICH CONTAINS
* A VALID NUMBER.  THE PROGRAM ACCUMULATES THE SUM OF
*
*     THE POSITIVE NUMBERS
*
*     THE NEGATIVE NUMBERS
*
* AND THE ABSOLUTE VALUES OF THE NUMBERS
*
*
* WHEN EOF IS DETECTED, THE PROGRAM PRINTS A SINGLE LINE
* DISPLAYING THE THREE SUMS.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  SET THE THREE ACCUMULATORS (POSITIVE, NEGATIVE,
*            AND ABSOLUTE VALUES) TO 0.
*
*   STEP 2.  TRY TO READ THE FIRST CARD.
*
*   STEP 3.  CHECK FOR END OF THE LOOP (EOF).  WHEN IT OCCURS
*            BRANCH TO STEP 6 TO PRINT THE RESULTS.
*
*   STEP 4.  ADD THE NUMBER OFF THE CARD TO THE APPROPRIATE
*            ACCUMULATORS.
*
*   STEP 5.  TRY TO READ THE NEXT CARD AND GO BACK TO THE TOP
*            OF THE LOOP (STEP 3).
*
*   STEP 6.  PRINT THE RESULTS.
*
*   STEP 7. EXIT FROM THE PROGRAM.
*
*****************************************************************
*
SUM3     CSECT
         USING SUM3,15
*
***<STEP 1>     ZERO THE ACCUMULATORS
*
         SR    3,3                R3 ACCUMULATES SUM OF POSITIVE #S
         SR    4,4                R4 ACCUMULATES SUM OF NEGATIVE #S
         SR    5,5                R5 ACCUMULATES ABSOLUTE VALUES
*
***<STEP 2>     TRY TO READ THE FIRST CARD
*
         XREAD CARD,80
*
***<STEP 3>     TEST FOR EOF (EXIT CONDITION FOR THE LOOP)
```

**Program 2-8 (continued)**

```
*
CHKEOF   BC     B'0100',EOF
*
***<STEP 4>     ACCUMULATE VALUES (ASSUME # ON CARD IS VALID)
*
         XDECI 2,CARD
         BC     B'0100',NEG          BRANCH IF VALUE IS NEGATIVE
*
         AR     3,2                  ADD TO SUM OF POSITIVE VALUES
         BC     B'1111',ADDABS       GO ADD IT TO ABSOLUTE VALUES
*
NEG      AR     4,2                  ADD IT TO SUM OF NEGATIVE VALUES
         LPR    2,2                  SET VALUE TO POSITIVE
*
ADDABS   AR     5,2                  ACCUMULATE ABSOLUTE VALUES
*
***<STEP 5>     TRY TO READ THE NEXT CARD AND GO BACK TO HEAD OF LOOP
*
         XREAD CARD,80
         BC     B'1111',CHKEOF
*
***<STEP 6>     PRINT THE RESULTS
*
EOF      XDECO 3,SUMPOS             PUT SUM OF POSITIVE VALUES INTO LINE
         XDECO 4,SUMNEG             PUT SUM OF NEGATIVE VALUES INTO LINE
         XDECO 5,SUMABS             PUT SUM OF ABSOLUTE VALUES INTO LINE
         XPRNT ANSWER,132           PRINT THE LINE
*
***<STEP 7>     EXIT
*
         BCR    B'1111',14
*
*****************************************************************
*
ANSWER   DC     C'1THE SUM OF THE POS. NUMBERS = '
SUMPOS   DS     CL12
         DC     C' THE SUM OF THE NEG. NUMBERS = '
SUMNEG   DS     CL12
         DC     C' THE SUM OF THE ABSOLUTE VALUES = '
SUMABS   DS     CL12
*
CARD     DS     CL80                 CARD INPUT AREA
*
         END    SUM3
```

## 2.10 MULTIPLICATION AND DIVISION

There are two quite similar instructions that can be utilized to create the product of two fullwords whose values are in binary integer format. These are the MR and M instructions.

In the instruction

MR r1,r2 (*Multiply Register*)

the first operand, r1, must be an even register and will designate an even/odd pair of registers. The multiplicand (the number to be multiplied) is taken from the odd register of the even/odd pair. Thus, if r1 were 4, the multiplicand would be taken from R5. The multiplier is taken from r2. The execution of this instruction causes the product of the multiplicand and the multiplier

to be formed as a 64-bit signed integer, which replaces the original contents of the even/odd pair of registers designated by r1. The contents of r2 are unaltered unless r2 is one of the registers of the even/odd pair designated by r1.

An example may help to clarify the use of the MR instruction. Suppose that

R1 contains 00000004
R2 contains 0000FFFF
R3 contains 00000005

Then if

```
        MR      2,1
```

is executed, the multiplicand in R3 will be multiplied by the multiplier from R1. The result will replace the R2-R3 pair, giving

R1: unchanged
R2-R3: 00000000 00000014 ($4 \times 5 = 14_{16}$)

Two points are worth noting:

- The product would have to be very large (greater than 7FFFFFFF) or very small (less than −80000000) before the even register of the pair would contain anything but an extension of the sign bit. Thus, if the result were positive, the even register would normally contain 00000000; if the result were negative (and not $< -2^{31}$), the even register would contain FFFFFFFF.
- r2 can be the number of either register in the pair designated by r1. For example, execution of the instruction

  ```
          MR      0,1
  ```

  causes the square of the number in R1 to replace the contents of the even/odd pair R0-R1.

Now consider the RX counterpart of the MR instruction:

```
        M       r,D(X,B)                    (Multiply)
```

This instruction is like the MR except that the multiplier is taken from the fullword of storage beginning at the address given by D(X,B). Hence, if R1 contained 00000001, then execution of the instructions

```
        M       R0,TWO
        .
        .
        .
TWO     DC      F'2'
```

would cause the product to replace the contents of the pair R0-R1. (R0 would

be set to 00000000, and R1 would be set to 00000002.) Addressing, protection, and specification exceptions can occur, just as with other RX instructions, if the resolution of D(X,B) produces an erroneous effective address.

## Exercises

**1.** Assume that

R0 contains F01821F0
R1 contains FFFFFFFF
R2 contains 00000003
R3 contains 00000004

Show what would be in the registers after execution of each of the following instructions:

**a.** MR 2,1 **b.** MR 0,2 **c.** MR 2,3 **d.** MR 2,2

Assume further that WORD1 and WORD2 are defined by

```
WORD1    DC    F'10'
WORD2    DC    F'-2'
```

Show what would be in the registers after execution of each of the following instructions:

**e.** M 0,WORD1 **g.** M 2,WORD1
**f.** M 0,WORD2 **h.** M 2,WORD2

**2.** Assume that

R0 contains F0F1F2F3
R1 contains FFFFFFFE
R4 contains 00000002
R5 contains 00000005

Show what would be in the registers after execution of each of the following instructions.

**a.** MR 4,1 **b.** MR 0,4 **c.** MR 4,1 **d.** MR 4,4

Assume further that WORD3 and WORD4 are defined by

```
WORD3    DC    F'9'
WORD4    DC    F'-3'
```

Show what would be in the registers after execution of each of the following instructions.

**e.** M 0,WORD3 **g.** M 4,WORD3
**f.** M 0,WORD4 **h.** M 4,WORD4

Division of binary integer numbers is performed by using either a DR or a D instruction. The description of the DR instruction is

```
DR        r1,r2                    (Divide Register)
```

The first operand, r1, designates an even/odd pair of registers containing the dividend (the number to be divided). The second operand, r2, is the number of a register containing the divisor. The execution of the instruction causes the quotient result of the division to replace the contents of the odd register of the even/odd pair. The sign of the quotient is determined by normal algebraic rules. The remainder, which always has the same sign as the dividend, replaces the contents of the even register of the pair. If the quotient cannot be represented as a 32-bit signed integer, fixed-point overflow will occur.

The use of a DR instruction requires that care be exercised with respect to the contents of the even register of the even/odd pair, since the dividend is considered to be the entire 64-bit number contained in the linked pair of registers. If the dividend is small enough to be contained in only the odd register of the pair, one of two things must be done to initialize the contents of the even register:

- If the dividend is positive (i.e., the odd register contains a positive number), then the even register must be set to all zeros.
- If the dividend is negative, the even register must be set to FFFFFFFF.

The action in either case is to extend the sign bit of the odd register through the even register. As an example of the effects of executing a DR instruction, suppose that

```
R2 contains 00000000
R3 contains 00000007
R4 contains FFFFFFFE   (-2)
```

Then, execution of the instruction

```
DR        2,4
```

would leave the registers as follows:

- R2 would contain the remainder signed consistent with the dividend: 00000001.
- R3 would contain the quotient with the correct sign: FFFFFFFD (−3).
- The contents of R4 would remain unchanged.

The RX counterpart of DR is D:

```
D         r,D(X,B)                 (Divide)
```

The D instruction functions just like the DR instruction except that the divisor is taken from the fullword beginning at D(X,B). Thus,

```
         D       2,MINUS2
         .
         .
         .
MINUS2   DC      F'-2'
```

would have produced the same results in R2 and R3 as the preceding example.

As mentioned earlier, the even register of the even/odd pair used in a divide operation must be set carefully. There is a simple way to handle the problem. Suppose that R3 contains the dividend and that R2 must be set to the correct sign extension. Then,

```
         M       2,ONE
         .
         .
         .
ONE      DC      F'1'
```

accomplishes this (since multiplication by 1 just converts the 32-bit value in R3 to a 64-bit value in R2-R3). This technique is used in several of the sample programs.

## Exercises

**3.** Suppose that

R1 contains 00000003
R2 contains 00000000
R3 contains 00000014
R4 contains FFFFFFFF
R5 contains FFFFFF10

Show what would be in the registers after execution of each of the following instructions:

**a.** DR 2,1 **b.** DR 2,4 **c.** DR 2,5 **d.** DR 4,1

Further suppose that WORD1 and WORD2 are defined as follows:

```
WORD1    DC      F'-4'
WORD2    DC      F'14'
```

Show the results of executing each of the following instructions:

**e.** D 2,WORD1 **g.** D 4,WORD1

**f.** D 2,WORD2 **h.** D 4,WORD2

**4.** Suppose that

R1 contains 00000005
R2 contains 00000000
R3 contains 00000016
R4 contains FFFFFFFF
R5 contains FFFFFFEC

Show what would be in the registers after execution of the following instructions:

**a.** DR 2,1 **b.** DR 2,4 **c.** DR 2,5 **d.** DR 4,1

Further suppose that WORD3 and WORD4 are defined as follows:

```
WORD3    DC    F'-3'
WORD4    DC    F'15'
```

Show the results of executing each of the following instructions:

**e.** D 2,WORD3 **g.** D 4,WORD3
**f.** D 2,WORD4 **h.** D 4,WORD4

---

Program 2-9 illustrates the use of the multiply and divide instructions. It reads two numbers from each card; it multiplies the two numbers and also divides the second number into the first. Both results are then printed.

**Program 2-9**

```
*****************************************************************
*
* THIS PROGRAM IS USED TO ILLUSTRATE THE MULTIPLY AND DIVIDE
* INSTRUCTIONS.  IT READS CARDS, EACH OF WHICH CONTAINS TWO NUMBERS.
* THE PRODUCT OF THE TWO NUMBERS IS CALCULATED, AND THE RESULT OF
* DIVIDING THE SECOND NUMBER INTO THE FIRST IS FOUND.  BOTH RESULTS
* ARE PRINTED FOR EACH INPUT CARD.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  READ THE FIRST CARD.
*
*   STEP 2.  IF EOF HAS OCCURRED, GO TO STEP 6 TO EXIT.
*
*   STEP 3.  GET THE TWO NUMBERS OFF THE CARD (WE ASSUME THAT THEY
*            ARE VALID) AND COMPUTE THE PRODUCT AND QUOTIENT.
*
*   STEP 4.  PRINT THE PRODUCT AND QUOTIENT.
```

**Program 2-9 (continued)**

```
*
*   STEP 5.  READ THE NEXT CARD AND GO BACK TO STEP 2.
*
*   STEP 6.  EXIT.
*
*****************************************************************
*
MULTDIV  CSECT
         USING MULTDIV,15
*
***<STEP 1>    READ THE FIRST CARD.
*
         XREAD CARD,80
*
***<STEP 2>    IF EOF HAS OCCURRED, GO TO STEP 6.
*
TESTEOF  BC    B'0100',EXIT
*
***<STEP 3>    CALCULATE PRODUCT AND QUOTIENT.
*
         XDECI 3,CARD              GET THE FIRST NUMBER
*
         XDECI 4,0(1)              AND NOW THE SECOND
*
         LR    7,3
         MR    6,4                 PUT THE PRODUCT IN R6-R7
*
* NOTE THAT IN ALMOST ALL CASES ONE MAY ASSUME THAT THE RESULT
* WILL FIT INTO THE ODD REGISTER OF THE PAIR.  THIS PROGRAM
* WILL WORK PROPERLY ONLY IF THAT ASSUMPTION IS MADE.
*
         LR    9,3
         M     8,ONE               THIS PUTS THE CORRECT VALUE IN R8
*
* THE MULTIPLY PROPAGATES THE SIGN BIT THRU R8.  THUS, IF THE NUMBER
* IN R3 IS POSITIVE, R8 WILL GET SET TO 00000000.  IF IT'S NEGATIVE,
* R8 GETS SET TO FFFFFFFF.
*
         DR    8,4                 R9 NOW HAS THE QUOTIENT
*
***<STEP 4>    PRINT THE COMPUTED VALUES.
*
         XDECO 7,PROD
         XDECO 9,QUOT              PUT THE VALUES INTO PRINT LINE
*
         XPRNT PLINE,54            PRINT THE LINE
*
***<STEP 5>    TRY TO READ THE NEXT CARD.
*
         XREAD CARD,80
         BC    B'1111',TESTEOF     AND GO BACK TO TEST FOR EOF
*
***<STEP 6>    EXIT.
*
EXIT     BCR   B'1111',14
*
*****************************************************************
*
ONE      DC    F'1'                USED TO SET UP SIGN IN EVEN REG FOR
*                                  THE DIVIDE
PLINE    DC    C'0'                CARRIAGE CONTROL FOR DOUBLE-SPACING
         DC    C'PRODUCT IS '
PROD     DS    CL12                PUT THE PRODUCT HERE
         DC    C'  THE QUOTIENT IS '
QUOT     DS    CL12                PUT THE QUOTIENT HERE
*
CARD     DS    CL80                CARD INPUT AREA
         END   MULTDIV
```

## 2.11 REGISTER EQUATES AND EXTENDED MNEMONICS

The EQU is an assembler instruction that causes no machine code to be generated. The instruction is used simply to establish a correspondence between a label and an expression. For now, we shall consider only EQUates of the form

```
label      EQU      expression
```

where expression is an integer. The effect of the instruction is to establish a correspondence between label and expression so that any occurrence of label in the program will be treated in the same manner as an occurrence of expression.

The following EQU statements should occur in every program:

```
R0         EQU      0
R1         EQU      1
           .
           .
           .
R15        EQU      15
```

Then, wherever a reference is made to a register in the program, the appropriate label should be used. For example, the statement

```
           L        R1,WORD
```

should be used rather than the statement

```
           L        1,WORD
```

The reason for using these EQU statements is that most assemblers produce a cross-reference table with the program listing. This table lists, for each label, the number of the instruction in which the label was defined and the numbers of all instructions in which the label is used. Thus, a ready reference to the use of each of the registers is provided. When macros are discussed in Chapter 9, a technique for eliminating the drudgery of inserting these 16 statements in each program will be presented.

The extended mnemonics are a convenience, provided by the assembler, that allows the coding of many of the conditional branches without the necessity of explicitly specifying the masks. Since this feature provides a facility for specifying branch conditions through the use of mnemonics, it simplifies the task of coding programs. The readability of assembler listings is also greatly enhanced through the use of extended mnemonics, because the tedious chore of continually checking the meanings of particular masks in BC

and BCR instructions is eliminated. The following two sets of instructions illustrate the use of this option:

1. Using the BC instruction:

```
CR      3,4
BC      B'1000',ADDR
```

2. Using an extended mnemonic:

```
CR      3,4
BE      ADDR
```

The same code is generated for each of these sets of instructions. That is, the

```
BE      address
```

is just an alternative to

```
BC      B'1000',address
```

Appendix B contains a table of the extended mnemonics, together with the corresponding BC and BCR instructions. Note that each extended mnemonic is intended to be used with a particular class of instructions that sets the condition code. Thus, both

```
BZ      LOOP
```

and

```
BE      LOOP
```

are equivalent to

```
BC      B'1000',LOOP
```

However, the BZ (Branch Zero) mnemonic is intended to be used following an arithmetic operation, while BE (Branch Equal) should be used following a compare instruction.

A discussion of the use of the NOP and NOPR instructions is deferred to Section 8.2. Though these instructions may seem pointless, since they generate branches with masks of B'0000', the reader is asked to accept on faith at this point that they do have important uses.

It is unfortunate but true that, with most assemblers, only the NOPR and BR mnemonics can be used as alternatives for BCR instructions. However, since by far the most common use of the BCR instruction is to effect an unconditional branch, the BR mnemonic provides an alternative to most uses of the BCR instruction.

The programming examples in the remainder of this text will utilize both register EQUates and extended mnemonics.

## 2.12 LITERALS

It will frequently be necessary to use constants that are not altered by the program. For example, if 4 were to be added to the contents of R1, the following instructions could be used:

```
        A       R1,FOUR
        .
        .
        .
FOUR    DC      F'4'
```

In this case FOUR is a constant that is never altered. As a convenience, the two instructions above could be replaced by the single instruction

```
        A       R1,=F'4'
```

In this case, the second operand is a *literal*, which is simply a constant specification preceded by an equality symbol. If a literal is used, the assembler will automatically generate the constant and use the address of the generated constant in the encoding of the instruction. For example,

```
        D       R2,=F'10'
```

will cause the assembler to generate a fullword containing 0000000A and to use the address of that generated constant in the encoding of the Divide instruction.

Literals may be used for character constants as well. For example, the instruction

```
        XPRNT   =C'1THIS PRINTS A HEADER',21
```

will cause a character string to be printed at the top of a page. This technique is particularly convenient for printing error messages and output headings.

Unless the user specifies otherwise, the assembler will store the generated constants used as literals immediately following the end of a program. The user may specify exactly where the literals are to be generated by using a

```
        LTORG
```

command. The LTORG instructs the assembler to store at this point in the program all literals that have been generated but have not been stored as the result of any previous LTORG. Normally, the LTORG is placed before the user-defined constants in a program but after the last instruction in the program.

The reader is urged to utilize both literals and the LTORG command in future programs.

Program 2-10 illustrates the use of both character and fullword literals.

**Program 2-10**

```
*****************************************************************
*
* THIS PROGRAM READS A SERIES OF CARDS, EACH OF WHICH CONTAINS
* TWO NUMBERS.  FOR EACH CARD THE PROGRAM PRINTS THE TWO NUMBERS AND
* THEIR AVERAGE.  THE LOGIC IS:
*
*   STEP 1.  PRINT A HEADER.
*
*   STEP 2.  TRY TO READ THE FIRST CARD.
*
*   STEP 3.  IF EOF HAS OCCURRED, GO TO STEP 7.
*
*   STEP 4.  GET THE 2 NUMBERS OFF THE CARD AND COMPUTE
*            THEIR AVERAGE.
*
*   STEP 5.  PRINT THE TWO NUMBERS AND THE AVERAGE.
*
*   STEP 6.  READ THE NEXT CARD AND GO BACK TO STEP 3.
*
*   STEP 7.  PRINT "END OF REPORT" MESSAGE AND EXIT.
*
*****************************************************************
*
AVERAGE  CSECT
         USING AVERAGE,R15
*
***<STEP 1>    PRINT THE HEADER
*
         XPRNT =C'1AVERAGES REPORT',16
*
***<STEP 2>    READ THE FIRST CARD
*
         XREAD CARD,80
*
***<STEP 3>    LOOP UNTIL END-OF-FILE
*
LOOP     BC    B'0100',EXIT
*
***<STEP 4>    GET THE NUMBERS AND THEIR AVERAGE
*
         XDECI R2,CARD            GET 1ST NUMBER
         XDECI R3,0(R1)           AND THE SECOND
*
         LR    R5,R3
         AR    R5,R2              R5 NOW HAS THE SUM OF THE NUMBERS
*
         M     R4,=F'1'           THIS PUTS THE CORRECT SIGN
*                                 EXTENSION INTO R4
         D     R4,=F'2'           R5 NOW HAS THE AVERAGE
*
***<STEP 5>    PRINT THE NUMBERS AND THEIR AVERAGE
*
         XDECO R2,NUMBER1         PUT 1ST NUMBER INTO CHARACTER FORM
         XDECO R3,NUMBER2         PUT 2ND NUMBER INTO CHARACTER FORM
         XDECO R5,AVG             PUT AVERAGE INTO CHARACTER FORM
*
         XPRNT PRNTLINE,93        PRINT THE RESULTS
*
***<STEP 6>    READ THE NEXT CARD AND GO BACK TO STEP 3.
*
         XREAD CARD,80
         B     LOOP
*
***<STEP 7>    PRINT "END OF REPORT" MESSAGE AND EXIT.
*
EXIT     XPRNT =C'0END OF REPORT',14
         BR    R14                EXIT
*
*****************************************************************
```

**Program 2-10 (continued)**

```
*
         LTORG
*
CARD     DS    CL80                CARD INPUT AREA
*
PRNTLINE DC    C'OTHE FIRST NUMBER WAS'
NUMBER1  DS    CL12                PUT THE 1ST NUMBER HERE
         DC    C'   THE SECOND NUMBER WAS'
NUMBER2  DS    CL12                PUT 2ND NUMBER HERE
         DC    C'   AVERAGE ='
AVG      DS    CL12                PUT AVERAGE HERE
*
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   AVERAGE
```

## 2.13 THE LA INSTRUCTION

The LA instruction, the last instruction to be covered in this chapter, performs a simple operation but proves to be a very useful instruction:

```
LA      r,D(X,B)          (Load Address)
```

Execution of an LA instruction will cause the effective address given by D(X,B) to be resolved and the address itself to be inserted into the register designated by r. (Since the calculated address is only 24 bits long, it will occupy only the rightmost three bytes of r; the left byte of r will be set to zero.) Thus, execution of the instruction

```
LA      R1,WORD
```

puts the address of WORD into R1.

Carefully note the difference between

```
LA      R1,WORD
```

and

```
L       R1,WORD
```

The first instruction—the LA—"points" R1 at WORD (i.e., puts the address of WORD into R1), while the second actually loads the contents at the address of WORD into R1. Hence, the instruction

```
L       R1,WORD
```

has exactly the same effect as the pair of instructions

```
LA      R1,WORD
L       R1,0(R1)
```

Two special* but very common uses for the LA instruction should be emphasized.

1. A value n in the range $0 \leq n \leq 4095$ may be loaded into a register r by executing an instruction of the form

   ```
   LA      r,n
   ```

   In this case the value n is an example of a D(X,B) address in which X and B are omitted. For example, execution of the instruction

   ```
   LA      R2,20
   ```

   resolves the storage address into the value 20 and puts this value into R2 (setting R2 to 00000014). This is usually the most efficient way of loading small, positive-constant values in binary integer form into a register.

2. Suppose that a register r contains a nonnegative number. To add an increment n less than 4096 to r, an instruction of the following form could be used:

   ```
   LA      r,n(r)
   ```

   For example, execution of the instruction

   ```
   LA      R14,32(R14)
   ```

   adds 32 to R14 and puts the result into R14. Note that this will work only if the sum can be represented as a 24-bit binary number. This is usually the most efficient way of incrementing registers by small, positive-integer values.

In later sections of this text, many examples will deal with manipulating tables of numbers. In such programs, LA instructions frequently appear. Program 2-11 simply builds a table of numbers and then XDUMPs the completed table. Study carefully both the logic of the program and the uses of the LA instruction.

*These are special only in the sense that the value being loaded into r is not an "address" as implied by the instruction's name.

**Program 2-11**

```
*****************************************************************
*
* THE FOLLOWING PROGRAM BUILDS A TABLE OF FULLWORDS, AND THEN XDUMPS
* THE COMPLETED TABLE.  IT READS ONE NUMBER OFF EACH INPUT CARD,
* RECOGNIZING THE END OF INPUT WHEN A TRAILER CARD CONTAINING
* 999999 IS ENCOUNTERED.  THE LOGIC OF THE PROGRAM IS:
*
*   STEP 1.  INITIALIZE R3 TO POINT TO THE FIRST ENTRY IN THE TABLE.
*            R4, WHICH IS USED TO COUNT THE ENTRIES IN THE TABLE, IS
*            INITIALLY SET TO 0.
*
*   STEP 2.  READ THE FIRST CARD.
*
*   STEP 3.  CHECK FOR THE TRAILER. IF IT IS THE TRAILER, GO TO STEP 6
*            TO XDUMP THE TABLE.
*
*   STEP 4.  PUT THE NUMBER INTO THE TABLE (ADDING 1 TO THE COUNT OF
*            ENTRIES AND INCREMENTING THE POINTER TO THE NEXT ENTRY).
*
*   STEP 5.  READ THE NEXT CARD AND GO BACK TO STEP 3.
*
*   STEP 6.  XDUMP OUT THE CONTENTS OF THE TABLE AND EXIT.
*
*****************************************************************

*
TABUILD  CSECT
         USING TABUILD,R15
*
***<STEP 1>     INITIALIZE COUNTER AND POINTER TO NEXT ENTRY
*
         SR    R4,R4          SET COUNT OF ENTRIES TO 0
         LA    R3,TABLE       POINT AT FIRST ENTRY (NEXT ENTRY TO FILL)
*
***<STEP 2>     READ THE FIRST CARD
*
         XREAD CARD,80        IT IS ASSUMED THAT THERE IS A CARD AND
*                             THAT IT CONTAINS A NUMBER
         XDECI R2,CARD
*
***<STEP 3>     CHECK FOR TRAILER
*
TRAILCHK C     R2,=F'999999' CHECK FOR TRAILER
         BE    ENDINPUT
*
***<STEP 4>     ADD THE NUMBER TO THE TABLE
*
         ST    R2,0(R3)       PUT NUMBER INTO NEXT SLOT IN THE TABLE
         LA    R4,1(R4)       ADD 1 TO COUNT OF ENTRIES IN THE TABLE
         LA    R3,4(R3)       MOVE "NEXT ENTRY" POINTER FORWARD 1 ENTRY

*
***<STEP 5>     READ THE NEXT CARD AND GET THE NUMBER INTO R2
*
         XREAD CARD,80
         XDECI R2,CARD        THE NEXT NUMBER IS NOW IN R2
*
         B     TRAILCHK
*
***<STEP 6>     XDUMP THE COMPLETED TABLE
*
ENDINPUT XDUMP TABLE,200
         XDUMP
*
* THE SECOND XDUMP IS TO DISPLAY R4, WHICH HAS THE COUNT OF THE NUMBER
* OF ENTRIES IN THE TABLE.
*
         BR    R14            EXIT FROM THE PROGRAM
```

**Program 2-11 (continued)**

```
*
         LTORG
CARD     DS    CL80          CARD INPUT AREA
TABLE    DS    50F           ROOM FOR 50 ENTRIES
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   TABUILD
```

## Exercises

The process of locating errors in assembler language programs is called "debugging." You will find that programs run under ASSIST/I can be easily debugged by "stepping" through execution, one instruction at a time. However, it is still a useful skill to learn how to deduce "what happened" from a program dump. When you run programs under a normal IBM operating system, when an error is detected, you will need to determine the error from just

a. the PSW,
b. the registers, and
c. the contents of memory

at the time the error occurred. The first two exercises ask you to "determine what you can about what went wrong" from just these three types of information.

**1.** What can be determined from the following dump?

```
PSW AT BREAK:  FF000000 AF000018

R0-7 :F4F4F4F4 00000029 00000083 00000000 F4F4F4F4 00000004 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000084 000000CC 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      4720F078   1B33E000   F0280050   4740F026      *..0...\.0..&. 0.*
000010      5350F028   50520000   5A20F080   E000F028      *.&0.&...!.0.\.0.*
000020      005047F0   F00C07FE   F4404040   40404040      *.&.00...4       *
000030      40404040   40404040   40404040   40404040      *                *
            LINES:   000030 - 000060    ARE IDENTICAL
000070      40404040   40404040   00000001   00000002      *        ........*
000080      00000003   F5F5F5F5   F5F5F5F5   F5F5F5F5      *....555555555555*
000090      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**2.** What can be determined about the error that caused the following dump?

```
PSW :   FF000000 9F000034

R0-7 :F4F4F4F4 00000090 0000009B 00000000 F4F4F4F4 00000003 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 0000009C 000000E4 00000000


USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      4720F090   1B33E000   F03E0050   4740F026      *..0...\.0..&. 0.*
000010      5350F03E   50520000   5A20F098   E000F03E      *.&0.&...!.0q\.0.*
000020      005047F0   F00C4110   F0901912   4780F03C      *.&.00...0.....0.*
000030      5A300001   41110004   47F0F02A   07FEF340      *!........00...3 *
000040      40404040   40404040   40404040   40404040      *                *
            LINES:   000040 - 000070    ARE IDENTICAL
000080      40404040   40404040   40404040   4040F5F5      *              55*
000090      00000001   00000002   00000003   F5F5F5F5      *............5555*
0000A0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**3.** Write a program that can be used to calculate the cost per square foor of a plot of land. The program should accept as input one or more records, each of which will contain three values for the plot of land: its length, width, and total cost. The program should print the three input values, as well as the calculated cost per square foot. For example, suppose that the following two records were used as input:

| | | |
|---|---|---|
| 250 | 75 | 2678 |
| 100 | 50 | 6754 |

The program should produce the following output:

| LENGTH | WIDTH | COST IN DOLLARS | COST/SQUARE FOOT IN CENTS |
|---|---|---|---|
| 250 | 75 | 2678 | 14 |
| 100 | 50 | 6754 | 135 |

**4.** Write a program that can be used to balance a checkbook. The program should accept as input a sequence of records such that:

a. The first record will contain a single value, the beginning balance.
b. Each of the remaining records will contain two numbers. The first number will be a 0 or a 1, indicating that the second number represents either a deposit or a withdrawal, respectively.

The program should print the input values, as well as a remaining balance, following the processing of each record. After all input records have been processed, the program should print

a. the total number of withdrawals
b. the total number of deposits

c. the average amount per withdrawal
d. the average amount per deposit

For example, if

```
4295
0 5210
1 1011
1 1246
0 1000
```

were the input values, the program should print

| CHECK/DEPOSIT CODE | AMOUNT (IN CENTS) | BALANCE (IN CENTS) |
|---|---|---|
| | | 4295 |
| 0 | 5210 | 9505 |
| 1 | 1011 | 8494 |
| 1 | 1246 | 7248 |
| 0 | 1000 | 8248 |

| | | |
|---|---|---|
| # CHECKS | = | 2 |
| # DEPOSITS | = | 2 |
| AVG. AMT./CHECK | = | 1128 |
| AVG. AMT./DEPOSIT | = | 3105 |

**5.** Write a program to tabulate test scores. As input, the program should read a sequence of records, each of which will contain a test score in the range 0 to 100. Output similar to the following should be produced by the program:

TEST SCORE SUMMARY

| RANGE | # SCORES | % OF TOTAL |
|---|---|---|
| 91–100 | 13 | 18 |
| 81–90 | 24 | 34 |
| 71–80 | 16 | 22 |
| 61–70 | 10 | 14 |
| 0–60 | 7 | 10 |

TOTAL # OF TEST SCORES = 70

**6.** Suppose that a person invested a specified sum of money at a known interest rate. Write a program to calculate the amount of money represented by the investment after $n$ years. (Assume that the interest is compounded annually.) Specifically, the program should accept as input a single record containing three values—the amount of the original investment, the interest

rate, and the number of years for which the money is to be invested. The program should produce output similar to the following:

INVESTMENT SUMMARY

| | | |
|---|---|---|
| ORIGINAL AMOUNT | = | 50000 (IN CENTS) |
| PER CENT | = | 7 |
| # YEARS | = | 4 |

| # YEARS | AMOUNT |
|---|---|
| 1 | 53500 |
| 2 | 57245 |
| 3 | 61252 |
| 4 | 65540 |

AVERAGE INTEREST EARNED PER YEAR = 3884

**7.** Write a program that can be used to calculate the capacity of a series of swimming pools and the amount of water required to fill each pool to 80 percent of its capacity. As input, the program should accept parameter records containing three values—the length, width, and depth of a particular design of swimming pool. As output, a report similar to the following should be produced:

CAPACITY REPORT

| LENGTH | WIDTH | DEPTH | VOLUME | 80% FILLED |
|---|---|---|---|---|
| 20 | 60 | 6 | 7200 | 5760 |
| 15 | 25 | 4 | 1500 | 1200 |
| 60 | 40 | 8 | 19200 | 15360 |

**8.** A grocery firm has commissioned you to do a study on customer purchases. Your first task is to read in a set of records, each containing two values: the quantity of an item purchased and the cost of the item in cents.

You must find the following:

a. the total cost of each set of items
b. the average number of items per purchase
c. the average cost per item (of all items sold)

Your output should consist of one line per input record (containing the quantity, the cost per item, and the total cost) and one summary line (containing the average number of items per purchase and the average cost per item). All output should be suitably labeled.

The input records contain two values, separated by one or more blanks. Do not worry about rounding the averages.

**9.** Let us call two vectors of positive integers "complementary" if

a. they are of the same length and
b. at least 80% of the entries in the vectors "complement one another." Two entries are said to complement one another, if their product is less than 2000.

Thus, consider the following two vectors:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 18 | 392 | 1026 | 616 | 18 | 4 | 8 | 420 |
| 126 | 7 | 0 | 2 | 99 | 430 | 389 | 4 |

Here, only the second entries (392 and 7) fail to complement one another; hence, the two vectors are complementary.

Write a program that reads in two vectors, each containing 20 positive entries (one number per input record). Compute the number of entries that complement one another. Then print the percentage of entries that complement one another, as well as the actual number of entries that complement one another.

# 3

# Looping, Subroutines, and More Instructions

## 3.1 THE STC AND IC INSTRUCTIONS

The STC and IC instructions are quite similar to the ST and L instructions. The main difference is that characters instead of fullwords are stored or loaded.

Execution of the instruction

```
STC     r,D(X,B)          (Store Character)
```

will cause the rightmost byte of r (bits 24–31) to be stored into the byte of memory indicated by D(X,B). Since D(X,B) does not have to be on a fullword boundary, a specification error cannot occur. However, if D(X,B) is outside the boundaries of the program containing the STC instruction, a protection exception or an addressing exception might occur. The condition code is not altered.

For example, execution of the instructions

```
LA      R2,64        64 = X'40' =  C' '
STC     R2,BLANK
```

causes a blank to be stored into the first byte of the field labeled BLANK.

The instruction

```
IC      r,D(X,B)          (Insert Character)
```

can be used to transfer a single byte from memory into the rightmost byte of a register. The register to be altered is designated by the first operand, and the address of the byte in memory is specified by the second operand. The condition code is not altered, and the only errors that can occur are protection and addressing exceptions. Note that the left three bytes of r are not altered by the execution of the instruction.

Thus, execution of the instruction

```
IC      R14,FLAG
```

causes the rightmost byte of R14 to be replaced by the contents of FLAG.

## 3.2 LOOPING USING THE BCT AND BCTR INSTRUCTIONS

The construction of loops is one of an assembly-language programmer's most important tasks. The recognition that efficient looping is critical to the performance of many programs led to the creation of several instructions designed specifically to facilitate looping. In this section, two such instructions, BCT and BCTR, are described.

One common type of loop is encountered whenever a particular routine is to be executed a known number of times—say, $n$ times. The general form of this type of loop is as follows:

*Step 1.* Set I equal to $n$.
*Step 2.* Execute the body of the loop.
*Step 3.* Set I equal to I − 1.
*Step 4.* If I is not equal to 0, go to Step 2.
*Step 5.* Continue with the rest of the program.

A flowchart of this type of loop is given in Figure 3-1.

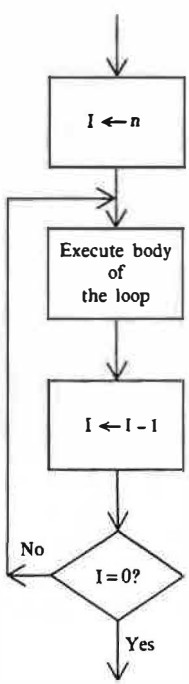



**Figure 3-1**

This type of loop is best implemented through use of either the BCT or the BCTR instruction. The format of the BCT is

```
        BCT     r,D(X,B)        (Branch on Count)
```

Execution of this instruction causes the contents of r to be decremented by 1. If r does not then contain 0, a branch to the address given by D(X,B) is taken. If r does contain 0, then the instruction following the BCT instruction will be executed next. The setting of the CC is not altered.

The format of the BCTR is

```
        BCTR    r1,r2           (Branch on Count Register)
```

This instruction performs the same task as the BCT except that the address to be branched to is contained in r2. However, there is one important point: If r2 is R0, 1 is subtracted from r1, but no branch is taken.

It should be clear at this point how the general form of the loop given in Figure 3-1 can be implemented. Assume that the register r is not used in the body of the loop and that the loop is to be executed *n* times. Then, the following code could be used:

```
                LA      r,n         PUT N INTO R
label           .
                .
                (body of loop)
                .
                .
                BCT     r,label     BRANCH BACK N-1 TIMES
```

An alternative method to illustrate the use of the BCTR would be

```
                LA      r1,n
                LA      r2,label
label           .
                .
                body of loop
                .
                .
                BCTR    r1,r2
```

Actually, the BCTR is utilized for looping far less frequently than the BCT. Its main use is simply to decrement a register by 1. For example, execution of the instruction

```
        BCTR    R11,0
```

subtracts 1 from R11. Since the second operand is 0, no branch is ever taken.

This entire discussion may be made more concrete with some examples.

- *Example 1.* It is often required to have a program reuse the storage reserved for a print line. In this case, blanks are usually written over the line before refilling it. Although a more efficient way to clear a print line will be discussed in Section 4.4, the following small loop would achieve this purpose:

```
         XIC   R1,=C' '          PUT BLANK INTO R1
         LA    R3,133            BLANK OUT 133 CHARACTERS
BLANK1   STC   R1,PLINE-1(R3)    PUT IN ONE BLANK
         BCT   R3,BLANK1         BRANCH BACK 132 TIMES
         .
         .
         .
PLINE    DS    CL133
```

Note the following about this loop:

a. IC R1,=C' ' uses a character literal. The effect is to set the rightmost byte of R1 to the character representation of the code for a blank.

b. PLINE−1(R3) is an implicit address that uses an index register (it specifies the address of PLINE−1 offset by the contents of R3). The first time through the loop R3 will contain 133 and PLINE−1(R3) will equal PLINE+132, the last character of the print line. When R3 contains 1 on the last time through the loop, PLINE−1(R3) will be equal to PLINE. Thus, the entire print line is blanked out by the loop.

- *Example 2.* A program that reads in five numbers (one number per input record) and finds their sum is to be written. The BCT could be used for this purpose as in Program 3-1.

**Program 3-1**

```
*****************************************************************
*
* THE FOLLOWING PROGRAM SUMS 5 INPUT NUMBERS AND PRINTS THE RESULT.
* THE LOGIC IS AS FOLLOWS:
*
*   STEP 1. SET TOTAL TO 0.  SET UP THE LOOP COUNTER WITH A
*           VALUE OF 5 (THE NUMBER OF TIMES THE LOOP WILL BE
*           EXECUTED).
*
*   STEP 2. READ A CARD AND ADD THE VALUE ON THE CARD TO THE
*           TOTAL.
*
*   STEP 3. DECREMENT THE LOOP COUNTER.  IF IT'S > 0, GO
*           BACK TO STEP 2.
*
*   STEP 4. PRINT THE TOTAL.
*
*   STEP 5. EXIT.
*
*****************************************************************
```

**Program 3-1 (continued)**

```
*
SUM5     CSECT
         USING SUM5,R15
*
***<STEP 1>    INITIALIZE TOTAL AND LOOP COUNTER
*
         SR    R4,R4                SET TOTAL TO 0
         LA    R2,5                 SET LOOP COUNTER TO 5
*
***<STEP 2>    READ A CARD AND ADD THE VALUE ON IT TO TOTAL.
*
READNXT  XREAD CARD,80
         XDECI R3,CARD              GET THE VALUE
         AR    R4,R3                AND ADD IT TO TOTAL
*
***<STEP 3>    TEST FOR TIME TO STOP.
*
         BCT   R2,READNXT           BRANCH IF MORE CARDS TO PROCESS
*
***<STEP 4>    PRINT THE RESULT
*
         XDECO 4,TOTAL
         XPRNT CRG,13               PRINT THE RESULT
*
***<STEP 5>    EXIT.
*
         BR    R14
*
*****************************************************************
*
CARD     DS    CL80                 CARD INPUT AREA
*
CRG      DC    C'1'                 CARRIAGE CONTROL - TOP-OF-PAGE
TOTAL    DS    CL12                 PUT THE TOTAL HERE
*
         LTORG
*
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   SUM5
```

- *Example 3.* Program 3-2 reads in two positive numbers, $x$ and $y$, from a single input record. It then prints out the expansion of $x/y$ to 50 decimal places except in the case where $x < y$.

Note the following about Program 3-2:

a. The routine ERROR is branched to if either $x$ or $y$ fails to be positive or if $x$ is not less than $y$.

b. After execution of the instruction

```
DR      R2,R4
```

R3 contains the digit that should be printed. That digit, however, is in binary. 240 decimal is added to convert the binary digit to a character digit. (This would convert 00 to F0, 01 to F1, etc.) Remember that a binary number cannot be printed without first converting it to character format.

**Program 3-2**

```
*********************************************************************
*
* THIS PROGRAM READS TWO POSITIVE NUMBERS, X AND Y.  IT THEN CALCULATES
* X/Y TO 50 PLACES PAST THE DECIMAL AND PRINTS THE RESULT.  IT
* IS ASSUMED THAT X < Y.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  READ THE INPUT CARD AND GET X AND Y.  IF EOF OCCURS,
*            OR IF EITHER NUMBER IS INVALID, GO TO STEP 2; ELSE
*            GO TO STEP 3.
*
*   STEP 2.  PRINT AN ERROR MESSAGE AND GO TO STEP 7 TO EXIT.
*
*   STEP 3.  SET THE LOOP COUNTER (NUMBER OF TIMES TO EXECUTE
*            THE LOOP) TO 50.  SET A POINTER TO WHERE THE FIRST
*            DIGIT GOES IN THE PRINT LINE (INCREMENTED ONE
*            POSITION EACH TIME THRU THE LOOP).
*
*   STEP 4.  CALCULATE THE NEXT DIGIT IN THE EXPANSION AND PUT
*            IT INTO THE PRINT LINE.
*
*   STEP 5.  INCREMENT THE POINTER TO THE NEXT POSITION IN THE
*            PRINT LINE.  THEN DECREMENT THE LOOP COUNTER;
*            IF IT HASN'T REACHED 0, GO BACK TO STEP 4.
*
*   STEP 6.  PRINT THE CONSTRUCTED LINE.
*
*   STEP 7.  EXIT.
*
*********************************************************************
*
EXPAND   CSECT
         USING EXPAND,R15
*
***<STEP 1>    GET THE INPUT VALUES.  IF OK, GO TO STEP 3.
*
         XREAD CARD,80
         BC    B'0100',ERROR       EOF IS AN ERROR
*
         XDECI R3,CARD             GET X
         BNP   ERROR               IT MUST BE POSITIVE
*
         XDECI R4,0(R1)            GET Y
         BNP   ERROR               Y MUST BE POSITIVE TOO
*
         CR    R3,R4               X MUST BE LESS THAN Y
         BL    OK                  BRANCH IF EVERYTHING IS OK
*
***<STEP 2>    PRINT AN ERROR MESSAGE AND GO EXIT.
*
         XPRNT =C'1ERROR IN INPUT',15
         B     EXIT
*
***<STEP 3>    SET UP LOOP COUNTER AND POSITION FOR RESULTS.
*
OK       LA    R5,50               SET LOOP COUNTER TO 50
         LA    R6,EXOUT            SET POINTER TO FIRST DIGIT
*
***<STEP 4>    PRODUCE THE NEXT DIGIT IN THE EXPANSION.
```

**Program 3-2 (continued)**

```
*
LOOP     M     R2,=F'10'          MULTIPLY DIVIDEND BY 10
         DR    R2,R4              THE DIGIT TO PRINT IS THE QUOTIENT
         LA    R3,240(R3)         CONVERT IT TO PRINTABLE CHARACTER
         STC   R3,0(R6)           PUT IT IN THE PRINT LINE
         LR    R3,R2              PUT REMAINDER BACK FOR NEXT DIVIDE
*
***<STEP 5>    INCREMENT POSITION IN RESULT AND CHECK FOR END OF LOOP.
*
         LA    R6,1(R6)           INCREMENT POSITION FOR NEXT DIGIT
         BCT   R5,LOOP
*
***<STEP 6>    PRINT THE RESULT.
*
         XPRNT CRG,52
*
***<STEP 7>    EXIT.
*
EXIT     BR    R14
*
*****************************************************************
*
CARD     DS    CL80               CARD INPUT AREA
*
CRG      DC    C'1.'              CARRIAGE CONTROL AND DECIMAL POINT
EXOUT    DS    CL50               DECIMAL EXPANSION GOES HERE
*
         LTORG
*
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   EXPAND
```

## Exercises

**1.** For each of the following loops, indicate the number of times the body of the loop will be executed.

**a.**

```
         LA    R14,6
LOOP     .
         .
         BCT   R12,LOOP
```

**b.**

```
LOOP     LA    R12,200
         .
         .
         BCT   R12,LOOP
```

**c.**
```
        LA      R10,LOOP
        LA      R11,413
LOOP    .
        .
        BCTR    R11,R10
```

---

**d.**
```
        LA      R0,LOOP
        LA      R1,10
LOOP    .
        .
        BCTR    R1,R0
```

---

**e.**
```
        SR      R1,R1
LOOP    .
        .
        BCT     R1,LOOP
```

---

**2**

**a.**
```
        LA      R1,18
LOOP    .
        .
        BCT     R1,LOOP
```

---

**b.**
```
LOOP    LA      R13,15
        .
        .
        BCT     R13,LOOP
```

---

**c.**
```
        LA      R1,LOOP
        LA      R0,13
LOOP    .
        .
        BCTR    R0,R1
```

---

**d.**
```
        LA      R0,LOOP
        LA      R2,15
LOOP    .
        .
        BCTR    R3,R0
```

## 3.3 THE BXLE AND BXH INSTRUCTIONS

In constructing complex programs, it is common to manipulate data in tables. In such cases, loops utilizing the logic shown in Figure 3-2 frequently arise. Such a loop can certainly be implemented with the repertoire of instructions

introduced so far. However, since this pattern of logic is so common, a specific instruction was introduced to facilitate its implementation:

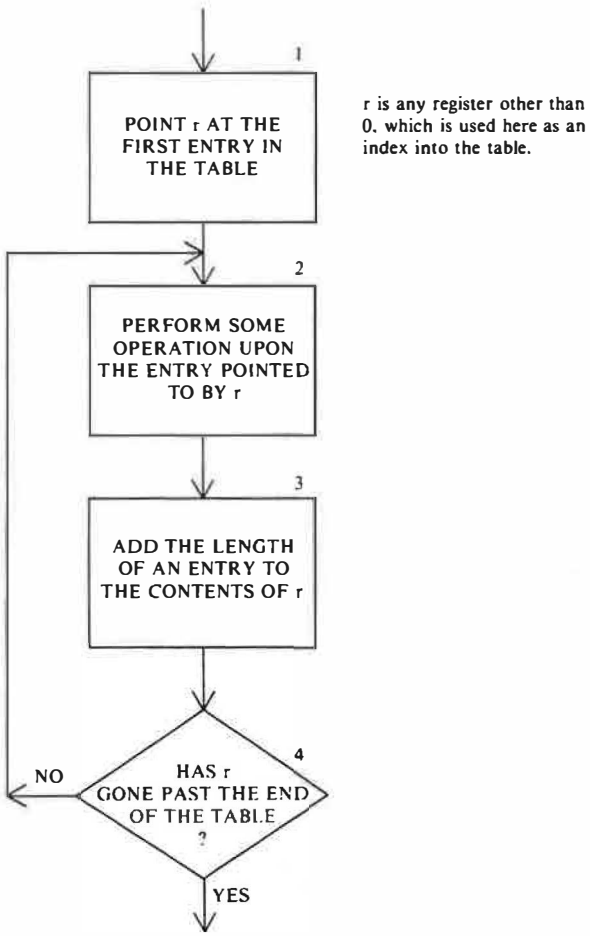



**Figure 3-2**

BXLE r1,r2,D(B) (*Branch on Index Low or Equal*)

To describe the actions resulting from the execution of a BXLE instruction, we will refer to the index register, the increment register, and the limit register. These registers are determined as follows:

- r1 is the index register.
- If r2 is an even register, it represents an even/odd pair. In this case, the even register is the increment register, and the odd register is the limit register.

- If r2 is an odd register, then r2 is both the increment register and the limit register.

The actions caused by the execution of the BXLE are then:

1. The contents of the increment register are added to the contents of the index register.
2. If the new contents of the index register are less than or equal to the limit register, a branch to D(B) takes place. Otherwise, execution continues, with the instruction immediately following the BXLE instruction.

If the contents of the index, increment, and limit registers are represented by

<r(index)>
<r(incr)>
<r(limit)>

respectively, the effects of the BXLE can be portrayed in a flowchart as in Figure 3-3.

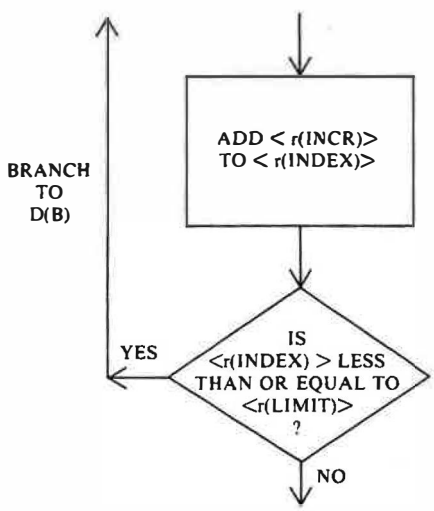



**Figure 3-3**

It should now be clear that the BXLE instruction alone can be used to implement blocks 3 and 4 of Figure 3-2.

An example of the use of the BXLE will illustrate its power. Suppose that a table of fullwords, TABLE, exists and that R3 contains the address of the last entry in the table. Each of the following two sections of code scans

TABLE for the smallest integer in the table. In the first case, no BXLE is employed; in the second, a BXLE is used.

```
* IT IS ASSUMED THAT THE TABLE CONTAINS AT LEAST 2 ENTRIES AND
* THAT R3 CONTAINS THE ADDRESS OF THE LAST ENTRY.
         L     R4,TABLE          GET 1ST ENTRY - SMALLEST-SO-FAR
         LA    R5,TABLE+4        POINTS TO NEXT ENTRY TO LOOK AT
LOOP     C     R4,0(R5)          COMPARE SMALLEST-SO-FAR AND CURRENT
         BNH   CHKEND
         L     R4,0(R5)          WE HAVE A NEW SMALLEST-SO-FAR
CHKEND   LA    R5,4(R5)          GO TO NEXT ENTRY
         CR    R5,R3             CHECK FOR END OF TABLE
         BNH   LOOP              BRANCH IF NOT PAST END


* THE SAME LOOP USING A BXLE.
         LA    R2,4              GET THE LENGTH OF A TABLE ENTRY
         L     R4,TABLE          GET 1ST ENTRY - SMALLEST-SO-FAR
         LA    R5,TABLE+4        POINTS TO NEXT ENTRY TO LOOK AT
LOOP     C     R4,0(R5)          COMPARE SMALLEST-SO-FAR AND CURRENT
         BNH   CHKEND
         L     R4,0(R5)          WE HAVE A NEW SMALLEST-SO-FAR
CHKEND   BXLE  R5,R2,LOOP        BRANCH IF MORE ENTRIES TO SCAN
```

The use of the BXLE clearly results in a shorter sequence of instructions in the loop itself. The execution time of the program using the BXLE is considerably less also. In fact, in most programs where a table must be searched, the BXLE should be used.

The perceptive reader will have noted that the format of the BXLE does not conform to the normal RX format. In fact, the BXLE is an RS instruction, not an RX instruction. The symbolic form for an RS instruction is

| label | mnemonic | r1,r2,D(B) |
|---|---|---|

where r1 and r2 are register numbers
D(B) is an address (no index register can be used)

The format for the generated machine instruction is

$$h_0h_0h_{r1}h_{r2}h_Bh_Dh_Dh_D$$

where $h_0h_0$ is the op code
$h_{r1}$ is r1
$h_{r2}$ is r2
$h_B$ is the base register
$h_Dh_Dh_D$ is the 12-bit displacement

There are two main differences between the RX and the RS formats:

- There are three operands in an RS instruction and only two in an RX instruction.

- An index register may be used in an RX instruction, but not in an RS instruction.

The instruction

BXH r1,r2,D(B) (*Branch on Index High*)

is another RS instruction closely related to the BXLE instruction. It can be used to implement the pattern of logic in Figure 3-4.

The function of the BXH is identical to the function of the BXLE except that the branch to D(B) will occur only when the addition of the increment makes the index register greater than the limit register. The actions caused by the execution of a BXH are visually depicted in Figure 3-5.

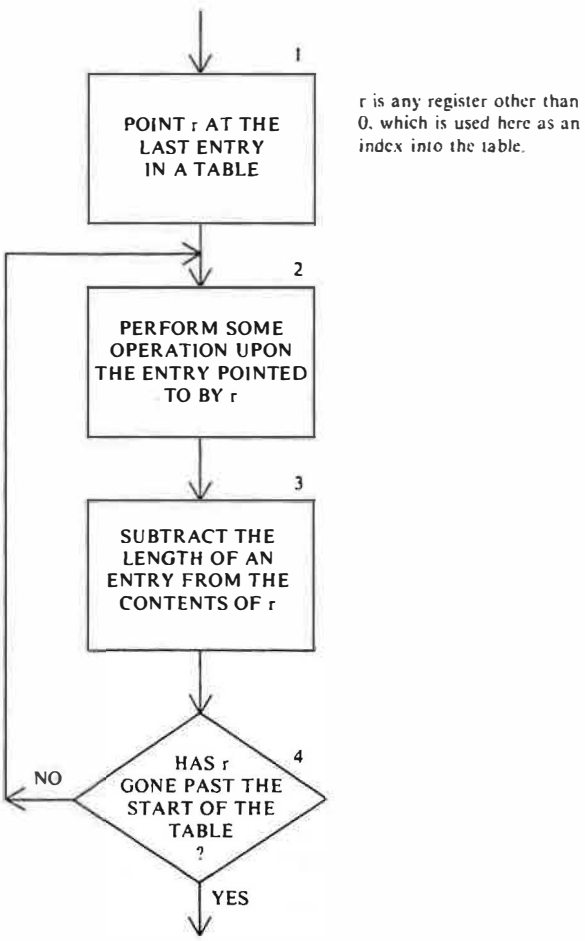



Figure 3-4

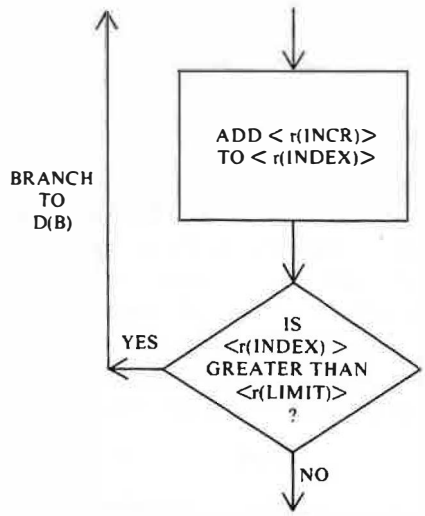



Figure 3-5

The key to scanning through a table with a BXH is to put a negative value in the increment register. Thus, our previous example, in which a table was scanned for its least integer, couid have been coded as

```
* IT IS ASSUMED THAT THE TABLE CONTAINS AT LEAST 2 ENTRIES AND THAT
* R3 CONTAINS THE ADDRESS OF THE LAST ENTRY.
         L     R4,=F'-4'        PUT IN MINUS THE LENGTH OF AN ENTRY
         LR    R6,R3            R6 <-ADDRESS OF LAST ENTRY
         L     R2,TABLE         R2 <-SMALLEST-SO-FAR
         LA    R5,TABLE         SET POINTER TO FIRST ENTRY
LOOP     C     R2,0(R6)         CHECK FOR NEW SMALLEST
         BNH   CHKEND
         L     R2,0(R6)         NEW SMALLEST-SO-FAR
CHKEND   BXH   R6,R4,LOOP
```

In the above example, it was again assumed that R3 pointed to the last entry in the table.

The reader might at this point wonder why a programmer would ever choose to make the second operand in a BXLE or BXH an odd register. By being reasonably clever, it is often possible to implement a loop with one less register by making the increment register the limit register as well. For example, the section of code presented above need not have required the use of R4. Instead, the following code could have been used:

```
         L     R5,=F'-4'        INCREMENT AND LIMIT REG ARE -4
         LR    R6,R3            R6 <- ADDRESS OF LAST ENTRY
         LA    R2,TABLE+4       NOW CONVERT R6 FROM A POINTER TO
*                               A DISPLACEMENT
         SR    R6,R2
         L     R2,TABLE         R2 <- SMALLEST-SO-FAR
LOOP     C     R2,TABLE+4(R6)   CHECK FOR A SMALLER VALUE
         BNH   CHKEND
         L     R2,TABLE+4(R6)
CHKEND   BXH   R6,R5,LOOP       BRANCH IF MORE TO SCAN
```

There may be a question about how to recognize when to use a BXLE or BXH. In a loop where a fixed increment is to be added to a pointer each time through the loop, either a BXLE or BXH should probably be used. A few extra instructions will be required for initialization of the loop variables before entering the loop, but the execution time will be more than compensated for if the program executes the instructions in the loop more than just once or twice.

Another question that often arises is: Why worry about saving a few microseconds here and there? It is true that too much programmer time can be spent in an attempt to determine how to minimize the execution time of a program. However, a major part of the execution time of many programs is spent in processing loops; therefore, it is definitely important to try to optimize code within these loops. The efficient coding of loops may often speed up the execution of a program by 100 percent or more. A small amount of time spent now learning how to code loops efficiently will make the task far easier in the future.

## Exercises

**1.** For each of the following loops, indicate the number of times the body of the loop will be executed.

**a.**

```
         LA      R5,TABEND-10
         L       R6,=F'-10'
         LA      R7,TABLE-10
LOOP     .
         .
         BXH     R5,R6,LOOP
         .
         .
TABLE    DS      8CL10
TABEND   DS      0C
```

**b.**

```
         LA      R3,TABLE+20
         L       R4,=F'-5'
         LA      R5,TABLE
LOOP     .
         .
         BXH     R3,R4,LOOP
         .
TABLE    DS      10CL5
```

**c.**

```
         LA      R5,40
         L       R7,=F'-10'
LOOP     LA      R2,TABLE(R5)
         .
         .
         BXH     R5,R7,LOOP
```

**d.**

```
         LA      R3,TABLE
         LA      R4,5
         LA      R5,TABLE+20
LOOP     .
         .
         BXLE    R3,R4,LOOP
```

**e.**

```
        L       R7,=A(TABLE)
        LA      R8,4
        L       R9,=A(TEND)
LOOP    .
BXLE    .       R7,R8,LOOP
TABLE   DS      5F
TEND    DS      0F
```

**2**

**a.**

```
        LA      R7,TEND-4
        L       R8,=F'-4'
        LA      R9,TAB-4
LOOP    .
        .
        BXH     R7,R8,LOOP
        .
        .
TAB     DS      100F
TEND    DS      0F
```

**b.**

```
        LA      R11,TABLE+160
        L       R14,=F'-8'
        LA      R15,TABLE
LOOP    .
        .
        BXH     R11,R14,R15
```

**c.**

```
        LA      R7,100
        L       R11,=F'-10'
LOOP    LA      R10,TAB(R7)
        .
        .
        BXH     R7,R11,LOOP
        .
        .
TAB     DS      101CL10
```

**d.**

```
        LA      R1,TABLE
        LA      R4,18
        LA      R5,TABLE+180
LOOP    .
        .
        BXLE    R1,R4,LOOP
```

**e.**

```
        L       R1,=A(TAB)
        LA      R10,4
```

```
         L      R11,=A(TEND-4)
LOOP     .
         .
         BXLE   R1,R10,LOOP
         .
TAB      DS     50F
TEND     DS     0F
```

**3.** Write a program to build a table of not more than 50 fullword integers. Having built the table, the program should print out the values in the table, *n* per line, where *n* is an input value. The input of the program should consist of a sequence of records characterized by the following:

- The first record contains *n* (which will be less than or equal to 8), the number of integers to be displayed on each print line.
- The remaining records each contain a single integer to be stored in the table.

After building the table, the program should XDUMP the contents of the table before printing them *n* per line. The following programming considerations should be noted:

a. In building and printing the table, it is often convenient to use an index register to address a fullword or a 12-byte field in the print line.
b. To build a table, a loop containing a BXH with an odd increment register should be used.
c. Avoid sequences of instructions of the type

```
LA     R3,4(R3)
CR     R3,R5
BNH    LOOP
```

and use a BXLE or perhaps a BCT instead.

**4.** Write a program to perform the following operations:

a. Read a sequence of records, each of which will contain a single integer, and build a table of up to 50 words from the values on the records. While storing the values into the table, the program should accumulate their sum.
b. The program should then calculate the average value of the entries in the table and XDUMP the contents of the table, the sum, and the average.
c. Finally, the program should calculate and print out the number of values in the table that are greater than the average, the number of values equal to the average, and the number of values less than the average.

**5.** Suppose that a bank has recorded for a particular day the number of customers who entered the bank during every half-hour that the bank was open. Furthermore, suppose that the bank was open a total of seven hours, so that there were 14 time periods for which numbers were recorded. Write a program to read 14 cards, each of which contains the number of people who entered the bank during the corresponding half-hour, and print a report conforming to the following format:

BANK ACTIVITY REPORT

| PERIOD | # OF CUSTOMERS | % OF TOTAL | CUMULATIVE % |
|---|---|---|---|
| 1 | 8 | 2 | 2 |
| 2 | 13 | 4 | 7 |
| 3 | 12 | 4 | 11 |
| 4 | 18 | 6 | 17 |
| 5 | 24 | 8 | 25 |
| 6 | 23 | 8 | 33 |
| 7 | 37 | 12 | 46 |
| 8 | 33 | 11 | 57 |
| 9 | 29 | 9 | 67 |
| 10 | 18 | 6 | 73 |
| 11 | 19 | 6 | 80 |
| 12 | 17 | 5 | 85 |
| 13 | 21 | 7 | 93 |
| 14 | 20 | 6 | 100 |

TOTAL # CUSTOMERS = 292

**6.** Suppose that a company maintains a master file of records containing information detailing how many units of each item that the company sells are in stock. Specifically, each record contains two nonnegative integers: an item number (a unique item number is assigned to each product that the company sells) and the number of units in stock. Furthermore, the records occur in ascending order, based on the item number. Write a program to process requests for information about how much stock is in store. The program should accept as input

- the master records
- a single record containing $-1$
- a set of request records, each of which contains a single item number

The program should first read in the master records and build a table. Each entry in the table should contain two fullwords, the first containing the item

number and the second the number of units of that item that are in stock. After the record containing −1 has been read, the program should XDUMP the constructed table so that the contents can be verified. Then, as the request records are read, a report similar to the following should be produced:

INVENTORY INFORMATION REPORT

| ITEM # | UNITS IN STOCK |
|---|---|
| 234 | 842 |
| 421 | 0 |
| 24 | NO ENTRY IN MASTER DECK |
| 1840 | 13 |

**7.** Write a program to do the following tasks:

a. First the program should read a sequence of records, each of which contains two integers, and store the values into two separate tables. There will be at most 50 input records. The program should XDUMP the contents of the two tables.
b. The program should construct a third table by adding corresponding entries in the existing tables. Thus, if −5 and 24 were the fourth elements in the first and second tables, respectively, 19 would be the resulting element that should be stored as the fourth element in the third table.
c. Finally, the program should print out the contents of the third table, printing one number per print line.

**8.** Write a program that (1) reads in a table of integers (and XDUMPs it), (2) compacts the table by removing duplicate entries, and (3) prints out the resulting table.

Each input record contains a single integer. There will be at most 30 input values. (Assume that the values occur in ascending order.)

One way to compact the table is as follows:

a. Set two pointers to point at the first table entry. The first pointer gives the next entry to look at, and the second pointer gives the position of the next-kept value.
b. Now move the first pointer through all the entries in the table except the last. Whenever a value is not equal to its successor, move it to the position given by the second pointer (and update the second pointer).
c. Finally, move over the last entry.

Make sure that your program will work if the table contains fewer than two values.

Print the values one per line, after printing a suitable heading.

**9.** This problem differs from Exercise 8 in two ways:

a. The values may not occur in ascending order. (Think your algorithm out carefully before coding.)
b. Each input record can contain any number of values.

To set the values of an input record, define the CARD input area as follows:

```
CARD     DS     CL80
         DC     C'*'
```

Then, use repeated XDECIs until a condition code of 3 (invalid value) results.

---

## 3.4 BAL, BALR, AND SUBROUTINES

A standard technique employed in the design of complex programs involves partitioning a program into smaller *subroutines*. The logic of each subroutine is far simpler than that of the whole program. To implement this technique, it is first helpful to draw a *block diagram,* which pictorially represents the segmentation of the given program. Flowcharts of the individual subroutines are then constructed to complete the description of the logic of the program. Occasionally, a subroutine itself will be complex enough to warrant a block diagram. In this case, the entire process is carried one step further by breaking the subroutine down into "lower-level" subroutines.

As an illustration of this process, consider the problem of creating a program to accomplish the following tasks:

1. Read a set of numbers arranged in ascending order into a table.
2. Print out the numbers in the table.
3. Read in a second table.
4. Print out the second table.
5. Merge the two tables.
6. Print out the one large table.

A detailed flowchart of a program to perform these six tasks without utilizing subroutines would be large and complex. If instead the program were broken down into subroutines, the overall logic could be represented by Figure 3-6.

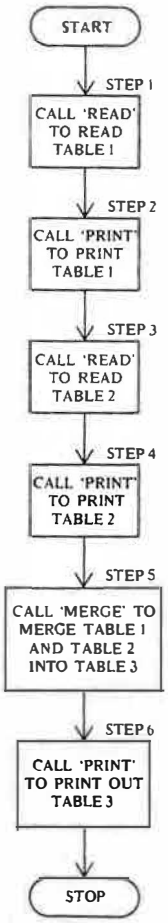



**Figure 3-6**

Since the flowcharts of the subroutines would divert attention from this discussion, they have been relegated to Appendix A.

Now that the logic required to perform the desired functions has been described, the job of implementing it in an actual program remains to be done. The BAL instruction can be used to facilitate this process.

BAL r,D(X,B) (*Branch and Link*)

Execution of this instruction causes the following actions to occur:

- The right 32 bits of the Program Status Word (PSW) are stored in r. This means that, after the execution of the BAL, r will contain the address of

the instruction immediately following the BAL (since the PSW contains that address in bits 40–63).

- A branch to D(X,B) is taken.

Thus, execution of the instruction

```
BAL     R10,SORT
```

causes a branch to SORT. Furthermore, to cause a return to the instruction following the BAL, the instruction

```
BR      R10
```

could be used.

Program 3-3 utilizes the BAL instruction to implement the logic depicted in Figure 3-6. The code for the subroutines has been included in Appendix A, along with the detailed flowcharts. The reader should finish this section and Section 3.5 before carefully examining the program in the appendix.

**Program 3-3**

```
*********************************************************************
*
* THIS PROGRAM ILLUSTRATES THE USE OF SUBROUTINES.  THE PROGRAM
*
*        1) READS A SET OF NUMBERS INTO 'TABLE1'.  IT IS
*           ASSUMED THAT THE INPUT VALUES HAVE BEEN SORTED INTO
*           ASCENDING ORDER.
*
*        2) PRINTS OUT THE NUMBERS IN 'TABLE1'.
*
*        3) READS IN A SECOND SET OF NUMBERS INTO 'TABLE2'.
*
*        4) PRINTS OUT THE NUMBERS IN 'TABLE2'.
*
*        5) MERGES THE NUMBERS IN THE TWO TABLES INTO 'TABLE3'.
*
*        6) PRINTS OUT THE NUMBERS IN 'TABLE3'.
*
* THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*        STEP 1.  CALL 'READ' TO READ IN THE FIRST TABLE.  THIS WILL
*                 REQUIRE PASSING TO 'READ' THE ADDRESS OF THE TABLE
*                 TO FILL.  THE 'READ' ROUTINE WILL RETURN THE ADDRESS
*                 OF THE LAST ENTRY, WHICH IS STORED IN 'ENDT1'.
*
*        STEP 2.  CALL 'PRINT' TO PRINT OUT THE VALUES IN 'TABLE1'.
*
*        STEP 3.  CALL 'READ' TO READ IN THE VALUES FOR 'TABLE2', AND
*                 SAVE THE ADDRESS OF THE LAST ENTRY IN 'ENDT2'.
*
*        STEP 4.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE2'.
*
*        STEP 5.  CALL 'MERGE' TO MERGE THE VALUES IN 'TABLE1' AND
*                 'TABLE2' INTO 'TABLE3'.
*
*        STEP 6.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE3'.
*
*        STEP 7.  EXIT.
*
*********************************************************************
```

**Program 3-3 (continued)**

```
MAINPROG CSECT
         USING MAINPROG,R15
*
*** <STEP 1>     READ IN THE VALUES FOR 'TABLE1'.
*
         LA     R2,TABLE1          R2 IS USED TO PASS THE ADDRESS OF
*                                  WHERE THE VALUES ARE TO BE STORED
         BAL    R10,READ           READ IN 'TABLE1'
         ST     R3,ENDT1           SAVE THE ADDRESS OF THE LAST VALUE
*
*** <STEP 2>     PRINT OUT THE VALUES IN 'TABLE1'.
*
         BAL    R10,PRINT          R2 MUST HAVE ADDRESS OF 'TABLE1' AND
*                                  R3 MUST HAVE ADDRESS OF LAST ENTRY
*
***<STEP         READ IN THE VALUES FOR 'TABLE2'.
*
         LA     R2,TABLE2          POINT TO THE SECOND TABLE
         BAL    R10,READ           READ IN THE VALUES
         ST     R3,ENDT2           SAVE ADDRESS OF LAST ENTRY
*
                PRINT OUT THE VALUES IN 'TABLE2'.
*
         BAL    R10,PRINT
*
***<STEP 5>     NOW MERGE THE TWO TABLES INTO 'TABLE3'.
*
         LA     R2,TABLE1          R2 <- ADDRESS OF FIRST TABLE
         LA     R3,TABLE2          R3 <- ADDRESS OF SECOND TABLE
         LA     R4,TABLE3          R4 <- ADDRESS OF TABLE TO BUILD
*
         L      R5,ENDT1           R5 <- ADDRESS OF LAST ENTRY IN TABLE1
         L      R6,ENDT2           R6 <- ADDRESS OF LAST ENTRY IN TABLE2
*
         BAL    R10,MERGE          NOW MERGE THE TWO TABLES
*
*** <STEP 6>     PRINT OUT THE CONTENTS OF 'TABLE3'.
*
         LA     R2,TABLE3
         LR     R3,R7              'MERGE' PUT ADDRESS OF LAST ENTRY
*                                  INTO R7
         BAL    R10,PRINT          NOW PRINT THE MERGED TABLE
*
                EXIT.
*
         BR     R14
*
*****************************************************************
*
*               STORAGE AREAS FOR THE MAIN ROUTINE
*
*****************************************************************
*
         LTORG
ENDT1    DS     F                  ADDRESS OF LAST ENTRY IN TABLE1
ENDT2    DS     F                  ADDRESS OF LAST ENTRY IN TABLE2
TABLE1   DS     50F                BUILD THE FIRST TABLE HERE
TABLE2   DS     50F                AND THE SECOND TABLE HERE
TABLE3   DS     100F               AND THE MERGED TABLE HERE
*
*****************************************************************
*
*                       READ ROUTINE
*
* THIS IS THE READ ROUTINE.  WHEN IT IS ENTERED, R2 CONTAINS THE
* ADDRESS OF THE TABLE TO BE FILLED.  EACH DATA CARD CONTAINS ONE
* NUMBER. END OF THE TABLE IS DESIGNATED BY A CARD CONTAINING
* 999999.  UPON EXITING, R3 CONTAINS THE ADDRESS OF THE LAST ENTRY
* OF THE TABLE.  NO OTHER REGISTERS ARE ALTERED.  R10 IS THE LINK
* REGISTER.
*
*****************************************************************
```

the READ routine

**Program 3-3 (continued)**

```
*********************************************************************
*
*                        PRINT ROUTINE
*
* THIS ROUTINE PRINTS OUT THE VALUES IN THE TABLE POINTED TO BY
* R2.  R3 MUST CONTAIN THE ADDRESS OF THE LAST ENTRY IN THE TABLE.
* R10 IS THE LINK REGISTER.  ENTRIES ARE PRINTED OUT 1 PER LINE.
* NO REGISTERS ARE ALTERED BY A CALL TO THIS ROUTINE.
* THE LOGIC IS AS FOLLOWS:
*
*********************************************************************

          the PRINT routine

*********************************************************************
*
*                        MERGE ROUTINE
*
* THIS ROUTINE MERGES THE TWO SORTED TABLES INTO A THIRD TABLE.  UPON
* ENTRANCE
*
*        R2 = ADDRESS OF FIRST TABLE
*        R3 = ADDRESS OF SECOND TABLE
*        R4 = ADDRESS OF THIRD TABLE
*        R5 = ADDRESS OF LAST ENTRY IN FIRST TABLE
*        R6 = ADDRESS OF LAST ENTRY IN SECOND TABLE
*
* THE ROUTINE WILL SET R7 TO THE ADDRESS OF THE LAST ENTRY IN THE
* THIRD TABLE, WHICH IS PRODUCED BY MERGING THE FIRST TWO TABLES.
* R10 IS THE LINK REGISTER.  ONLY R7 IS ALTERED BY A CALL TO THIS
* ROUTINE.
*
*********************************************************************

          the MERGE routine

         LTORG
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   MAINPROG
```

There are at least two good reasons why subroutines should be used:

- They save a considerable amount of code. READ, for example, was coded only once in the sample program, although it was invoked from two separate points in the program.
- Subroutines make the logical structure of a program more obvious. Thus, although MERGE was called only once, it performed a logically distinct task and was, therefore, coded as a separate subroutine.

Remember these points when defining a subroutine:

- All *input conventions* should be clearly stated in the comment statements and should be such that the routine can be called from any point in the program.
- Anything that is altered by the subroutine should be noted clearly in the comments. Registers that are altered for reasons other than to return information to the calling program are usually restored to their original contents before exiting from the subroutine.

There is an RR counterpart of the BAL instruction:

```
        BALR    r1,r2        (Branch and Link Register)
```

This instruction is similar to BAL except that the branch address is taken from r2. Thus, execution of the instructions

```
        LA      R9,ROUTINE
        BALR    R10,R9
```

is equivalent to execution of the instruction

```
        BAL     R10,ROUTINE
```

The main use of the BALR will be with external subroutines, which are covered in Section 6.2. There is one special rule concerning the BALR: If r2 is 0, then no branch is taken. Hence,

```
        BALR    R12,0
        USING   BASEAD,R12
BASEAD  instruction
```

could be used to establish R12 as a base register. The BALR will just cause the address of BASEAD to be put into R12, and the USING statement notifies the assembler of that fact.

## 3.5 STM AND LM INSTRUCTIONS

The two instructions STM and LM can be used for storing and restoring the contents of registers, several at a time.

Execution of the RS-type instruction

```
        STM     r1,r2,D(B)        (Store Multiple)
```

causes all registers from r1 through r2 to be stored in contiguous fullwords of storage, starting at the address given by D(B). Thus, execution of the instruction

```
        STM     R4,R8,SAVE
```

will cause the contents of R4, R5, R6, R7, and R8 to be stored into five fullwords starting at SAVE. If r2 is less than r1, then r1 through R15 followed by R0 through r2 are stored. For example, execution of the instruction

```
        STM     R14,R1,SAVE
```

will cause the contents of four registers, R14, R15, R0, and R1, to be stored.

The instruction

```
        LM      r1,r2,D(B)          (Load Multiple)
```

is similar to STM except that the registers are loaded rather than stored. Hence, execution of the instruction

```
        LM      R12,R2,REGSAVE
```

loads R12 through R15, and R0 through R2, from the seven fullwords starting at REGSAVE.

In Section 3.4, we emphasized that a subroutine should restore the contents of registers that are altered in the execution of the subroutine. This can be very easily implemented with the STM and LM instructions. For example, the code

```
ROUTINE STM  R0,R15,SAVE  STORE CALLER'S REGISTERS
        .
        .
        body of routine
        .
        .
        LM   R0,R15,SAVE  RELOAD THE CALLER'S REGISTERS
        BR   R10          RETURN TO CALLER
SAVE    DS   16F          STORE REGISTERS HERE
```

would allow any register other than the base register to be altered in the routine. (Note that this technique is used in the subroutines contained in Appendix A.)

## 3.6 A-TYPE ADDRESS CONSTANTS

We shall conclude this chapter with a discussion of another form of the DC statement:

```
        label   DC      A(exp)
```

In this form of the DC statement, the operand is referred to as an *A-type address constant.* The statement generates a fullword, according to the following rules:

- If exp is a nonnegative integer, the generated fullword will contain the binary representation of the integer (i.e., F'exp' could have been used instead of A(exp)).
- If exp is a label or is of the form label±n, the generated fullword will contain the appropriate address.

Thus, the statement

```
DC      A(5)
```

generates 00000005, and

```
DC      A(SAVE)
```

generates a fullword containing the address of SAVE. Several expressions can be included in one statement. For example, the statement

```
DC      A(L1,20,L2)
```

generates three words: the first word contains the address of L1; the second, the value 20; and the third, the address of L2.

A-type constants can also be used in literals. Frequently, this feature is utilized to load registers with input parameters before a call is issued to a subroutine. For example, in Step 5 of Program 3-3, the instructions

```
      LA    R2,TABLE1    R2 <- ADDRESS OF FIRST TABLE
      LA    R3,TABLE2    R3 <- ADDRESS OF SECOND TABLE
      LA    R4,TABLE3    R4 <- ADDRESS OF TABLE TO BUILD
*
      L     R5,ENDT1     R5 <- ADDRESS OF LAST ENTRY IN TABLE1
      L     R6,ENDT2     R6 <- ADDRESS OF LAST ENTRY IN TABLE2
```

could have been replaced with

```
LM      R2,R4,=A(TABLE1,TABLE2,TABLE3)
LM      R5,R6,ENDT1
```

A-type constants can be particularly useful when dealing with several large tables in the same program. Normally, the instructions

```
LA      R1,TABLE
```

and

```
L       R1,=A(TABLE)
```

would have the same effect. The major difference, however, is that to use the LA, TABLE must be addressable as a displacement of the contents of the base register. Since the maximum allowable displacement is 4095, this

means that TABLE must be within 4095 bytes of the address in the active base register. On the other hand, use of the instruction

```
L        R1,=A(TABLE)
```

requires only that the literal itself be addressable. As an example, in Program 3-3, suppose that TABLE1 and TABLE2 had each contained 500 fullwords rather than 50. In that case, use of the instruction

```
LA       R4,TABLE3
```

would have caused an addressability error (since the start of TABLE3 is more than 4095 bytes past the address in the base register), while use of the instruction

```
L        R4,=A(TABLE3)
```

would have been acceptable.

## Exercises

In these first two exercises, indicate what can be determined from these two small "memory dumps";

**1.** The following dump occurred, with an indication that an addressing exception produced the actual termination:

```
PSW AT BREAK:  FF000000 9F000806

R0-7 :F4F4F4F4 0000081F 00000908 00000900 00000003 00000003 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000904 0000094C 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      4720F87C   1B33E000   F81E0050   4740F7F6      *..8@..\.8..&. 76*
000010      5350F81E   50520000   5A20F8F8   E000F81E      *.&8.&...!.88\.8.*
000020      005047F0   F00CF5F5   F5F5F5F5   F5F5F5F5      *.&.00.5555555555*
000030      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000030 - 0007E0    ARE IDENTICAL
0007F0      F5F5F5F5   F5F55B20   F8FC4130   F9005840      *555555$.8...9.. *
000800      F87C5942   F87C47B0   F80E5842   F87C8623      *8@..8@..8...8@f.*
000810      F8025240   F86EE020   F86E000C   07FEF340      *8.. 8>\.8>....3 *
000820      40404040   40404040   40404040   40404040      *                *
            LINES:   000820 - 000850    ARE IDENTICAL
000860      40404040   40404040   40404040   4040F5F5      *              55*
000870      F5F5F5F5   F5F5F5F5   F5F5F5F5   00000001      *555555555555....*
000880      00000002   00000003   F5F5F5F5   F5F5F5F5      *........55555555*
000890      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000890 - 0008E0    ARE IDENTICAL
0008F0      F5F5F5F5   F5F5F5F5   00000004   00000880      *55555555........*
000900      FFFFFFFC   F5F5F5F5   F5F5F5F5   F5F5F5F5      *....555555555555*
000910      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**2.** Similarly, the following dump was produced by an addressing exception:

```
PSW AT BREAK:  FF000000 AF000808

R0-7 :F4F4F4F4 1B33E874 1B33E000 E4CC2880 00000001 00000003 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000008F4 0000093C 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      4720F874   1B33E000   F8180050   4740F7F6      *..8...\.8..&. 76*
000010      5350F818   50520000   5A20F8F0   E000F818      *.&8.&...!.80\.8.*
000020      005047F0   F00CF5F5   F5F5F5F5   F5F5F5F5      *.&.00.5555555555*
000030      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000030 - 0007E0    ARE IDENTICAL
0007F0      F5F5F5F5   F5F54110   F8741832   58200004      *555555..8.......*
000800      1B321B44   5A410000   8712F804   5240F868      *....!...g.8.. 8.*
000810      E020F868   000C07FE   F3404040   40404040      *\.8.....3       *
000820      40404040   40404040   40404040   40404040      *                *
            LINES:   000820 - 000850    ARE IDENTICAL
000860      40404040   40404040   F5F5F5F5   F5F5F5F5      *        55555555*
000870      F5F5F5F5   00000001   00000002   00000003      *5555............*
000880      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000880 - 0008E0    ARE IDENTICAL
0008F0      00000004   F5F5F5F5   F5F5F5F5   F5F5F5F5      *....555555555555*
000900      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**3.** Write a program to perform the following tasks:

a. Read in a sequence of records, each of which contains a single integer. Store the integers in a table of fullwords. You may assume that the recordss were arranged so that each integer is at least as large as the one that preceded it.
b. Print the contents of the table.
c. Remove duplicate numbers from the table. Thus, if three consecutive words each contain the integer 4, the resulting table will contain only one word with the value 4.
d. Print the "compressed" table.

Your program should utilize three subroutines—one to read in a table of integers, one to print a table of integers, and one to compress a table of integers. The subroutines should be coded so that they could be used to read, print, or compress any table—not just the table in the program. This means that the address of this particular table must be an input parameter to each of the subroutines.

**4.** Write a program to perform the following tasks:

a. Read a sequence of records, each of which contains a single positive integer, and store the values in a table of fullwords. The end of the sequence is determined when a record containing 0 is read. The 0 should not be entered in the table.

b. Display the contents of the table.
c. Read in a sequence of records containing values that are to be stored in a second table. Again, the end of the input sequence is detected when a record containing 0 is read.
d. Display the contents of the second table.
e. Build a third table containing only those values that occur in both of the tables previously constructed.
f. Display the contents of the third table.

Your program should contain three subroutines—one to read in a sequence of integers and construct a table, one to print the values stored in a table, and one to build a table of integers that occur in both of two specified tables. You may assume that neither of the tables contains two identical entries.

**5.** Write a program to perform the following tasks:

a. Read in a sequence of records, each of which contains a single test score in the range 0 to 100. The scores should then be stored in a table of fullwords.
b. Display the scores stored in the table.
c. Rearrange the scores in the table so that they occur in descending order. This process is usually referred to as *sorting* a table.
d. Display the contents of the table again.

Your program should utilize three internal subroutines—one to read the test scores, one to display the test scores, and one to sort the scores.

A variety of algorithms can be used to sort a table. One of the simplest can be described as follows:

*Step 1.* Find the largest number in the table.
*Step 2.* Swap the first entry in the table with the largest entry.
*Step 3.* If more than one entry remains to the right of the largest number (in the unsorted section of the table), repeat the procedure for the remaining unsorted section of the table.

For example, if

4 −5 20 −10

were to be sorted, the following events would occur:

- Since 20 is the largest number, 20 and 4 will be swapped. This gives

  20 −5 4 −10

- Since 4 is the largest of the right three numbers, it will be swapped with −5. This gives

  20 4 −5 −10

- Since $-5$ is the larger of the right two entries, it will be swapped with itself (which leaves the table unaltered).
- Since only one entry remains in the unsorted section of the table ($-10$), the sort has been completed.

**6.** This exercise is identical to the preceding exercise except that a different algorithm should be used to sort the table. The algorithm for this exercise can be briefly described as follows:

For each element in the table except the leftmost, starting from the left, repeat the following step as often as possible: *If the element to the left of the given element is less than the given element, swap the two elements.*

For example, if

$$-1 \qquad 0 \qquad 32 \qquad -10 \qquad 5 \qquad 0$$

were to be sorted, the following steps would occur:

- Since $-1$ is less than 0, swap the two numbers. This gives

$$0 \qquad -1 \qquad 32 \qquad -10 \qquad 5 \qquad 0$$

- Since 32 is greater than both 0 and $-1$, it gets swapped twice. This gives

$$32 \qquad 0 \qquad -1 \qquad -10 \qquad 5 \qquad 0$$

- Since $-1$ is greater than $-10$, no swaps are necessary to move $-10$ to its proper spot in the sorted section of the table.
- Since 5 is greater than $-10$, $-1$, and 0, three swaps are necessary to move 5 to its correct location. This gives

$$32 \qquad 5 \qquad 0 \qquad -1 \qquad -10 \qquad 0$$

- Finally, two swaps are needed to move the rightmost 0 to its proper location. The result is

$$32 \qquad 5 \qquad 0 \qquad 0 \qquad -1 \qquad -10$$

**7.** Suppose that we agree to encode characters, punctuation, and the like as integers, using the following correspondence:

| *Character* | *Value* |
|---|---|
| A | 1 |
| B | 2 |
| C | 3 |
| . | . |
| . | . |
| Z | 26 |

| | |
|---|---|
| blank | 27 |
| , | 28 |
| . | 29 |
| 0 | 30 |
| 1 | 31 |
| 2 | 32 |
| . | . |
| . | . |
| 9 | 39 |

Thus, "SEE YOU AT 2." would be encoded as

19 5 5 27 25 15 21 27 1 20 27 32 29

Write the following subroutines:

- READSTR reads an encoded string into a table. Upon entrance, R2 must have the address of the table. Each input record will contain one integer. The routine should stop reading when it encounters a 0. (0 marks the end of a string.) R3 is the only altered register; it is set to the length of the string (the number of integers in it). If end-of-file occurs before reaching a 0, R3 should be set to 0.
- COMPSTR compares two strings. Upon entrance, R2 points to one string and R4 points to a second string. R3 contains the number of characters to compare. R6 is the only altered register. It is set to 0 if the strings match. Otherwise, it is set to 1.
- FINDSTR searches through a string, looking for a given substring. Upon entrance, R2 contains the address of the string and R3 contains the length of the string. R4 contains the address of the substring and R5 contains its length. R6 is the only altered register; it is set to the address of the first occurrence of the substring in a given string (or to 0, if there are no such occurrences).

Now write a program that performs the following actions until end-of-file occurs:

a. Read in a string (call this the "message").
b. Read in a second string (call this the "word").
c. XDUMP both the message and the word.
d. Find the first occurrence of the word in the message.
e. XDUMP the address.

When you have finished, take time to reflect. You could now write routines to encode/decode messages using complex arithmetic functions (for security purposes). By constructing a library of routines, you could build up all of the functions required for "text processing." If you became worried about memory space, you could store each integer in a single byte.

# 4

# Rounding Out the Essentials

## 4.1 THE SPACE, EJECT, AND TITLE INSTRUCTIONS

There are several assembler instructions that the programmer should make frequent use of to improve the readability of a program listing. SPACE, EJECT, and TITLE are instructions that generate no object code, and so in no way affect the execution of the program. They do, however, alter the format of the printed listing that the assembler produces.

The SPACE instruction

```
SPACE    n
```

causes n blank lines to be inserted into the assembler listing at that point in the source code. If n is omitted, it is assumed to be 1. If there are fewer than n lines left on a page of the listing, it will cause a skip to the top of the next page.

The EJECT instruction

```
EJECT
```

skips the assembler listing to the top of the next page.

The TITLE instruction

```
TITLE    'header'
```

causes the following to happen:

1. The assembler listing skips to the top of the next page.
2. The "header" prints at the top of the new page as well as at the top of all following pages until another TITLE command is encountered. Apostrophes and ampersands may be used in the header by following the same convention as for a DC statement: To have one apostrophe or ampersand printed, code two of them adjacent in the header.

Every assembler program should contain at least one TITLE instruction, make frequent use of the SPACE instruction to accent breaks in logic, and contain occasional instances of the EJECT instruction to indicate major breaks in logic. The short time required to insert these instructions will be more than offset by the increased readability of the program listing.

Program 4-1 is intended to illustrate the techniques discussed in this section. This program is a recoded version of the program that appears in Appendix A. A listing of the source program has been included along with the actual program listing so that the positions of the SPACE, TITLE, and EJECT cards may be observed. Carefully examine both of these listings and observe the improvements that have been obtained through the use of these simple techniques.

**Program 4-1**

```
         TITLE 'PROGRAM ILLUSTRATING SUBROUTINES - MAIN PROGRAM'
*********************************************************************
*
* THIS PROGRAM ILLUSTRATES THE USE OF SUBROUTINES.  THE PROGRAM
*
*        1) READS A SET OF NUMBERS INTO 'TABLE1'.  IT IS
*           ASSUMED THAT THE INPUT VALUES HAVE BEEN SORTED INTO
*           ASCENDING ORDER.
*
*        2) PRINTS OUT THE NUMBERS IN 'TABLE1'.
*
*        3) READS IN A SECOND SET OF NUMBERS INTO 'TABLE2'.
*
*        4) PRINTS OUT THE NUMBERS IN 'TABLE2'.
*
*        5) MERGES THE NUMBERS IN THE TWO TABLES INTO 'TABLE3'.
*
*        6) PRINTS OUT THE NUMBERS IN 'TABLE3'.
*
* THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*        STEP 1.  CALL 'READ' TO READ IN THE FIRST TABLE.  THIS WILL
*                 REQUIRE PASSING TO 'READ' THE ADDRESS OF THE TABLE
*                 TO FILL.  THE 'READ' ROUTINE WILL RETURN THE ADDRESS
*                 OF THE LAST ENTRY, WHICH IS STORED IN 'ENDT1'.
*
*        STEP 2.  CALL 'PRINT' TO PRINT OUT THE VALUES IN 'TABLE1'.
*
*        STEP 3.  CALL 'READ' TO READ IN THE VALUES FOR 'TABLE2', AND
*                 SAVE THE ADDRESS OF THE LAST ENTRY IN 'ENDT2'.
*
*        STEP 4.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE2'.
*
*        STEP 5.  CALL 'MERGE' TO MERGE THE VALUES IN 'TABLE1' AND
*                 'TABLE2' INTO 'TABLE3'.
*
*        STEP 6.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE3'.
*
*        STEP 7.  EXIT.
*
*********************************************************************
         SPACE 3
MAINPROG CSECT
         USING MAINPROG,R15
*
***<STEP 1>    READ IN THE VALUES FOR 'TABLE1'.
*
         LA    R2,TABLE1          R2 IS USED TO PASS THE ADDRESS OF
*                                 WHERE THE VALUES ARE TO BE STORED
```

**Program 4-1 (continued)**

```
         BAL   R10,READ            READ IN 'TABLE1'
         ST    R3,ENDT1            SAVE THE ADDRESS OF THE LAST VALUE
*
***<STEP 2>    PRINT OUT THE VALUES IN 'TABLE1'.
*
         BAL   R10,PRINT           R2 MUST HAVE ADDRESS OF 'TABLE1' AND
*                                  R3 MUST HAVE ADDRESS OF LAST ENTRY

         SPACE 2
*
***<STEP 3>    READ IN THE VALUES FOR 'TABLE2'.
*
         LA    R2,TABLE2           POINT TO THE SECOND TABLE
         BAL   R10,READ            READ IN THE VALUES
         ST    R3,ENDT2            SAVE ADDRESS OF LAST ENTRY
*
***<STEP 4>    PRINT OUT THE VALUES IN 'TABLE2'.
*
         BAL   R10,PRINT
         SPACE 2
*
***<STEP 5>    NOW MERGE THE TWO TABLES INTO 'TABLE3'.
*
         LA    R2,TABLE1           R2 <- ADDRESS OF FIRST TABLE
         LA    R3,TABLE2           R3 <- ADDRESS OF SECOND TABLE
         LA    R4,TABLE3           R4 <- ADDRESS OF TABLE TO BUILD
*
         L     R5,ENDT1            R5 <- ADDRESS OF LAST ENTRY IN TABLE1
         L     R6,ENDT2            R6 <- ADDRESS OF LAST ENTRY IN TABLE2
*
         BAL   R10,MERGE           NOW MERGE THE TWO TABLES
*
***<STEP 6>    PRINT OUT THE CONTENTS OF 'TABLE3'.
*
         LA    R2,TABLE3
         LR    R3,R7               'MERGE' PUT ADDRESS OF LAST ENTRY
*                                  INTO R7
         BAL   R10,PRINT           NOW PRINT THE MERGED TABLE
*
***<STEP 7>    EXIT.
*
         BR    R14
*
         SPACE 5
*****************************************************************
*
*              STORAGE AREAS FOR THE MAIN ROUTINE
*
*****************************************************************
*
         LTORG
ENDT1    DS    F                   ADDRESS OF LAST ENTRY IN TABLE1
ENDT2    DS    F                   ADDRESS OF LAST ENTRY IN TABLE2
TABLE1   DS    50F                 BUILD THE FIRST TABLE HERE
TABLE2   DS    50F                 AND THE SECOND TABLE HERE
TABLE3   DS    100F                AND THE MERGED TABLE HERE
*
```

**Program 4-1 (continued)**

```
         TITLE 'SUBROUTINES - READ, PRINT, AND MERGE'
*****************************************************************
*
*                        READ ROUTINE
*
* THIS IS THE READ ROUTINE.  WHEN IT IS ENTERED, R2 CONTAINS THE
* ADDRESS OF THE TABLE TO BE FILLED.  EACH DATA CARD CONTAINS ONE
* NUMBER. END OF THE TABLE IS DESIGNATED BY A CARD CONTAINING
* 999999.  UPON EXITING, R3 CONTAINS THE ADDRESS OF THE LAST ENTRY
* OF THE TABLE.  NO OTHER REGISTERS ARE ALTERED.  R10 IS THE LINK
* REGISTER.
*
*
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  READ THE NEXT CARD AND GET THE VALUE OFF IT.
*
*        STEP 2.  IF THE VALUE ON THE CARD IS 999999, GO TO STEP 5.
*
*        STEP 3.  STORE THE VALUE INTO THE TABLE BEING BUILT.
*                 INCREMENT THE POINTER TO WHERE THE NEXT VALUE GOES.
*
*        STEP 4.  READ THE NEXT CARD, GET THE VALUE OFF IT, AND GO
*                 BACK TO STEP 2.
*
*        STEP 5.  SET R3 TO POINT TO THE LAST ENTRY.
*
*        STEP 6.  EXIT.
*
*****************************************************************
         SPACE 3
READ     STM   R4,R2,READSAVE      SAVE ALL REGS EXCEPT R3
*
***<STEP 1>    READ THE NEXT CARD AND GET THE VALUE OFF IT.
*
         XREAD CARD,80             IT IS ASSUMED THAT THERE IS A CARD
         XDECI R4,CARD             AND THAT THE NUMBER IS VALID
*
***<STEP 2>    TEST FOR END OF LOOP (VALUE OF 999999).
*
READLOOP C     R4,=F'999999'
         BE    SETLAST             BRANCH IF END OF INPUT VALUES
*
***<STEP 3>    STORE VALUE INTO TABLE AND INCREMENT NEXT ENTRY POINTER.
*
         ST    R4,0(R2)            STORE ENTRY
         LA    R2,4(R2)            POINT TO NEXT ENTRY
*
***<STEP 4>    READ THE NEXT CARD, GET VALUE, AND GO TO STEP 2.
*
         XREAD CARD,80             READ THE CARD
         XDECI 4,CARD              AND GET THE VALUE
         B     READLOOP
```

**Program 4-1 (continued)**

```
*
***<STEP 5>    SET POINTER TO LAST ENTRY.
*
SETLAST  LR    R3,R2                R2 HAS ADDRESS OF "NEXT ENTRY"
         S     R3,=F'4'             R3 NOW POINTS TO LAST ENTRY
*
***<STEP 6>    RETURN TO CALLER.
*
         LM    R4,R2,READSAVE       RESTORE ALL REGISTERS BUT R3
         BR    R10                  AND RETURN
*
         LTORG
*
CARD     DS    CL80                 CARD INPUT AREA
*
READSAVE DS    15F                  ROOM FOR ALL REGISTERS, EXCEPT R3
*
         SPACE 5
*******************************************************************
*
*                       PRINT ROUTINE
*
* THIS ROUTINE PRINTS OUT THE VALUES IN THE TABLE POINTED TO BY
* R2.  R3 MUST CONTAIN THE ADDRESS OF THE LAST ENTRY IN THE TABLE.
* R10 IS THE LINK REGISTER.  ENTRIES ARE PRINTED OUT 1 PER LINE.
* NO REGISTERS ARE ALTERED BY A CALL TO THIS ROUTINE.
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  PRINT A HEADING.
*
*        STEP 2.  IF ALL OF THE ENTRIES HAVE BEEN PRINTED, GO
*                 TO STEP 4.
*
*        STEP 3.  PRINT ONE ENTRY, INCREMENT POINTER TO NEXT ENTRY,
*                 AND GO BACK TO STEP 2.
*
*        STEP 4.  PRINT "END OF TABLE" MESSAGE.
*
*        STEP 5.  EXIT.
*
*******************************************************************
         SPACE 3
PRINT    STM   R0,R15,PRINTSAV      SAVE ALL OF THE REGISTERS
*
***<STEP 1>    PRINT A HEADING.
*
         XPRNT =C'0*** START OF TABLE ***',23
*
***<STEP 2>    CHECK FOR END OF TABLE.
*
PRINTLP  CR    R2,R3                COMPARE CURRENT AGAINST LAST
         BH    PRINTEND             BRANCH IF PAST LAST ENTRY
*
***<STEP 3>    PRINT ONE ENTRY AND GO BACK TO STEP 2.
*
         L     R4,0(R2)             GET A VALUE FROM THE TABLE
         XDECO R4,OUTVAL            CONVERT TO PRINTABLE FORMAT
         XPRNT PRNTLINE,13          PRINT IT
*
         LA    R2,4(R2)             INCREMENT POINTER TO NEXT ENTRY
         B     PRINTLP
*
***<STEP 4>    PRINT "END OF TABLE" MESSAGE.
*
PRINTEND XPRNT =C'0*** END OF TABLE ***',21
*
```

**Program 4-1 (continued)**

```
***<STEP 5>    EXIT.
*
         LM    R0,R15,PRINTSAV     RESTORE ALL REGISTERS
         BR    R10                 EXIT
*
         LTORG
*
PRNTLINE DC    C' '                CARRIAGE CONTROL
OUTVAL   DS    CL12                OUTPUT THE VALUES HERE
*
PRINTSAV DS    16F                 SAVE REGISTERS HERE
         EJECT
*********************************************************************
*
*                       MERGE ROUTINE
*
* THIS ROUTINE MERGES THE TWO SORTED TABLES INTO A THIRD TABLE.  UPON
* ENTRANCE
*
*        R2 = ADDRESS OF FIRST TABLE
*        R3 = ADDRESS OF SECOND TABLE
*        R4 = ADDRESS OF THIRD TABLE
*        R5 = ADDRESS OF LAST ENTRY IN FIRST TABLE
*        R6 = ADDRESS OF LAST ENTRY IN SECOND TABLE
*
* THE ROUTINE WILL SET R7 TO THE ADDRESS OF THE LAST ENTRY IN THE
* THIRD TABLE, WHICH IS PRODUCED BY MERGING THE FIRST TWO TABLES.
* R10 IS THE LINK REGISTER.  ONLY R7 IS ALTERED BY A CALL TO THIS
* ROUTINE.
*
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  IF ALL VALUES FROM BOTH TABLES ARE IN THE THIRD
*                 TABLE, GO TO STEP 6.
*
*        STEP 2.  IF (ALL VALUES IN TABLE2 ARE ALREADY IN TABLE3 OR
*                    (SOME VALUES IN TABLE1 HAVE NOT YET BEEN
*                     MOVED AND THE NEXT ONE FROM TABLE1 IS LESS
*                     THAN THE NEXT ONE FROM TABLE2)), GO TO STEP 3.
*                     ELSE, GO TO STEP 4.
*
*        STEP 3.  MOVE A VALUE FROM TABLE1 TO TABLE3, UPDATING THE
*                 POINTER TO THE NEXT ENTRY IN TABLE1.  GO TO STEP 5.
*
*        STEP 4.  MOVE A VALUE FROM TABLE2 TO TABLE3, UPDATING THE
*                 POINTER TO THE NEXT ENTRY IN TABLE2.
*
*        STEP 5.  UPDATE THE POINTER TO THE NEXT ENTRY IN TABLE3 AND
*                 GO BACK TO STEP 1.
*
*        STEP 6.  SET R7 TO POINT TO THE LAST ENTRY IN TABLE3.
*
*        STEP 7.  EXIT.
*
*********************************************************************
         SPACE 3
MERGE    STM   R8,R6,MERGESAV      SAVE ALL REGS, EXCEPT R7
*
***<STEP 1>    BRANCH TO STEP 6, IF ALL ENTRIES HAVE BEEN MOVED.
*
MERGELP  CR    R2,R5
         BNH   SOMELEFT            BRANCH IF NOT ALL OF TABLE1 HAS
*                                  BEEN MOVED
         CR    R3,R6
         BH    POINTR7             BRANCH IF ALL ENTRIES HAVE BEEN
*                                  MOVED TO TABLE3
         SPACE 2
```

**Program 4-1 (continued)**

```
*
***<STEP 2>     FIGURE OUT WHICH TABLE THE NEXT ENTRY COMES FROM.
*
SOMELEFT CR     R3,R6
         BH     FROMT1              BRANCH IF TABLE2 EXHAUSTED
*
         CR     R2,R5
         BH     FROMT2              BRANCH IF TABLE1 EXHAUSTED
*
         L      R8,0(R2)            R8 <- NEXT ENTRY FROM TABLE1
         C      R8,0(R3)
         BH     FROMT2              BRANCH IF T1'S ENTRY IS HIGH
         SPACE 2
*
***<STEP 3>     MOVE ENTRY FROM TABLE1 TO TABLE3.
*
FROMT1   L      R8,0(R2)            LOAD ENTRY FROM TABLE1
         ST     R8,0(R4)            STORE INTO TABLE3
         LA     R2,4(R2)            INCREMENT POINTER INTO TABLE1
         B      INCRT3              GO INCREMENT TABLE3'S POINTER
*
***<STEP 4>     MOVE ENTRY FROM TABLE2 TO TABLE3.
*
FROMT2   L      R8,0(R3)            LOAD ENTRY FROM TABLE2
         ST     R8,0(R4)            AND PUT IT INTO TABLE3
         LA     R3,4(R3)            INCREMENT POINTER INTO TABLE2
*
***<STEP 5>     INCREMENT TABLE3'S POINTER AND GO BACK TO STEP 1.
*
INCRT3   LA     R4,4(R4)            INCREMENT POINTER TO NEXT ENTRY
*                                   FOR TABLE3
         B      MERGELP
*
***<STEP 6>     POINT R7 AT LAST ENTRY IN TABLE3.
*
POINTR7  LR     R7,R4               R4 POINTS JUST PAST LAST ENTRY
         S      R7,=F'4'            NOW R7 POINTS AT LAST ENTRY
*
***<STEP 7>     EXIT.
*
         LM     R8,R6,MERGESAV      RESTORE ALL REGISTERS BUT R7
         BR     R10                 AND RETURN
*
MERGESAV DS     15F                 REGISTER SAVEAREA
         SPACE 5
         LTORG
R0       EQU    0
R1       EQU    1
R2       EQU    2
R3       EQU    3
R4       EQU    4
R5       EQU    5
R6       EQU    6
R7       EQU    7
R8       EQU    8
R9       EQU    9
R10      EQU    10
R11      EQU    11
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
         END    MAINPROG
```

**Program 4-1 (Second version)**

```
     PROGRAM ILLUSTRATING SUBROUTINES - MAIN PROGRAM                                                    PAGE    1

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                   2 ***********************************************************************
                                   3 *
                                   4 * THIS PROGRAM ILLUSTRATES THE USE OF SUBROUTINES.  THE PROGRAM
                                   5 *
                                   6 *        1) READS A SET OF NUMBERS INTO 'TABLE1'.  IT IS
                                   7 *           ASSUMED THAT THE INPUT VALUES HAVE BEEN SORTED INTO
                                   8 *           ASCENDING ORDER.
                                   9 *
                                  10 *        2) PRINTS OUT THE NUMBERS IN 'TABLE1'.
                                  11 *
                                  12 *        3) READS IN A SECOND SET OF NUMBERS INTO 'TABLE2'.
                                  13 *
                                  14 *        4) PRINTS OUT THE NUMBERS IN 'TABLE2'.
                                  15 *
                                  16 *        5) MERGES THE NUMBERS IN THE TWO TABLES INTO 'TABLE3'.
                                  17 *
                                  18 *        6) PRINTS OUT THE NUMBERS IN 'TABLE3'.
                                  19 *
                                  20 * THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
                                  21 *
                                  22 *        STEP 1.  CALL 'READ' TO READ IN THE FIRST TABLE.  THIS WILL
                                  23 *                 REQUIRE PASSING TO 'READ' THE ADDRESS OF THE TABLE
                                  24 *                 TO FILL.  THE 'READ' ROUTINE WILL RETURN THE ADDRESS
                                  25 *                 OF THE LAST ENTRY, WHICH IS STORED IN 'ENDT1'.
                                  26 *
                                  27 *        STEP 2.  CALL 'PRINT' TO PRINT OUT THE VALUES IN 'TABLE1'.
                                  28 *
                                  29 *        STEP 3.  CALL 'READ' TO READ IN THE VALUES FOR 'TABLE2', AND
                                  30 *                 SAVE THE ADDRESS OF THE LAST ENTRY IN 'ENDT2'.
                                  31 *
                                  32 *        STEP 4.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE2'.
                                  33 *
                                  34 *        STEP 5.  CALL 'MERGE' TO MERGE THE VALUES IN 'TABLE1' AND
                                  35 *                 'TABLE2' INTO 'TABLE3'.
                                  36 *
                                  37 *        STEP 6.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE3'.
                                  38 *
                                  39 *        STEP 7.  EXIT.
                                  40 *
                                  41 ***********************************************************************


000000                            43 MAINPROG CSECT
000000                            44          USING MAINPROG,R15
                                  45 *
```

```
                                    46 ***<STEP 1>    READ IN THE VALUES FOR 'TABLE1'.
                                    47 *
000000 4120 F050            00050   48          LA    R2,TABLE1          R2 IS USED TO PASS THE ADDRESS OF
                                    49 *                                 WHERE THE VALUES ARE TO BE STORED
000004 45A0 F370            00370   50          BAL   R10,READ           READ IN 'TABLE1'

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
000008 5030 F048            00048   51          ST    R3,ENDT1           SAVE THE ADDRESS OF THE LAST VALUE
                                    52 *
                                    53 ***<STEP 2>    PRINT OUT THE VALUES IN 'TABLE1'.
                                    54 *
00000C 45A0 F43C            0043C   55          BAL   R10,PRINT          R2 MUST HAVE ADDRESS OF 'TABLE1' AND
                                    56 *                                 R3 MUST HAVE ADDRESS OF LAST ENTRY


                                    58 *
                                    59 ***<STEP 3>    READ IN THE VALUES FOR 'TABLE2'.
                                    60 *
000010 4120 F118            00118   61          LA    R2,TABLE2          POINT TO THE SECOND TABLE
000014 45A0 F370            00370   62          BAL   R10,READ           READ IN THE VALUES
000018 5030 F04C            0004C   63          ST    R3,ENDT2           SAVE ADDRESS OF LAST ENTRY
                                    64 *
                                    65 ***<STEP 4>    PRINT OUT THE VALUES IN 'TABLE2'.
                                    66 *
00001C 45A0 F43C            0043C   67          BAL   R10,PRINT


                                    69 *
                                    70 ***<STEP 5>    NOW MERGE THE TWO TABLES INTO 'TABLE3'.
                                    71 *
000020 4120 F050            00050   72          LA    R2,TABLE1          R2 <- ADDRESS OF FIRST TABLE
000024 4130 F118            00118   73          LA    R3,TABLE2          R3 <- ADDRESS OF SECOND TABLE
000028 4140 F1E0            001E0   74          LA    R4,TABLE3          R4 <- ADDRESS OF TABLE TO BUILD
                                    75 *
00002C 5850 F048            00048   76          L     R5,ENDT1           R5 <- ADDRESS OF LAST ENTRY IN TABLE1
000030 5860 F04C            0004C   77          L     R6,ENDT2           R6 <- ADDRESS OF LAST ENTRY IN TABLE2
                                    78 *
000034 45A0 F4EC            004EC   79          BAL   R10,MERGE          NOW MERGE THE TWO TABLES
                                    80 *
                                    81 ***<STEP 6>    PRINT OUT THE CONTENTS OF 'TABLE3'.
                                    82 *
000038 4120 F1E0            001E0   83          LA    R2,TABLE3
00003C 1837                         84          LR    R3,R7              'MERGE' PUT ADDRESS OF LAST ENTRY
                                    85 *                                 INTO R7
00003E 45A0 F43C            0043C   86          BAL   R10,PRINT          NOW PRINT THE MERGED TABLE
                                    87 *
                                    88 ***<STEP 7>    EXIT.
                                    89 *
000042 07FE                         90          BR    R14
                                    91 *
```

```
                                  93 ***********************************************************************
                                  94 *
                                  95 *                STORAGE AREAS FOR THE MAIN ROUTINE
                                  96 *
                                  97 ***********************************************************************
                                  98 *
                                  99          LTORG
  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
000048                            100 ENDT1    DS    F                ADDRESS OF LAST ENTRY IN TABLE1
00004C                            101 ENDT2    DS    F                ADDRESS OF LAST ENTRY IN TABLE2
000050                            102 TABLE1   DS    50F              BUILD THE FIRST TABLE HERE
000118                            103 TABLE2   DS    50F              AND THE SECOND TABLE HERE
0001E0                            104 TABLE3   DS    100F             AND THE MERGED TABLE HERE
                                  105 *
```

```
LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                 107 ***********************************************************************
                                 108 *
                                 109 *                        READ ROUTINE
                                 110 *
                                 111 * THIS IS THE READ ROUTINE.  WHEN IT IS ENTERED, R2 CONTAINS THE
                                 112 * ADDRESS OF THE TABLE TO BE FILLED.  EACH DATA CARD CONTAINS ONE
                                 113 * NUMBER. END OF THE TABLE IS DESIGNATED BY A CARD CONTAINING
                                 114 * 999999.  UPON EXITING, R3 CONTAINS THE ADDRESS OF THE LAST ENTRY
                                 115 * OF THE TABLE.  NO OTHER REGISTERS ARE ALTERED.  R10 IS THE LINK
                                 116 * REGISTER.
                                 117 *
                                 118 *
                                 119 * THE LOGIC IS AS FOLLOWS:
                                 120 *
                                 121 *        STEP 1.  READ THE NEXT CARD AND GET THE VALUE OFF IT.
                                 122 *
                                 123 *        STEP 2.  IF THE VALUE ON THE CARD IS 999999, GO TO STEP 5.
                                 124 *
                                 125 *        STEP 3.  STORE THE VALUE INTO THE TABLE BEING BUILT.
                                 126 *                 INCREMENT THE POINTER TO WHERE THE NEXT VALUE GOES.
                                 127 *
                                 128 *        STEP 4.  READ THE NEXT CARD, GET THE VALUE OFF IT, AND GO
                                 129 *                 BACK TO STEP 2.
                                 130 *
                                 131 *        STEP 5.  SET R3 TO POINT TO THE LAST ENTRY.
                                 132 *
                                 133 *        STEP 6.  EXIT.
                                 134 *
                                 135 ***********************************************************************


000370 9042 F400            00400  137 READ     STM   R4,R2,READSAVE     SAVE ALL REGS EXCEPT R3
                                   138 *
                                   139 ***<STEP 1>    READ THE NEXT CARD AND GET THE VALUE OFF IT.
                                   140 *
000374 E000 F3B0 0050 003B0        141          XREAD CARD,80            IT IS ASSUMED THAT THERE IS A CARD
00037A 5340 F3B0            003B0  142          XDECI R4,CARD            AND THAT THE NUMBER IS VALID
                                   143 *
                                   144 ***<STEP 2>    TEST FOR END OF LOOP (VALUE OF 999999).
                                   145 *
00037E 5940 F3A8            003A8  146 READLOOP C     R4,=F'999999'
000382 4780 F39C            0039C  147          BE    SETLAST            BRANCH IF END OF INPUT VALUES
                                   148 *
                                   149 ***<STEP 3>    STORE VALUE INTO TABLE AND INCREMENT NEXT ENTRY POINTER.
                                   150 *
000386 5042 0000            00000  151          ST    R4,0(R2)           STORE ENTRY
00038A 4122 0004            00004  152          LA    R2,4(R2)           POINT TO NEXT ENTRY
                                   153 *
                                   154 ***<STEP 4>    READ THE NEXT CARD, GET VALUE, AND GO TO STEP 2.
                                   155 *
00038E E000 F3B0 0050 003B0        156          XREAD CARD,80            READ THE CARD
000394 5340 F3B0            003B0  157          XDECI 4,CARD             AND GET THE VALUE
000398 47F0 F37E            0037E  158          B     READLOOP
                                   159 *
```

```
LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                 160 ***<STEP 5>    SET POINTER TO LAST ENTRY.
                                 161 *
00039C 1832                      162 SETLAST  LR    R3,R2              R2 HAS ADDRESS OF "NEXT ENTRY"
00039E 5B30 F3AC          003AC  163          S     R3,=F'4'           R3 NOW POINTS TO LAST ENTRY
                                 164 *
                                 165 ***<STEP 6>    RETURN TO CALLER.
                                 166 *
0003A2 9842 F400          00400  167          LM    R4,R2,READSAVE     RESTORE ALL REGISTERS BUT R3
0003A6 07FA                      168          BR    R10                AND RETURN
                                 169 *
                                 170          LTORG
0003A8 000F423F                  171                =F'999999'
0003AC 00000004                  172                =F'4'
                                 173 *
0003B0                           174 CARD     DS    CL80               CARD INPUT AREA
                                 175 *
000400                           176 READSAVE DS    15F                ROOM FOR ALL REGISTERS, EXCEPT R3
                                 177 *


                                 179 ***********************************************************************
                                 180 *
                                 181 *                        PRINT ROUTINE
                                 182 *
                                 183 * THIS ROUTINE PRINTS OUT THE VALUES IN THE TABLE POINTED TO BY
                                 184 * R2.  R3 MUST CONTAIN THE ADDRESS OF THE LAST ENTRY IN THE TABLE.
                                 185 * R10 IS THE LINK REGISTER.  ENTRIES ARE PRINTED OUT 1 PER LINE.
                                 186 * NO REGISTERS ARE ALTERED BY A CALL TO THIS ROUTINE.
                                 187 * THE LOGIC IS AS FOLLOWS:
                                 188 *
                                 189 *        STEP 1.  PRINT A HEADING.
                                 190 *
                                 191 *        STEP 2.  IF ALL OF THE ENTRIES HAVE BEEN PRINTED, GO
                                 192 *                 TO STEP 4.
                                 193 *
                                 194 *        STEP 3.  PRINT ONE ENTRY, INCREMENT POINTER TO NEXT ENTRY,
                                 195 *                 AND GO BACK TO STEP 2.
                                 196 *
                                 197 *        STEP 4.  PRINT "END OF TABLE" MESSAGE.
                                 198 *
                                 199 *        STEP 5.  EXIT.
                                 200 *
                                 201 ***********************************************************************


00043C 900F F4AC          004AC  203 PRINT    STM   R0,R15,PRINTSAV    SAVE ALL OF THE REGISTERS
                                 204 *
                                 205 ***<STEP 1>    PRINT A HEADING.
                                 206 *
000440 E020 F470 0017 00470      207          XPRNT =C'0*** START OF TABLE ***',23
                                 208 *
```

```
 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                 209 ***<STEP 2>    CHECK FOR END OF TABLE.
                                 210 *
000446 1923                      211 PRINTLP  CR    R2,R3              COMPARE CURRENT AGAINST LAST
000448 4720 F462            00462 212         BH    PRINTEND           BRANCH IF PAST LAST ENTRY
                                 213 *
                                 214 ***<STEP 3>    PRINT ONE ENTRY AND GO BACK TO STEP 2.
                                 215 *
00044C 5842 0000            00000 216         L     R4,0(R2)           GET A VALUE FROM THE TABLE
000450 5240 F49D            0049D 217         XDECO R4,OUTVAL          CONVERT TO PRINTABLE FORMAT
000454 E020 F49C 000D 0049C      218         XPRNT PRNTLINE,13        PRINT IT
                                 219 *
00045A 4122 0004            00004 220         LA    R2,4(R2)           INCREMENT POINTER TO NEXT ENTRY
00045E 47F0 F446            00446 221         B     PRINTLP
                                 222 *
                                 223 ***<STEP 4>    PRINT "END OF TABLE" MESSAGE.
                                 224 *
000462 E020 F487 0015 00487      225 PRINTEND XPRNT =C'0*** END OF TABLE ***',21
                                 226 *
                                 227 ***<STEP 5>    EXIT.
                                 228 *
000468 980F F4AC            004AC 229         LM    R0,R15,PRINTSAV    RESTORE ALL REGISTERS
00046C 07FA                      230         BR    R10                EXIT
                                 231 *
                                 232         LTORG
000470 F05C5C5C40E2E3C1          233               =C'0*** START OF TABLE ***'
000487 F05C5C5C40C5D5C4          234               =C'0*** END OF TABLE ***'
                                 235 *
00049C 40                        236 PRNTLINE DC    C' '               CARRIAGE CONTROL
00049D                           237 OUTVAL   DS    CL12               OUTPUT THE VALUES HERE
                                 238 *
0004AC                           239 PRINTSAV DS    16F                SAVE REGISTERS HERE
```

```
LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT

                                 241 ***********************************************************************
                                 242 *
                                 243 *                        MERGE ROUTINE
                                 244 *
                                 245 * THIS ROUTINE MERGES THE TWO SORTED TABLES INTO A THIRD TABLE.  UPON
                                 246 * ENTRANCE
                                 247 *
                                 248 *        R2 = ADDRESS OF FIRST TABLE
                                 249 *        R3 = ADDRESS OF SECOND TABLE
                                 250 *        R4 = ADDRESS OF THIRD TABLE
                                 251 *        R5 = ADDRESS OF LAST ENTRY IN FIRST TABLE
                                 252 *        R6 = ADDRESS OF LAST ENTRY IN SECOND TABLE
                                 253 *
                                 254 * THE ROUTINE WILL SET R7 TO THE ADDRESS OF THE LAST ENTRY IN THE
                                 255 * THIRD TABLE, WHICH IS PRODUCED BY MERGING THE FIRST TWO TABLES.
                                 256 * R10 IS THE LINK REGISTER.  ONLY R7 IS ALTERED BY A CALL TO THIS
                                 257 * ROUTINE.
                                 258 *
                                 259 * THE LOGIC IS AS FOLLOWS:
                                 260 *
                                 261 *        STEP 1.  IF ALL VALUES FROM BOTH TABLES ARE IN THE THIRD
                                 262 *                 TABLE, GO TO STEP 6.
                                 263 *
                                 264 *        STEP 2.  IF (ALL VALUES IN TABLE2 ARE ALREADY IN TABLE3 OR
                                 265 *                    (SOME VALUES IN TABLE1 HAVE NOT YET BEEN
                                 266 *                     MOVED AND THE NEXT ONE FROM TABLE1 IS LESS
                                 267 *                     THAN THE NEXT ONE FROM TABLE2)), GO TO STEP 3.
                                 268 *                     ELSE, GO TO STEP 4.
                                 269 *
                                 270 *        STEP 3.  MOVE A VALUE FROM TABLE1 TO TABLE3, UPDATING THE
                                 271 *                 POINTER TO THE NEXT ENTRY IN TABLE1.  GO TO STEP 5.
                                 272 *
                                 273 *        STEP 4.  MOVE A VALUE FROM TABLE2 TO TABLE3, UPDATING THE
                                 274 *                 POINTER TO THE NEXT ENTRY IN TABLE2.
                                 275 *
                                 276 *        STEP 5.  UPDATE THE POINTER TO THE NEXT ENTRY IN TABLE3 AND
                                 277 *                 GO BACK TO STEP 1.
                                 278 *
                                 279 *        STEP 6.  SET R7 TO POINT TO THE LAST ENTRY IN TABLE3.
                                 280 *
                                 281 *        STEP 7.  EXIT.
                                 282 *
                                 283 ***********************************************************************


0004EC 9086 F544          00544  285 MERGE    STM   R8,R6,MERGESAV     SAVE ALL REGS, EXCEPT R7
                                 286 *
                                 287 ***<STEP 1>    BRANCH TO STEP 6, IF ALL ENTRIES HAVE BEEN MOVED.
                                 288 *
0004F0 1925                      289 MERGELP  CR    R2,R5
0004F2 47D0 F4FC          004FC  290          BNH   SOMELEFT           BRANCH IF NOT ALL OF TABLE1 HAS
                                 291 *                                  BEEN MOVED
```

```
 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
0004F6 1936                       292          CR    R3,R6
0004F8 4720 F538            00538 293          BH    POINTR7            BRANCH IF ALL ENTRIES HAVE BEEN
                                  294 *                                 MOVED TO TABLE3


                                  296 *
                                  297 ***<STEP 2>    FIGURE OUT WHICH TABLE THE NEXT ENTRY COMES FROM.
                                  298 *
0004FC 1936                       299 SOMELEFT CR    R3,R6
0004FE 4720 F514            00514 300          BH    FROMT1             BRANCH IF TABLE2 EXHAUSTED
                                  301 *
000502 1925                       302          CR    R2,R5
000504 4720 F524            00524 303          BH    FROMT2             BRANCH IF TABLE1 EXHAUSTED
                                  304 *
000508 5882 0000            00000 305          L     R8,0(R2)           R8 <- NEXT ENTRY FROM TABLE1
00050C 5983 0000            00000 306          C     R8,0(R3)
000510 4720 F524            00524 307          BH    FROMT2             BRANCH IF T1'S ENTRY IS HIGH


                                  309 *
                                  310 ***<STEP 3>    MOVE ENTRY FROM TABLE1 TO TABLE3.
                                  311 *
000514 5882 0000            00000 312 FROMT1   L     R8,0(R2)           LOAD ENTRY FROM TABLE1
000518 5084 0000            00000 313          ST    R8,0(R4)           STORE INTO TABLE3
00051C 4122 0004            00004 314          LA    R2,4(R2)           INCREMENT POINTER INTO TABLE1
000520 47F0 F530            00530 315          B     INCRT3             GO INCREMENT TABLE3'S POINTER
                                  316 *
                                  317 ***<STEP 4>    MOVE ENTRY FROM TABLE2 TO TABLE3.
                                  318 *
000524 5883 0000            00000 319 FROMT2   L     R8,0(R3)           LOAD ENTRY FROM TABLE2
000528 5084 0000            00000 320          ST    R8,0(R4)           AND PUT IT INTO TABLE3
00052C 4133 0004            00004 321          LA    R3,4(R3)           INCREMENT POINTER INTO TABLE2
                                  322 *
                                  323 ***<STEP 5>    INCREMENT TABLE3'S POINTER AND GO BACK TO STEP 1.
                                  324 *
000530 4144 0004            00004 325 INCRT3   LA    R4,4(R4)           INCREMENT POINTER TO NEXT ENTRY
                                  326 *                                 FOR TABLE3
000534 47F0 F4F0            004F0 327          B     MERGELP
                                  328 *
                                  329 ***<STEP 6>    POINT R7 AT LAST ENTRY IN TABLE3.
                                  330 *
000538 1874                       331 POINTR7  LR    R7,R4              R4 POINTS JUST PAST LAST ENTRY
00053A 5B70 F580            00580 332          S     R7,=F'4'           NOW R7 POINTS AT LAST ENTRY
                                  333 *
                                  334 ***<STEP 7>    EXIT.
                                  335 *
00053E 9886 F544            00544 336          LM    R8,R6,MERGESAV     RESTORE ALL REGISTERS BUT R7
000542 07FA                       337          BR    R10                AND RETURN
                                  338 *
000544                            339 MERGESAV DS    15F                REGISTER SAVEAREA
```

```
  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                    341          LTORG
000580 00000004                     342                =F'4'
000000                              343 R0       EQU   0
000001                              344 R1       EQU   1
000002                              345 R2       EQU   2
000003                              346 R3       EQU   3
000004                              347 R4       EQU   4
000005                              348 R5       EQU   5
000006                              349 R6       EQU   6
000007                              350 R7       EQU   7
000008                              351 R8       EQU   8
000009                              352 R9       EQU   9
00000A                              353 R10      EQU   10
00000B                              354 R11      EQU   11
00000C                              355 R12      EQU   12
00000D                              356 R13      EQU   13
00000E                              357 R14      EQU   14
00000F                              358 R15      EQU   15
                                    359          END   MAINPROG

***  NO   STATEMENTS FLAGGED -  NO   WARNINGS,  NO   ERRORS

*** DYNAMIC CORE AREA USED:  LOW:   14432 HIGH:    1168 LEAVING:  107280 FREE BYTES. AVERAGE:      43 BYTES/STMT ***

*** ASSEMBLY TIME =    0.283 SECS,     1272 STATEMENTS/SEC ***

*** PROGRAM EXECUTION BEGINNING - ANY OUTPUT BEFORE EXECUTION TIME MESSAGE IS PRODUCED BY USER PROGRAM ***

*** START OF TABLE ***
          1
          2
          3
         10
         11
         14

*** END OF TABLE ***
```

```
*** START OF TABLE ***
        -20
          1
          4
          5
         12
         16

*** END OF TABLE ***

*** START OF TABLE ***
        -20
          1
          1
          2
          3
          4
          5
         10
         11
         12
         14
         16

*** END OF TABLE ***

*** EXECUTION TIME =    0.023 SECS.       491 INSTRUCTIONS EXECUTED -    21347 INSTRUCTIONS/SEC ***

*** AM004 - NORMAL USER TERMINATION BY RETURN ***

*** TOTAL RUN TIME UNDER ASSIST =     0.000 SECS ***
```

## 4.2 DOCUMENTATION STANDARDS

The aspect of the function of a programmer that has been most liberally abused is that of providing adequate documentation of the programs produced. The fact that a programmer has prepared a sequence of optimally coded instructions that produces correct results when tested against trial data hardly means he has adequately fulfilled his function. The job of preparing a production program cannot be considered complete unless the program is supported by (1) a complete, detailed, and concise description of the function that the program is to perform, (2) a complete set of block diagrams and flowcharts that portray the logic of the program, (3) a step algorithm that is detailed in the program listing and relates individual sections of code to the blocks of the flowcharts, and (4) an adequate set of comments to explain the function of individual instructions within the program.

During the past decade, there has been a constant shift from assembler-language programs to programs written in higher-level languages. This conversion has taken place even though assembler-language programs are usually more efficient in the use of storage and time. One of the major causes of this shift is that programs coded in assembler language are characteristically more difficult to use, maintain, and alter. The difficulties encountered with the assembler-language programs result primarily from the fact that most of these programs are inadequately documented. There is no accurate estimate of the millions of dollars that could have been saved out of the vast sums spent on the use, maintenance, alteration, and recoding of assembler-language programs, had these programs been adequately documented when they were first written.

Although it is certainly true that many programs should be written in higher-level languages rather than in assembler language, the use of assembler language has been unnecessarily curtailed by the failure to adhere to adequate standards of documentation. The following minimal documentation standards are proposed for all assembler-language programs:

1. For each program, a block diagram and a set of flowcharts presenting a visual description of the logic of the program should be prepared. These diagrams should be neatly drawn and should conform to normal flowcharting practices. If the program includes subroutines, a separate set of diagrams should be included for each routine.
2. At the beginning of each routine of a program, comments conveying the following information should appear:
   a. A description of the function of the routine. This description should be complete enough to enable any qualified programmer to ascertain quickly the purpose of the routine.
   b. A description of the entry conditions. For example, if particular registers are assumed to contain specific parameters when the routine is entered, these assumptions should be stated.

c. A description of the exit conditions. For example, if any of the registers are altered by the routine, these alterations should be stated.
d. A step algorithm. The steps should be related to the blocks in the block diagram. Each step should completely describe, in readable English, the purpose of the related section of code.

3. Between the instructions for a routine, the steps of the step algorithm should be delimited by some appropriate comment cards. In this text, cards of the form

   ***<STEP n>

   will be used for this purpose.
4. Every statement defining a storage area should be followed by a comment containing a description of the use of that area.
5. Individual statements should be commented wherever appropriate. Each such comment should convey information that cannot be deduced from the instruction itself. For example the line

```
AR        R3,R4        ADD R4 TO R3
```

   gives the reader no more information than the instruction itself. However, the line

```
AR        R3,R4        ADD AMOUNT TO TOTAL
```

   conveys useful information that is not deducible from the instruction.

Compliance with these documentation standards may seem to introduce an unnecessary amount of effort into the production of a program. This is true if only the time spent by a programmer in completing a program is taken into account. However, consideration should be given to the fact that a program may be used frequently over a period of five or more years, requiring constant maintenance and, more often than not, periodic alterations. Clearly, adherence to strict documentation standards results in minimizing the time spent on these operations. Thus, in most cases, the proper documentation of a program will result in a net savings of programmer time.

## 4.3 TWO SI INSTRUCTIONS: MVI AND CLI

In this section, an instruction format—the SI format—which has not previously been discussed, and two instructions encoded in this format—MVI and CLI—will be introduced. The SI format is utilized for the encoding of instructions involving an area in storage and a single known byte. This known byte, which is referred to as the *immediate byte*, is actually generated in the encoded instruction itself. The symbolic form of an SI instruction is

```
label        mnemonic        address, byte
```

The format for encoded SI instructions is

$$h_0h_0h_Ih_I \quad h_Bh_Dh_Dh_D$$

where $h_0h_0$ is the op code
$h_Ih_I$ is the immediate byte
$h_B$ is the number of the base register
$h_Dh_Dh_D$ is the displacement

Note that the encoded form of the address must be D(B); no index register may be specified. As an example, the instruction

```
MVI     42(R15),C'$'
```

is encoded as 925B F02A.

The immediate byte of an SI instruction is almost invariably specified in one of three ways:

1. If the immediate byte is to be interpreted as a character, it should be specified by a single character enclosed within single quotes and preceded by the letter C. In the example,

   ```
   MVI     42(R15),C'$'
   ```

   the immediate byte is specified as the character $.
2. The immediate byte can be specified as a two-digit hexadecimal constant. This may be done by enclosing the hexadecimal digits within single quotes and preceding them with the letter X. Thus, the instruction

   ```
   MVI     42(R15),X'5B'
   ```

   generates exactly the same code as the instruction

   ```
   MVI     42(R15),C'$'
   ```
3. This way of specifying the immediate byte emphasizes the values of the bits in that byte. The method is to specify the immediate byte as an eight-digit binary number enclosed within single quotes and preceded by the letter B. In this form, the instruction generating the same code as do the previous examples is

   ```
   MVI     42(R15),B'01011011'
   ```

Of the SI instructions, MVI and CLI are perhaps the most useful and the most frequently used.

```
MVI     D(B),byte          (Move Immediate)
```

Execution of this instruction results in the replacement of the contents of the byte at the address D(B) with a copy of the immediate byte. For example, the instruction

```
MVI     PRNTLINE,C' '
```

has the effect of moving a blank to the first character of PRNTLINE.

```
CLI     D(B),byte          (Compare Logical
                            Immediate)
```

Execution of this instruction effects a comparison of the immediate byte with the byte at the address D(B). The condition code is set to reflect the outcome of this comparison. In the comparison, both operands are treated as unsigned binary numbers (i.e., X'00' is the lowest value, and X'FF' is the highest possible value). Such a comparison is called a *logical compare.* The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The operands are equal. |
| 1 | The first operand is low. |
| 2 | The first operand is high. |
| 3 | — |

As an illustration of the use of these two instructions, consider the following section of code:

```
         LA    R4,CARD        LOAD THE ADDRESS OF A CARD
*                             WHICH HAS BEEN READ
         LA    R2,1           R2 IS THE INCREMENT REGISTER
*                             FOR BXLE
         LA    R3,CARD+79     END MARKER FOR THE BXLE
*
SCAN     CLI   0(R4),C' '     LOOK FOR BLANKS
         BNE   BUMPINDX       REPLACE ONLY BLANKS
         MVI   0(R4),C'0'     REPLACE BLANKS WITH ZEROS
BUMPINDX BXLE  R4,R2,SCAN
```

This section of code simply has the effect of replacing every occurrence of a blank in CARD with a 0.

## Exercises

Give the encoded version of each of the following instructions.

**1.** a. MVI 0(R3),C'A'
b. CLI 37(R10),13
c. MVI 0(R2,R3),B'01010101'

**2.** a. MVI 125(R1),C'$'
b. CLI 11(R2),C''''
c. CLI 0(R0),12

Give the decoded version of each of the following instructions.

**3.** a. 956C3010
b. 9240D000
c. 957DC004

**4.** a. 92D14011
b. 95C43033
c. 9200B008

## 4.4 MVC AND CLC: THE SS COUNTERPARTS OF MVI AND CLI

In this section, another instruction format, the SS format, is introduced. The SS format is used to encode instructions involving two operands that are both fields in storage. The two SS instructions discussed here, MVC and CLC, are the SS counterparts of the MVI and CLI instructions discussed in Section 4.3.

There are two forms of the SS format. One is used when the operands are assumed to be of the same length, and the other is used when the two operands differ in length. For the purpose of this discussion, only the first form is introduced. This symbolic form of the SS format is

| | | |
|---|---|---|
| label | mnemonic | D1(L,B1),D2(B2) |

where D1(B1) is the address of the first operand
D2(B2) is the address of the second operand
L is the length of each operand

The corresponding encoded format has the form

| | | |
|---|---|---|
| $h_0h_0h_Lh_L$ | $h_{B1}h_{D1}h_{D1}h_{D1}$ | $h_{B2}h_{D2}h_{D2}h_{D2}$ |

where $h_0h_0$ is the op code
$h_Lh_L$ is the length less one
$h_{B1}h_{D1}h_{D1}h_{D1}$ specifies the address of the first operand
$h_{B2}h_{D2}h_{D2}h_{D2}$ specifies the address of the second operand

Note that the length specification in the encoded format is one less than the actual length of the operands. This encoded length is referred to as the *length code*. Since the length code is one less than the length of the operands, lengths from 1 to 256 may be specified. This is an important point to remember when working with SS instructions.

As a specific example, the SS instruction

MVC 14(8,R12),0(R1)

generates

```
L-1
D207   C00E      1000
```

Implicit addresses may be used with the SS instructions. Here, as in the case of RS and SI instructions, no index register can be specified in the implicit address. When an implicit address is used to specify the first operand, the length is specified by enclosing it within parentheses immediately following the implicit address. This is a possible source of confusion. For example, the instruction

```
MVC      FIELD1(15),FIELD2
```

specifies that the length of the operands is 15 and the address of the first operand is FIELD1 (not FIELD1 offset by the contents of R15).

It is permissible to specify a length of 0 in an SS instruction. If this is done, the length code generated is 00. Thus, a length specification of 0 causes the same code to be generated as does a length specification of 1. The conditions under which it might be desirable to specify a length of 0 are covered in Section 8.6.

A length attribute is associated with each label in a program. If no length is specified in an SS instruction, the length attribute of the label used to specify the first operand is taken to be the length by default. For example, if the statements

```
         MVC      FWORD,0(R2)
         .
         .
         .
FWORD    DS       F
```

are used in a program, the code generated by the MVC statement would indicate a length of 4. The rules governing which length attributes are assigned to various fields are covered in Section 8.1. Until you are familiar with these rules, a length should be explicitly assigned for each occurrence of an SS instruction.

Execution of the instruction

```
MVC      D1(L,B1),D2(B2)      (Move Character)
```

has the effect of replacing the contents of the L bytes beginning at D1(B1) with a copy of the contents of the L bytes beginning at D2(B2). The contents of these bytes are altered one at a time, starting from the left. This fact is unimportant if the fields do not overlap, but it is extremely important when the fields do overlap. The condition code is not altered by execution of the instruction.

The MVC is an extremely useful instruction. The following examples illustrate two of its most common uses.

It is common practice for a program to utilize a single storage area for the accumulation of information to be printed. During different phases of the execution of the program a variety of types of information may occupy such an area. This is most often accomplished by moving various fields into this area through the use of MVC statements. For example, execution of the statements

```
MVC     PRNTLINE(13),=C'0THE TOTAL IS'
XDECO   R2,PRNTLINE+13
XPRNT   PRNTLINE,25
```

causes the total from R2 to be printed, preceded by an appropriate character string.

The contents of a storage area may be altered so that each byte represents a blank. This is done by a single MVC instruction such as

```
MVC     PLINE,=CL133' '
```

Execution of this instruction, however, requires the generation of 133 bytes of blanks. A truly elegant method of accomplishing the same result involves the use of an MVC instruction with overlapping operands. This method is illustrated by the two following instructions:

```
MVI     PLINE,C' '
MVC     PLINE+1(132),PLINE
```

Execution of the MVI instruction alters the contents of the first byte of PLINE to 40 (a blank). Figure 4-1 depicts the sequence of actions effected by execution of the MVC instruction.

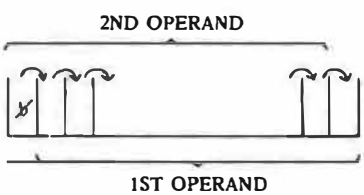



**Figure 4-1**

This process may be described as follows:

1. A copy of the first byte of the second operand is moved to the first byte of the first operand. That is, a copy of the blank in PLINE + 0 is moved to PLINE + 1.

2. A copy of the second byte of the second operand, PLINE+1 (now a blank), is moved to the second byte of the first operand, PLINE+2.
3. The process continues, with one byte being moved at a time, until PLINE contains only blanks.

This is a standard technique for blanking out a print line; you should become familiar with it.

Execution of the instruction

CLC D1(L,B1),D2(B2) (*Compare Logical*)

causes a logical comparison of the two operands to be made. (Recall that, in a logical comparison, both operands are treated as unsigned binary numbers.) Based on the result of this comparison, the condition code is set, with the following interpretation:

| *CC* | *Meaning* |
|---|---|
| 0 | The operands are equal. |
| 1 | The first operand is low. |
| 2 | The first operand is high. |
| 3 | — |

## Exercises

Give the encoded version of each of the following instructions. Here, you may assume that the field F1 occurs at a displacement of 50 (hex) from the base register R12.

**1.** a. MVC 0(4,R7),F1
b. MVC F1+3(8),0(R6)
c. CLC 0(3,R6),0(R7)

**2.** a. MVC F1(8),10(R2)
b. CLC 0(6,R7),12(R2,R3)
c. CLC 18(5,R6),F1+2

Decode the following instructions

**3.** a. D500C0021001
b. D2FF10081009
c. D2067007800D

**4.** a. D201E0004007
b. D50FB006A006
c. D505400C800A

Suppose that FIELD is a 4-byte field containing F1F2F3F4.

5. What will be the contents of FIELD after

```
MVC   FIELD+1(3),FIELD
```

is executed?

## 4.5 REFERENCING THE LOCATION COUNTER

At this point the reader is, of course, well aware that the general function of an assembler is the conversion of source statements into executable form. This process involves, among other things, a determination of the relative address of all instructions, constants, storage areas, and literals. These relative addresses are calculated by controlling the value of a location counter—an integral part of the assembler.

Before the processing of the set of source statements in any given assembly begins, the value in the location counter is initialized to 0. Then, after each successive instruction is processed, the value in the location counter is incremented by the length of the object code generated by that instruction. The value that the location counter contained when an instruction was encountered is displayed to the left of each instruction in the listing produced by the assembler. The location counter would be of little interest to the programmer if a facility did not exist for referencing the value of the location counter.

To reference the value of the location counter within a source code instruction, an asterisk is used. The value assigned to the asterisk in a given instruction will be the value that the location counter contained when the instruction was being assembled. Thus, the statements

```
         B       *+8
         L       R1,0(R2)
```

are equivalent to

```
         B       PASTLOAD
         L       R1,0(R2)
PASTLOAD DS      0H
```

since *+8 is interpreted as the value of the location counter before generation of the branch instruction, incremented by 8. The use of

```
PASTLOAD DS      0H
```

just establishes a position in the code. It does not generate any object code. Exactly why this works will be clarified in Chapter 8. Similarly, the instructions

```
         CLI     0(R1),C' '
         BE      *+12
         LA      R1,1(R1)
         B       *-12
```

are equivalent to

```
LOOP    CLI    0(R1),C' '
        BE     HIT
        LA     R1,1(R1)
        B      LOOP
HIT     DS     0H
```

The principal advantage of using references to the location counter is to avoid cluttering a listing with unnecessary labels. The use of such references can, however, lead to errors if instructions are later added to the program. For example, the instructions

```
        CLI    0(R1),C' '
        BE     *+12
        LA     R1,1(R1)
        LA     R2,1(R2)
        B      *-12
```

are definitely not equivalent to

```
LOOP    CLI    0(R1),C' '
        BE     HIT
        LA     R1,1(R1)
        LA     R2,1(R2)
        B      LOOP
HIT     DS     0H
```

To avoid such errors, extreme caution should be exercised whenever references to the location counter are made and programs containing such references are altered. A good rule-of-thumb limit is *+12 or *−12.

## Exercises

**1.** Rewrite the following short section of code without using the label LOOP:

```
LOOP    CLC    0(2,R4),=C'##'
        BE     HIT
        BXLE   R4,R8,LOOP
```

**2.** Will the following section of code run properly?

```
        SR     R5,R5
        LA     R3,INPUT+132
        LA     R4,132
        CLI    0(R3),C'$'
        BNE    *+8
        LA     R5,1(R5)
```

```
        BCTR    R3,R0
        BCT     R4,*-16
```

Why, or why not?

## 4.6 USES OF THE ORG INSTRUCTION

An ORG instruction actually alters the value in the location counter. The format for this instruction is

```
        ORG     [address]
```

The brackets are used to indicate that the operand is optional. If the operand is specified, the value in the location counter is reset to the value associated with this address. If the operand is not specified, the value in the location counter is set to the address of the first available location in the CSECT that contains the ORG instruction. For example, the code

```
HDR1        DC      C'1'                CARRIAGE CONTROL
            DC      CL38' '             WE'LL ORG IN THE CONSTANTS
            ORG     HDR1 + 15
            DC      C'CLASS LIST FOR'
HDRDEPT     DS      CL4                 PUT DEPT HERE
            DC      C' '
HDRCOURS    DS      CL4                 PUT COURSE HERE
            ORG
```

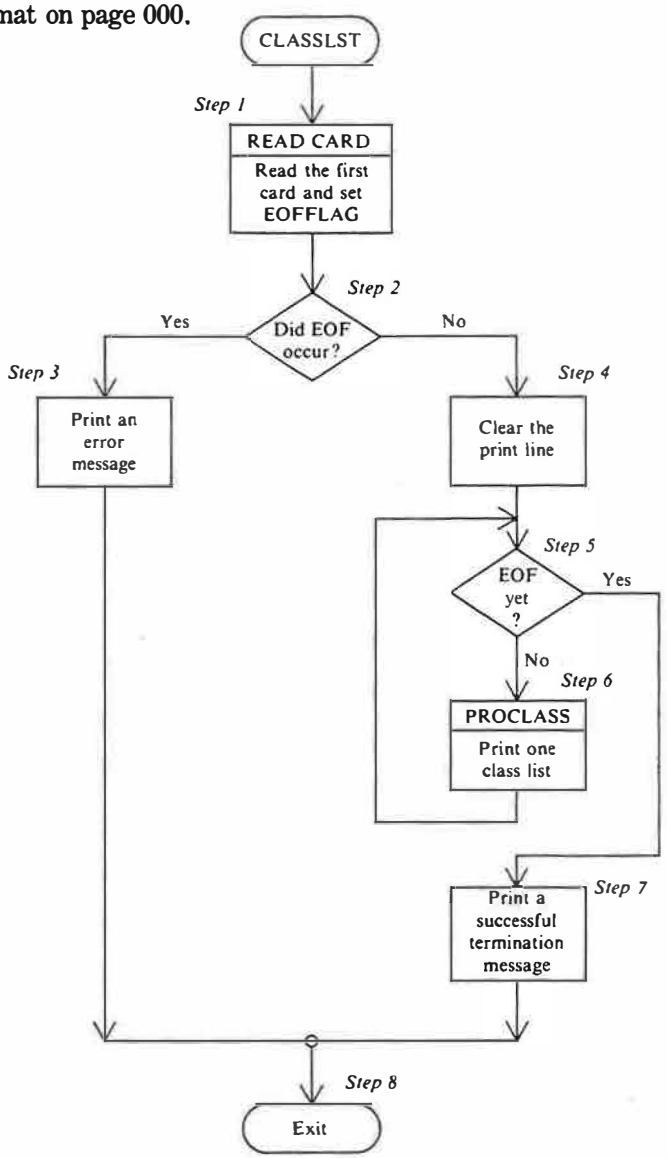
may be used to define a particular set of column headers. Note that the ORG instruction is used to position a constant as well as the areas for the department and course codes. This technique is especially useful, because changing the spacing of the headers requires only that the ORG statements be changed.

The following example illustrates how the ORG instruction may be used to assign several alternative labels to the same area in storage:

```
CARD        DS      CL80
            ORG     CARD
SOCSEC#     DS      CL9
NAME        DS      CL20
SAMPLE#     DS      CL4
SEX         DS      CL1
HAIR        DS      CL2
EYES        DS      CL2
            ORG     CARD
SAMPLE      DS      CL9
#MALES      DS      CL4
#FEMALES    DS      CL4
            ORG
```

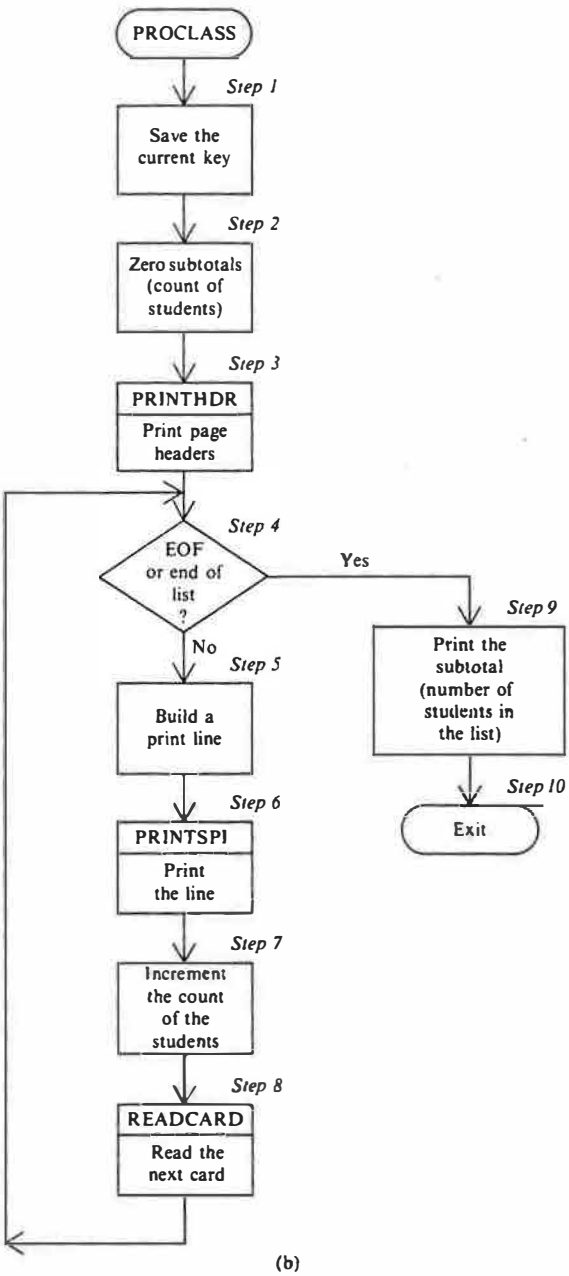
In this case, three alternative definitions of a single 80-byte area are specified. Thus, NAME and #MALES refer to exactly the same storage locations. In each case, the field being referenced is located at CARD+9.

The program presented in Figure 4-2 and Program 4-2 illustrates the use of the instructions presented in this chapter. The purpose of this program is to produce a "class list" for each of the classes taught in a given school. The input to the program is assumed to be a set of records that conform to the format on page 000.

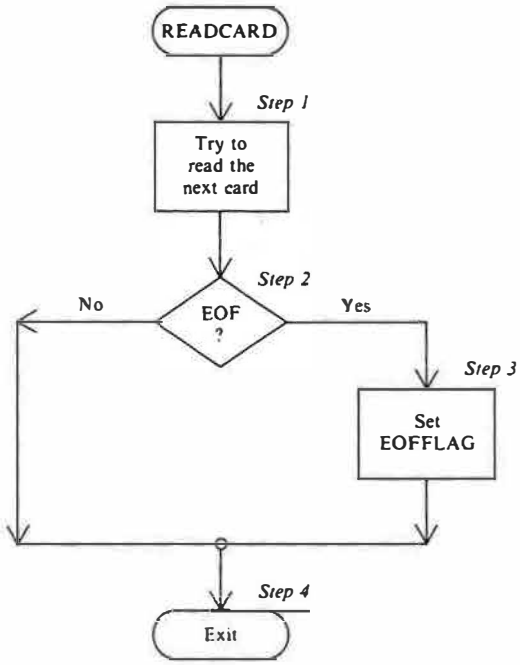



(a)

**Figure 4-2**




(b)

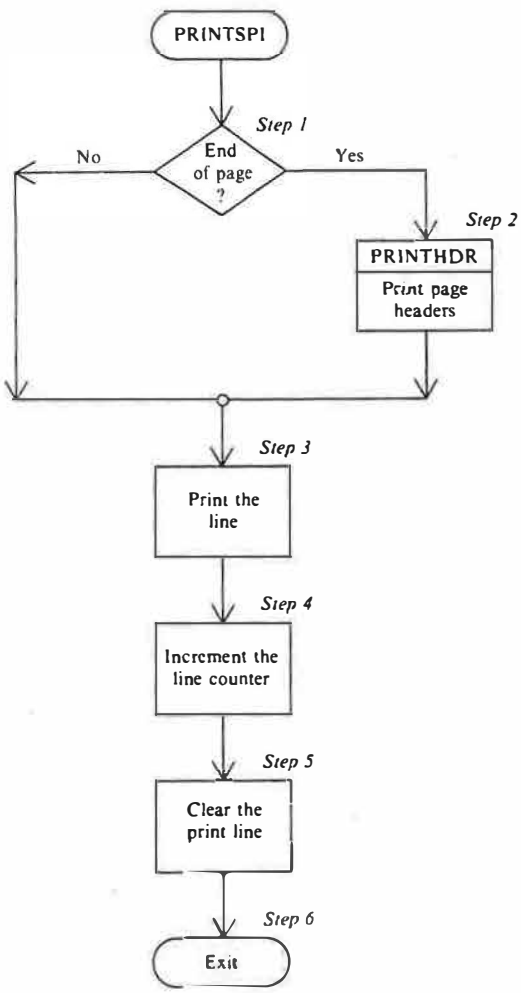



(c)

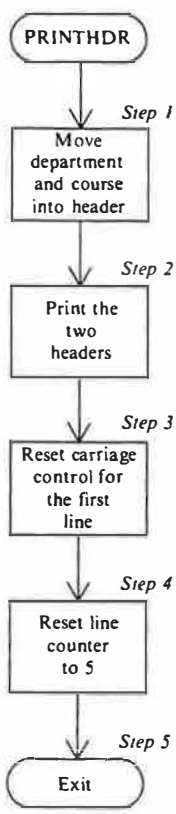
**Figure 4-2 (continued)**

| *Record Position* | *Contents* |
|---|---|
| 1–4 | Department offering the course |
| 5–8 | Course number |
| 9–18 | Last name of student |
| 19–28 | First name of student |
| 29–80 | Unused |

It is further assumed that this file has been sorted in ascending order, based on the first 28 columns of the records. The program produces a class list for each class, including the total number of students registered in the class.




(d)




(e)

**Figure 4-2 (continued)**

**Program 4-2**

```
         TITLE 'A PROGRAM TO PRODUCE CLASS LISTS'
*****************************************************************
*
* THE FOLLOWING PROGRAM CAN BE USED TO PRODUCE CLASS LISTS.  AS
* INPUT THE PROGRAM ACCEPTS CARDS PUNCHED ACCORDING TO THE FOLLOWING
* FORMAT:
*
*      1  - 4   DEPARTMENT OFFERING THE COURSE
*      5  - 8   COURSE NUMBER
*      9  - 18  LAST NAME
*      19 - 28  FIRST NAME OF THE STUDENT
*      29 - 80  UNUSED
*
* IT IS ASSUMED THAT THE CARDS HAVE BEEN SORTED INTO ASCENDING ORDER
* BASED ON THE FIRST 28 COLUMNS.  THE PROGRAM PRODUCES A SEPARATE
* LIST (BEGINNING ON A NEW PAGE) FOR EACH CLASS.  EACH LIST IS
* TERMINATED WITH A LINE GIVING THE NUMBER OF STUDENTS ENROLLED IN
* THAT CLASS.  THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*        STEP 1. CALL READCARD TO READ THE FIRST CARD AND SET
*                EOFFLAG TO SHOW WHETHER OR NOT EOF OCCURRED.
*
*        STEP 2. IF EOF DID NOT OCCUR, GO TO STEP 4.
*
*        STEP 3. PRINT AN ERROR MESSAGE (NO INPUT).  GO TO STEP 8.
*
*        STEP 4. CLEAR THE PRINT LINE.  AFTER THIS THE LINE IS
*                CLEARED IMMEDIATELY AFTER EACH NEW LINE IS PRINTED.
*
*        STEP 5. IF EOF HAS OCCURRED (NO MORE LISTS TO PRINT), GO TO
*                STEP 7.
*
*        STEP 6.  CALL PROCLASS TO PRINT ONE CLASS LIST.
*
*        STEP 7. PRINT A "SUCCESSFUL TERMINATION" MESSAGE.
*
*        STEP 8. EXIT.
*
*
*****************************************************************
*
CLASSLST CSECT
         USING CLASSLST,R15
*
***<STEP 1>    READ THE FIRST CARD AND SET EOFFLAG
*
         BAL   R11,READCARD       READ THE 1ST CARD
*
***<STEP 2>    IF THERE INPUT, GO TO STEP 4 TO PRINT THE LISTS.
*
         CLI   EOFFLAG,C'Y'
         BNE   CLEARLN            BRANCH IF EOF WAS NOT DETECTED
*
***<STEP 3>    PRINT A "NO INPUT" ERROR MESSAGE AND EXIT
*
         XPRNT =C'1*** NO INPUT ***',17
         B     EXIT
```

**Program 4-2 (continued)**

```
*
***<STEP 3>    CLEAR THE PRINT LINE TO ALL BLANKS
*
CLEARLN  MVI   PRNTLINE,C' '       CLEAR THE PRINT LINE
         MVC   PRNTLINE+1(132),PRNTLINE
*
***<STEP 4>    CALL PROCLASS REPEATEDLY UNTIL EOF OCCURS
*
PROCLOOP CLI   EOFFLAG,C'Y'        CONTINUE LOOPING UNTIL EOF
         BE    PRINTEND
*
         BAL   R11,PROCLASS        PRINT 1 CLASS LIST
*
         B     PROCLOOP
*
***<STEP 5>    PRINT "SUCCESSFUL TERMINATION" MESSAGE
*
PRINTEND XPRNT =C'1*** SUCCESSFUL TERMINATION ***',31
*
***<STEP 6>    LEAVE THE PROGRAM
*
EXIT     BR    R14                  LEAVE THE PROGRAM
*
*****************************************************************
*
* THE READCARD ROUTINE ATTEMPTS TO READ A CARD.  IF END-OF-FILE
* OCCURS, EOFFLAG WILL BE SET TO 'Y' (IT IS INITIALIZED TO 'N',
* SO IT WILL REMAIN 'N' UNTIL EOF OCCURS).
*
*        STEP 1. TRY TO READ THE NEXT CARD.
*
*        STEP 2. IF EOF OCURRED, SET EOFFLAG TO 'Y' (IT IS ASSUMED
*                THAT EOFFLAG WAS INITIALIZED TO 'N').
*
*        STEP 3. RETURN TO CALLER.
*
*****************************************************************
*
READCARD STM   R0,R15,READSAVE     SAVE CALLER'S REGISTERS
*
***<STEP 1>    TRY TO READ THE NEXT CARD.
*
         XREAD CARD,80             TRY TO READ THE NEXT CARD
*
***<STEP 2>    IF EOF OCCURRED, SET EOFFLAG TO 'Y'
*
         BC    B'1011',READEXIT    BRANCH IF NOT EOF
*
         MVI   EOFFLAG,C'Y'        SET EOF INDICATOR
*
***<STEP 3>    RETURN TO CALLER
*
READEXIT LM    R0,R15,READSAVE     RESTORE CALLER'S REGISTERS
         BR    R11                 RETURN TO CALLER
*
READSAVE DS    16F                 REGISTER SAVE AREA
*
```

**Program 4-2 (continued)**

```
*****************************************************************
*
* PROCLASS PRODUCES 1 CLASS LIST.  WHEN IT COMPLETES, EITHER
* EOF HAS OCCURRED (EOFFLAG WILL BE Y) OR THE FIRST CARD FOR THE
* NEXT CLASS LIST HAS BEEN READ.  THE LOGIC IS AS FOLLOWS:
*
*        STEP 1. SAVE THE DEPT AND COURSE FROM THE CARD.  THESE TWO
*                FIELDS REPRESENT THE "CURRENT KEY" - THEY
*                IDENTIFY THE COURSE FOR WHICH THE CURRENT LIST IS
*                TO BE PRINTED.  THE CURRENT LIST WILL INCLUDE ALL
*                CARDS UP TO THE POINT WHERE A NEW KEY OCCURS.
*
*        STEP 2. SET THE COUNT OF STUDENTS IN THE LIST TO 0.
*
*        STEP 3. CALL PRINTHDR TO PRINT PAGE AND COLUMN HEADERS FOR
*                THE FIRST PAGE OF THE CLASS LIST
*
*        STEP 4. CHECK TO SEE IF EOF HAS OCCURRED, OR IF A CARD FOR
*                THE NEXT CLASS LIST HAS BEEN READ.  IF EITHER EVENT
*                HAS OCCURRED, IT'S TIME TO END THIS LIST (SO GO TO
*                STEP 9).
*
*        STEP 5. BUILD A PRINT LINE FROM THE DATA ON THE CARD.
*
*        STEP 6. CALL PRINTSP1 TO PRINT THE LINE (AND HEADERS, IF
*                NECESSARY).  THE PRINT LINE WILL BE CLEARED AFTER
*                THE LINE IS PRINTED.
*
*        STEP 7. ADD 1 TO THE COUNT OF STUDENTS PRINTED IN THE LIST.
*
*        STEP 8. CALL READCARD TO TRY TO READ THE NEXT CARD.  THEN
*                GO BACK TO STEP 4 TO CHECK FOR END OF THE LOOP.
*
*        STEP 9. PRINT THE LAST LINE OF THE CLASS LIST, THE LINE
*                THAT GIVES THE TOTAL NUMBER OF STUDENTS IN THE CLASS.
*
*        STEP 10.RETURN TO CALLER.
*
*
*****************************************************************
*
PROCLASS STM   R0,R15,PRCLSAVE     SAVE CALLER'S REGISTERS
*
***<STEP 1>    SAVE KEY FOR THE CURRENT CLASS LIST
*
         MVC   CURRKEY,CARD        SAVE THE KEY (DEPT,COURSE)
*
***<STEP 2>    SET COUNT OF STUDENTS IN CLASS TO 0
*
         SR    R2,R2               SET COUNT OF STUDENTS IN THE
*                                  LIST TO 0
*
***<STEP 3>    PRINT THE HEADERS FOR THE FIRST PAGE OF THE LIST
*
         BAL   R11,PRINTHDR        PRINT THE PAGE HEADERS
*
***<STEP 4>    CHECK FOR END OF LIST (EOF OR NEXT KEY)
*
PROCCARD CLI   EOFFLAG,C'Y'        END LOOP ON EOF OR NEW KEY
         BE    PRINTTOT
         CLC   CURRKEY,CARD
         BNE   PRINTTOT            MISMATCH MEANS NEW KEY
*
***<STEP 5>    CONSTRUCT A PRINT LINE
*
         MVC   DEPTOUT,DEPTIN      NOW MOVE DATA FIELDS
         MVC   COURSOUT,COURSIN    THE PRINT LINE
         MVC   LNAMEOUT,LNAMEIN
         MVC   FNAMEOUT,FNAMEIN
*
```

**Program 4-2 (continued)**

```
***<STEP 6>    CALL PRINTSP1 TO PRINT THE LINE
*
         BAL   R11,PRINTSP1        PRINT THE LINE (AND HEADERS,
*                                  IF NECESSARY)
*
*
***<STEP 7>    ADD 1 TO COUNT OF STUDENTS IN THE LIST
*
         LA    R2,1(R2)            ADD 1 TO COUNT OF STUDENTS
*
***<STEP 8>    TRY TO READ THE NEXT CARD
*
         BAL   R11,READCARD        TRY TO READ THE NEXT CARD
*
         B     PROCCARD
*
***<STEP 9>    PRINT THE LAST LINE (TOTAL # STUDENTS) IN LIST
*
PRINTTOT XDECO R2,PRNTLINE+25      PUT TOTAL INTO PRINT LINE
         MVC   PRNTLINE+7(18),=C'TOTAL # STUDENTS ='
         MVI   PRNTLINE,C'0'       SET CARRIAGE CONTROL FOR
*                                  DOUBLE-SPACE
         XPRNT PRNTLINE,133        PRINT LAST LINE FOR LIST
         MVI   PRNTLINE,C' '       CLEAR THE PRINT LINE
         MVC   PRNTLINE+1(132),PRNTLINE
*
***<STEP 10>   RETURN TO CALLER
*
         LM    R0,R15,PRCLSAVE     RESTORE CALLER'S REGISTERS
         BR    R11
*
PRCLSAVE DS    16F                 REGISTER SAVE AREA
*
*****************************************************************
*
*
* THE PRINTHDR ROUTINE PRINTS PAGE AND COLUMN HEADERS AND THEN RESETS
* THE LINECTR TO 5 (THE NEXT LINE IS LINE 5 OF THE PAGE).
*
*        STEP 1.  PUT DEPT AND COURSE INTO HEADER LINE
*
*        STEP 2.  PRINT THE TWO HEADER LINES.
*
*        STEP 3.  RESET THE CARRIAGE CONTROL TO DOUBLE-SPACE FOR THE
*                 FIRST LINE OF THE PAGE.
*
*        STEP 4.  RESET THE LINE COUNTER TO 5 (THE FIFTH LINE OF THE
*                 PAGE IS THE "NEXT LINE").
*
*        STEP 5.  RETURN TO CALLER.
*
*****************************************************************
*
PRINTHDR STM   R0,R15,HDRSAVE      SAVE THE CALLER'S REGISTERS
*
***<STEP 1>    MOVE DEPT AND COURSE INTO PAGE HEADER
*
         MVC   HDRDEPT,CURRKEY     TAKE DEPT AND COURSE
         MVC   HDRCOURS,CURRKEY+4      FROM CURRKEY
*
***<STEP 2>    PRINT THE PAGE AND COLUMN HEADERS
*
         XPRNT HDR1,39
         XPRNT HDR2,43
*
***<STEP 3>    SET CARRIAGE CONTROL FOR FIRST LINE OF PAGE
*
         MVI   PRNTLINE,C'0'       SET CC FOR DOUBLE-SPACE
*
***<STEP 4>    RESET LINE COUNTER TO 5 (NEXT LINE IS 5TH OF PAGE)
*
```

**Program 4-2 (continued)**

```
         MVC   LINECTR,=F'5'       SET LINE COUNTER TO 5
*
***<STEP 5>    RETURN TO CALLER
*
         LM    R0,R15,HDRSAVE      RESTORE CALLER'S REGISTERS
         BR    R11                 RETURN TO CALLER
*
HDRSAVE  DS    16F                 REGISTER SAVE AREA
*
*
HDR1     DC    C'1'                CARRIAGE CONTROL
         DC    CL38' '             WE'LL ORG IN THE CONSTANTS
         ORG   HDR1+15
         DC    C'CLASS LIST FOR '
HDRDEPT  DS    CL4                 PUT DEPT HERE
         DC    C' '
HDRCOURS DS    CL4                 PUT COURSE HERE
         ORG
*
*
HDR2     DC    C'0'                CARRIAGE CONTROL
         DC    CL42' '             AGAIN, WE'LL ORG IN THE VALUES
         ORG   HDR2+4
         DC    C'DEPT'
         ORG   HDR2+9
         DC    C'COURSE'
         ORG   HDR2+19
         DC    C'LAST NAME'
         ORG   HDR2+33
         DC    C'FIRST NAME'
         ORG
*
*******************************************************************
*
*
* PRINTSP1 IS CALLED TO PRINT A LINE AFTER SINGLE-SPACING.  IF THE
* LINE WOULD OCCUR AFTER LINE 50 ON THE PAGE, HEADERS ARE PRINTED
* FIRST (AND THE FIRST LINE AFTER THE HEADER GETS DOUBLE-SPACED).
*
*        STEP 1.  IF THE LINE COUNTER SHOWS THE CURRENT LINE TO BE
*                 LESS THAN OR EQUAL TO FIFTY, GO TO STEP 3.
*
*        STEP 2.  CALL PRINTHDR TO ADVANCE TO THE NEXT PAGE, PRINTING
*                 PAGE AND COLUMN HEADERS.
*
*        STEP 3.  PRINT THE LINE.
*
*        STEP 4.  INCREMENT THE LINE COUNTER BY 1.
*
*        STEP 5.  CLEAR THE PRINT LINE.
*
*        STEP 6.  RETURN TO CALLER.
*
*******************************************************************
*
PRINTSP1 STM   R0,R15,PRSPSAVE     SAVE CALLER'S REGISTERS
*
***<STEP 1>    CHECK TO SEE IF IT'S TIME FOR A NEW PAGE
*
         CLC   LINECTR,=F'50'
         BNH   NOWPRINT            BRANCH IF HEADERS AREN'T
*                                  NECESSARY
*
***<STEP 2>    CALL PRINTHDR TO PRINT HEADERS ON THE NEXT PAGE
*
         BAL   R11,PRINTHDR        PRINT HEADERS
*
***<STEP 3>    PRINT THE LINE
*
NOWPRINT XPRNT PRNTLINE,133        PRINT THE LINE
```

**Program 4-2 (continued)**

```
*
***<STEP 4>     INCREMENT THE LINE COUNTER
*
         L      R3,LINECTR          INCREMENT THE LINECTR
         LA     R3,1(R3)
         ST     R3,LINECTR
*
***<STEP 5>     CLEAR THE PRINT LINE
*
         MVI    PRNTLINE,C' '       CLEAR THE PRINT LINE
         MVC    PRNTLINE+1(132),PRNTLINE
*
***<STEP 6>     RETURN TO CALLER
*
         LM     R0,R15,PRSPSAVE     RESTORE CALLER'S REGISTERS
         BR     R11
*
PRSPSAVE DS     16F                 REGISTER SAVE AREA
*
*****************************************************************
*
CURRKEY  DS     CL8                 CURRENT DEPT AND COURSE
*
CARD     DS     OCL80               CURRENT CARD
DEPTIN   DS     CL4                 DEPT OFFERING THE COURSE
COURSIN  DS     CL4                 COURSE #
LNAMEIN  DS     CL10                LAST NAME OF STUDENT
FNAMEIN  DS     CL10                FIRST NAME OF STUDENT
         DS     CL52
*
*
EOFFLAG  DC     C'N'                EOF INDICATOR (Y MEANS EOF)
*
LINECTR  DS     F                   LINE COUNTER (CURRENT LINE ON PAGE)
*
PRNTLINE DS     CL133               THE PRINT LINE
         ORG    PRNTLINE+4          WE ORG TO COLUMNS
DEPTOUT  DS     CL4                 DEPT OFFERING THE COURSE
         ORG    PRNTLINE+10
COURSOUT DS     CL4                 COURSE #
         ORG    PRNTLINE+19
LNAMEOUT DS     CL10                STUDENT'S LAST NAME
         ORG    PRNTLINE+33
FNAMEOUT DS     CL10                STUDENT'S FIRST NAME
         ORG
*
         LTORG
R0       EQU    0
R1       EQU    1
R2       EQU    2
R3       EQU    3
R4       EQU    4
R5       EQU    5
R6       EQU    6
R7       EQU    7
R8       EQU    8
R9       EQU    9
R10      EQU    10
R11      EQU    11
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
*
         END    CLASSLST
```

Particular attention should be given to the following sequence of statements from Program 4-2:

```
CARD      DS  0CL80  CURRENT CARD
DEPTIN    DS  CL4    DEPT OFFERING THE COURSE
COURSIN   DS  CL4    COURSE #
LNAMEIN   DS  CL10   LAST NAME OF STUDENT
FNAMEIN   DS  CL10   FIRST NAME OF STUDENT
          DS  CL52
```

The statement defining CARD reserves no storage, since the duplication factor is 0. The purpose of this statement is to signify that the next 80 bytes together give a more detailed description of the single field CARD. This technique is also used for reserving storage for the print line. In both cases, the advantage gained is the ability to reference subfields by meaningful labels. For example, CARD+8 and LNAMEIN refer to exactly the same address.

**Exercise**

Suppose that you are going to write a program that reads input records conforming to the following format:

| *Columns* | *Contents* |
|---|---|
| 1–20 | Customer's last nane |
| 21–30 | Customer's first name |
| 31–39 | Social security number |
| 40–49 | Telephone number |
| 50–80 | unused |

Write the lines to properly define the area, using ORGs to position the fields.

## 4.7 LOGICAL ARITHMETIC AND COMPARISON INSTRUCTIONS

To understand the significance of the instructions that will be introduced in this section, it is necessary first to understand exactly how addition and subtraction are executed on a computer. To illustrate the procedures involved, it will be helpful to consider specific examples. In these examples, four-bit instead of 32-bit signed binary integers will be used. The motivation for this

simplication will be obvious if the reader takes the time to try the algorithms on 32-bit integers.

To add two signed binary integers, one can proceed as follows:

1. Set the carry digit for the rightmost position to 0.
2. Starting from the rightmost digits, add the two corresponding digits and the carry digit to determine which digit is assigned to the result. If a 0 or a 1 results from the addition, this becomes the corresponding bit in the result, and the carry digit for the next position to the left is set to 0. If a 10 or an 11 results from the addition, a 0 or a 1 is written as the corresponding digit of the result, and the next carry digit is set to 1.
3. The carry digit resulting from the addition performed on the leftmost bits does not alter the result. However, if it differs from the digit carried into the leftmost position, overflow is recognized.

Thus, to add 1011 and 0010, the following steps are executed:

```
carry   0010
         1011
      +  0010
result   1101
```

In this case, 2 was added to $-5$, giving $-3$. Since the two leftmost carry digits agree, no overflow occurred.

The following examples illustrate the process more completely:

| | | | | |
|---|---|---|---|---|
| overflow | yes | no | yes | no |
| carry | 1000 | 1111 | 0110 | 0001 |
| | 1111 | 1101 | 0111 | 0101 |
| | 1000 | 1111 | 0010 | 0001 |
| result | 0111 | 1100 | 1001 | 0110 |

Subtraction can be explained quite easily in terms of addition. To subtract a number $n$ from a number $m$, add $-n$ to $m$. To understand this process, the reader must be completely familiar with the method of representing negative numbers introduced in Section 1.5. For example, to subtract 1101 from 0010:

- Convert 1101 to its complement, 0011.
- Add 0010 and 0011, giving 0101.

If overflow occurs when $-n$ and $m$ are added together, then overflow for the subtraction is recognized.

Now the AL, ALR, SL, SLR, CL, and CLR instructions can be discussed. Each of these instructions has a counterpart among the instructions that

have already been covered. This correspondence is presented in the following list:

| *Instruction* | *Format* | |
|---|---|---|
| Add | A | r,D(X,B) |
| Add Logical | AL | r,D(X,B) |
| Add Register | AR | r1,r2 |
| Add Logical Register | ALR | r1,r2 |
| Subtract | S | r,D(X,B) |
| Subtract Logical | SL | r,D(X,B) |
| Subtract Register | SR | r1,r2 |
| Subtract Logical Register | SLR | r1,r2 |
| Compare | C | r,D(X,B) |
| Compare Logical | CL | r,D(X,B) |
| Compare Register | CR | r1,r2 |
| Compare Logical Register | CLR | r1,r2 |

The only differences between the AL and ALR instructions and their counterparts are:

- If overflow occurs as a result of the execution of an AL or an ALR instruction, the overflow does not cause termination of the program.
- The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The result is 0 and the leftmost carry digit was 0. |
| 1 | The result is not 0 and the leftmost carry digit was 0. |
| 2 | The result is 0 and the leftmost carry digit was 1. |
| 3 | The result is not 0 and the leftmost carry digit was 1. |

The only differences between the SL and SLR instructions and their counterparts are:

- Just as for AL and ALR, overflow is ignored.
- The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | — |
| 1 | The result is not 0 and the leftmost carry digit was 0. |
| 2 | The result is 0. |
| 3 | The result is not 0 and the leftmost carry digit was 1. |

The CL and CLR instructions perform exactly like C and CR, except that the operands are treated as 32-bit unsigned integers.

Although the logical arithmetic and comparison instructions are used occasionally when no indication of overflow is desired, their main use is in the

construction of extended-precision operations. That is, one can build routines to add, subtract, or compare arbitrarily large integers using these instructions. As an example, routines to add, subtract and compare 64-bit signed integers are presented in Program 4-3. Note that similar routines could be contructed to manipulate integers of any size.

**Program 4-3**

```
* THE FOLLOWING ROUTINE ADDS THE DOUBLEWORD POINTED TO BY R3 TO
* THE DOUBLEWORD POINTED TO BY R4.  R10 IS USED AS THE LINK REGISTER.
*
ADDRT    LM    R0,R1,0(R3)        LOAD OPERAND1
         AL    R1,4(R4)           ADD RIGHT WORDS
         BC    B'1100',ADDLEFT    BRANCH IF NO CARRY RESULTED
         A     R0,=F'1'           ADD 1 IF CARRY OCCURRED
*
ADDLEFT  A     R0,0(R4)           ADD LEFT WORDS
         STM   R0,R1,0(R3)        STORE RESULT INTO OPERAND1
         BR    R10
* THIS ROUTINE CALCULATES THE DIFFERENCE OF THE TWO DOUBLEWORDS
* POINTED TO BY R3 AND R4.  THE RESULT IS STORED INTO THE FIRST
* OPERAND.  R10 IS ASSUMED TO CONTAIN THE EXIT ADDRESS.
*
SUBRT    LM    R0,R1,0(R3)        LOAD THE FIRST OPERAND
         SL    R1,4(R4)           SUBTRACT RIGHT WORD
         BC    B'0011',SUBLEFT    BRANCH IF CARRY OCCURRED
         BCTR  R0,0
SUBLEFT  S     R0,0(R4)           SUBTRACT LEFT WORDS
         STM   R0,R1,0(R3)        STORE BACK INTO OPERAND 1
         BR    R10

* THE FOLLOWING ROUTINE COMPARES TWO 64-BIT SIGNED INTEGERS
* WHICH ARE POINTED TO BY R3 AND R4.  R10 IS ASSUMED TO CONTAIN
* THE EXIT ADDRESS.
*
COMPRT   LM    R0,R1,0(R3)        LOAD FIRST OPERAND
         C     R0,0(R4)           COMPARE LEFT WORDS
         BCR   B'0110',R10        EXIT IF THEY AREN'T EQUAL
         CL    R1,4(R4)           ELSE, USE RIGHT WORDS
         BR    R10
```

## Exercises

The following two dumps were caused by an operation exception. What can be deduced about the causes of these errors?

**1.**

```
PSW: FF000000 DF000066

R0-7 :F4F4F4F4 F4F4F4F4 00000036 00000069 00000036 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000008C4 0000090C 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      47F0F078   D1D6C8D5   40E2D4C9   E3C8D4C1      *.00.JOHN SMITHMA*
000010      D9E840D9   C1E8C2E4   C7C5D6D9   C7C540C7      *RY RAYBUGEORGE G*
```

```
000020      D9C5D1C5   D9D9E840   D4C9D3C6   D3C9D5C4      *REJERRY MILFLIND*
000030      C140D4C1   C3C5F0D1   D6C8D540   E2D4C9E3      *A MACE0JOHN SMIT*
000040      C8D4C1D9   E840D9C1   E8C2E4C7   C5D6D9C7      *HMARY RAYBUGEORG*
000050      C540C7D9   C5D1C5D9   D9E840D4   C9D3C6D3      *E GREJERRY MILFL*
000060      C9D5C4C1   40D4C1C3   C5004000   4144000A      *INDA MACE. .....*
000070      4133000A   47F0F060   4120F004   E000F86C      *.....00-..0.\.8%*
000080      00504740   F054D209   2000F86C   5A20F8C0      *.&. 0.K...8%!.8{*
000090      E000F86C   005047F0   F082F5F5   F5F5F5F5      *\.8%.&.00b555555*
0000A0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   0000A0 - 000850    ARE IDENTICAL
000860      F5F5F5F5   F5F5F5F5   F5F507FE   D3C9D5C4      *5555555555..LIND*
000870      C140D4C1   C3C5D240   40404040   40404040      *A MACEK          *
000880      40404040   40404040   40404040   40404040      *                 *
            LINES:   000880 - 0008A0    ARE IDENTICAL
0008B0      40404040   40404040   40404040   F5F5F5F5      *             5555*
0008C0      0000000A   F5F5F5F5   F5F5F5F5   F5F5F5F5      *....555555555555*
0008D0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**2.**

```
PSW:  FF000000 DF00084E

R0-7 :F4F4F4F4 F4F4F4F4 00000806 00000849 00000806 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000008DC 00000924 00000000


USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      47F0F860   F5F5F5F5   F5F5F5F5   F5F5F5F5      *.08-555555555555*
000010      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000010 - 0007C0    ARE IDENTICAL
0007D0      F5F5F5F5   C6D6D9C4   40404040   4040C3C8      *5555FORD      CH*
0007E0      C5E5E840   40404040   C3C8D9E8   E2D3C5D9      *EVY     CHRYSLER*
0007F0      4040D6D3   E2D4D6C2   C9D3C540   E3D6E8D6      *  OLSMOBILE TOYO*
000800      E3C140E3   C5D992F0   F8164130   F8174140      *TA TERk08...8.. *
000810      F7D447F0   F848F0C6   D6D9C440   40404040      *7M.08.0FORD     *
000820      40C3C8C5   E5E84040   404040C3   C8D9E8E2      * CHEVY     CHRYS*
000830      D3C5D940   40D6D3E2   D4D6C2C9   D3C540E3      *LER  OLSMOBILE T*
000840      D6E8D6E3   C140E3C5   D9424780   F882D209      *OYOTA TER...8bK.*
000850      30004000   4144000A   4133000A   47F0F848      *.. ..........08.*
000860      4120F7D4   E000F884   00504740   F806D209      *..7M\.8d.&. 8.K.*
000870      2000F884   5A20F8D8   E000F884   005047F0      *..8d!.8Q\.8d.&.0*
000880      F86A07FE   E3D6E8D6   E3C140E3   C5D9C3C5      *8|..TOYOTA TERCE*
000890      D3404040   40404040   40404040   40404040      *L                *
0008A0      40404040   40404040   40404040   40404040      *                 *
            LINES:   0008A0 - 0008C0    ARE IDENTICAL
0008D0      40404040   F5F5F5F5   0000000A   F5F5F5F5      *    5555....5555*
0008E0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**3.** Suppose that we say that two strings, S1 and S2, "match," if each of the corresponding characters are "similar." Two characters are similar, if they are identical, or if one of the characters is a '?'. Write a program that reads

in a set of input records. Each input record will conform to the following format:

| *Positions* | *Contents* |
|---|---|
| 1–10 | pattern |
| 11–80 | data-string |

For each input record, the program must search for a 10-character substring of the data-string that is similar to the pattern. When such a substring is found, the program should print the pattern, the substring, and the location of the substring (displacement into the main string). Your program should use subroutines to

- test to see whether or not two 10-character strings are similar, locate the first similar substring (if there is one), and print the answer (for strings in which a match is detected).

**4.** Write a program to read in two lists of words and then merge them into one list. Each list will contain at most 50 English words in alphabetical order, and each word will consist of at most eight letters. The words should be read off records conforming to the following specifications:

a. There will be two sets of records, one for each list. (The records for the second list immediately follow the records for the first list.)
b. Each record in a set, except perhaps the last record, will contain exactly five words, starting in columns 10, 20, 30, 40, and 50.
c. The last record in a set can contain one to five words.
d. A $ immediately follows the last word in a set (i.e., in either column 18, 28, 38, 48, or 58).

Your program should contain three subroutines—one to read in a set of records and build a table of words, one to display the entries in a table of words, and one to merge two tables into a third table.

The actual steps in the program should be as follows:

*Step 1.* Read in the first list.
*Step 2.* Display the first list.
*Step 3.* Read in the second list.
*Step 4.* Display the second list.
*Step 5.* Merge the two lists.
*Step 6.* Display the merged lists.

Assume that neither of the first two lists contains duplicate entries. If a word were to occur in both of the two input lists, your program should insert only one copy of the word into the merged table.

**5.** Write a program to perform the following tasks:

a. Read in a set of records, each of which will contain from zero to six English words. Each word will contain up to 10 characters and will begin in either column 1, 11, 21, 31, 41, or 51. Thus, each card will contain six 10-character fields. Any field containing a blank in the leftmost position can be ignored. Store the words into a table.
b. Display the contents of the constructed table.
c. Sort the words in the table into alphabetical order.
d. Display the contents of the sorted table.

To sort the table, use an algorithm similar to the one discussed in Exercise 5 at the end of Section 3.6. In that case, however, entries in a table were to be sorted into descending order. To sort a table into ascending order, the following technique can be used:

*Step 1.* Find the "smallest" entry in the table (i.e., the word that should appear first).
*Step 2.* Swap the first entry in the table with the smallest entry.
*Step 3.* If more than one entry remains in the unsorted section of the table, repeat the procedure for that section of the table.

For example, if

ZOO MOUSE CAT APPLE

were to be sorted, the following events would occur:

- Since APPLE should appear at the head of the list, APPLE and ZOO are swapped, giving

  APPLE MOUSE CAT ZOO

  The unsorted section of the table is then composed of all words to the right of APPLE. Since three entries remain, more exchanges are necessary.
- Since CAT should appear at the head of the remainder of the list (i.e., the right three words), CAT and MOUSE are swapped, giving

  APPLE CAT MOUSE ZOO

- Since MOUSE should appear at the head of the remainder of the list, it is swapped with itself (which leaves the table unaltered). Since only one word remains to the right of MOUSE, the process has been completed.

**6.** This exercise is similar to the preceding exercise, except that a sort algorithm similar to the one discussed in Exercise 6 at the end of Section 3.6 should be used to sort the table. This algorithm can be described briefly as follows:

For each element in the table except the leftmost, starting from the left, repeat the following operation as often as possible: *If the element to the left of the given element should appear to the right of the given element, swap the two elements.*

For example, to sort

ZOO MOUSE CAT APPLE

using this algorithm, the following events would occur:

- Since ZOO should occur to the right of MOUSE, the two words are swapped, giving

  MOUSE ZOO CAT APPLE

- Two swaps are then required for CAT, which gives

  CAT MOUSE ZOO APPLE

- Since all three words to the left of APPLE should occur to the right of APPLE, three swaps occur, leaving

  APPLE CAT MOUSE ZOO

**7.** Suppose that all of the students in a class have personal information records in the following format:

| *Columns* | *Contents* |
|---|---|
| 1–20 | Student's name |
| 21 | A code giving the student's standing:<br>1—freshman<br>2—sophomore<br>3—junior<br>4—senior |
| 22–25 | Student's major |
| 26 | If a nonblank value occurs here, the student is auditing the class. |

Write a program to read the records and produce the following report:

CLASS REPORT

| FRESHMEN | | SOPHOMORES | | JUNIORS | | SENIORS | |
|---|---|---|---|---|---|---|---|
| NAME | MAJOR | NAME | MAJOR | NAME | MAJOR | NAME | MAJOR |
| JOHN DORN | ENGL | | | | | | |
| | | ELIZABETH DOE | PSYC | | | | |
| | | | | MARY CALLEY | MATH | | |
| . | | . | | . | | . | |
| . | | . | | . | | . | |
| . | | . | | . | | . | |

The following should be noted on the report:

a. One student name is printed per line under the appropriate column (given by his or her standing).
b. If a student is auditing the course, an asterisk should be printed immediately to the left of his or her name.
c. Information about 50 students should be printed on each page. Headers should appear on each page. Thus, if there were 80 students, two pages would be printed; both pages would contain page headers.

You may find it convenient to use a subroutine to print a line. The subroutine would use a variable LINECNT initially containing 51, and utilize the following logic:

*Step 1.* If LINECNT is less than or equal to 50, go to Step 3.
*Step 2.* Print page headers. Set LINECNT to 1. Print the line of the report, using a carriage control of 0 to cause double-spacing. Exit.
*Step 3.* Print the line of the report, using a blank as the carriage control character. Add 1 to LINECNT. Exit.

**8.** Many stores prepare invoices for their sales. Such an invoice might appear as follows:

| Item | # Units | Cost/Unit | Cost |
|---|---|---|---|
| 0421 | 2 | 1.14 | 2.28 |
| 3841 | 1 | 14.00 | 14.00 |
| | | Total | = 16.28 |

Suppose that a store wished to have a computer verify the calculations on each invoice. Write such a program. The program should accept records conforming to the following specifications:

a. There will be a set of records for each invoice. This set will be composed of one record for each "line item" and one record containing the total.
b. All of the line item records for an invoice will occur before the total record and will conform to the following format:

| *Columns* | *Contents* |
|---|---|
| 1 | 1 |
| 2–5 | Item number |
| 6–8 | Number of units |
| 10–15 | Cost per unit |
| 17–23 | Cost |

c. The total record for an invoice will follow the item cards and will conform to the following format:

| *Positions* | *Contents* |
|---|---|
| 1 | 2 |
| 2–10 | Total cost |

For each invoice, print the following:

| | | | | |
|---|---|---|---|---|
| LINE ITEMS | 1421 | 4 | 100 | 400 |
| | 2981 | 2 | 109 | 216* |
| | 0410 | 1 | 19100 | 19100 |
| | | | TOTAL = | 19716 |

If any field in a line item record contains only blanks or if the cost is incorrect, an asterisk should be printed to the right of the cost. Similarly, if the total is not accurate, print an asterisk to the right of it.

**9.** Write a program to perform the following tasks:

a. Read in a sequence of records, each of which will contain from zero to six English words of up to 10 characters in length. The words can begin in columns 1, 11, 21, 31, 41, or 51. Thus, each record will contain six 10-character fields. If the left character of a field is a blank, the field should be ignored. Construct a table from the words on the records. When a record containing END in columns 1–3 is read, all the records containing words to be put into the first table have been processed.
b. Display the contents of the table.
c. Read in a second sequence of records and construct a second table.
d. Display the second table.
e. Build a third table containing only those values that occur in both of the tables previously constructed.
f. Display the contents of the third table.

Assume that neither of the two original tables will contain more than 30 words and that neither table contains duplicate entries.

**10.** Write a program to print names and addresses "four up." The program should read records, each containing a single name and address. Each line of the name and address is 15 characters in length. Each record will contain from three to five lines. (The last five columns on each record are ignored.) For example, the following are all valid data records:

| | | | | |
|---|---|---|---|---|
| JOHN ANDERSON | 1527 STATE ST. | MORGANTOWN | OHIO | |
| ROBIN BENNIT | P.O. BOX 156 | KINROSS | MICHIGAN | |
| J. D. DORSCH | GODFREY LANE | JASPER, ILL. | | |
| MARY LARSON | 375 R.RT. 18 | BAKER | ARKANSAS | |
| BOB SMITH | 3155 FIRST ST | APT 3B | JACKSON | FLA |

The program should print the data from four records simultaneously, single-spacing between lines. The first line of each set of four should be double-spaced. Do not print any blank lines. (If all records in a set have four or less lines, do not print a fifth line.) For this input, the following lines would be printed:

```
JOHN ANDERSON      ROBIN BENNIT       J. D. DORSCH
1527 STATE ST.     P.O. BOX 156       GODFREY LANE
MORGANTOWN         KINROSS            JASPER, ILL.
OHIO               MICHIGAN

MARY LARSON        BOB SMITH
375 R.RT. 18       3155 FIRST ST
BAKER              APT 3B
ARKANSAS           JACKSON
                   FLA
```

Your program should use at least the following subroutines:

- READSET reads a set of up to four records into a designated area. It returns the number of records read (which may be zero).
- PRINTSET prints a set of records. It uses the routine FILLUP.
- FILLUP constructs one print line. It takes as input the array of records and the line number (1 to 5).

# 5

# Decimal Arithmetic

## 5.1 ZONED AND PACKED DECIMAL FORMATS

The decimal instruction set provides facilities for (1) performing arithmetic operations on integers represented in the familiar decimal system and (2) editing data (preparing data in readable form before printing). Two distinct formats, *zoned decimal* and *packed decimal*, are utilized for the representation of decimal numbers. The particular instruction used dictates which of these formats is required. Generally, the packed decimal format is required for arithmetic operations, while the zoned decimal format is utilized for input/output operations.

The decimal instruction set provides several advantages or conveniences over the binary instruction set in addition to the facility for performing operations on decimal numbers. All the decimal instructions are of the SS (storage to storage) type and allow operations to be performed on fields of varying lengths. This provides some added precision over binary arithmetic, since decimal numbers from one to 31 digits in length may be represented in the packed decimal format. Because the arithmetic operations are performed in storage, the operations generally require only a single instruction. For example, it requires only a single instruction to add two decimal fields in storage, but it would require an L, A, ST sequence to add the corresponding binary numbers. In addition, there is a convenient means for rounding decimal numbers, which some applications absolutely require.

In discussing either the zoned or packed decimal format, we will refer to the left hexadecimal digit of a byte as the *zone digit* and to the right digit as the *numeric digit*. A number may be represented in zoned decimal format according to the following rules:

- One decimal digit is represented per byte. The zone digit of all but the rightmost byte must be F. The numeric digit in each (including the rightmost byte) is the numeric digit represented by that byte.
- The zone digit of the rightmost byte is used to represent the sign of the number. A, C, E, and F are valid zone digits for the sign of a positive

number; a zone digit of B or D in the rightmost byte represents a negative number.

As an example,

F1F2F3F4

is a zoned decimal representation of +1234, and

F1F2F3D4

is a representation of −1234.

Note that a zoned decimal representation of a number can differ from the character representation of that number only in the zone digit of the rightmost byte. Note also that the character representation of a positive number is a valid zoned decimal representation of that number. For example,

```
DC      C'012'
```

generates F0F1F2, which is a zoned decimal representation for +012.

Zoned decimal numbers can be generated by the use of Z-type DC statements. The general format for this statement is

```
label      DC      mZLn'p'
```

where m is a valid duplication factor
Z specifies zoned decimal
Ln specifies a length
p is the decimal representation of the number to be generated

If m is omitted, a duplication factor of 1 is assumed. If Ln is omitted, the length of the field generated will equal the number of digits in p. If Ln specifies a length greater than the number of digits in p, zeros (F0) are added on the left. Optionally, p may contain a sign and a decimal point. If the sign is omitted, the number is assumed to be positive. A plus sign will generate a sign zone of C, and a minus sign will result in a sign zone of D. If a decimal point is included, there is no resulting effect on what is generated. The sole purpose of the decimal point is to remind anyone who may read the assembler listing that an assumed decimal point was intended.

The following list of examples should help to clarify these points:

| | *Coded* | *Generated* |
|---|---|---|
| DC | 2Z'−1' | D1D1 |
| DC | Z'+.2' | C2 |
| DC | Z'2' | C2 |
| DC | ZL3'4' | F0F0C4 |
| DC | 2ZL2'−.1' | F0D1F0D1 |
| DC | Z'1.10' | F1F1C0 |

In contrast to zoned decimal representations of numbers, each byte of a packed decimal representation except the rightmost represents two decimal digits. A number $n$ may be represented in packed decimal format by execution of the following steps:

1. Move the sign of $n$ to the right of a decimal representation of $n$.
2. If $n$ has an even number of digits, add a zero as the leftmost digit.
3. Pair the digits of $n$ starting from the left. This leaves the rightmost digit and the sign as the rightmost pair.
4. Each pair represents a byte, with the digits represented by four bits each. The valid signs are the same as for zoned decimal representations.

As an example, −1234 may be represented in packed decimal format as follows:

1. Move the sign to the right, giving 1234−.
2. Add a zero to the left, since there are an even number of digits. This gives 01234−.
3. Pair the digits from the left, giving 01 23 4−.
4. Encode each pair in a byte, using a valid sign. This gives 01234D or 01234B as a three-byte representation of −1234.

Packed decimal numbers may be generated by means of the P-type DC statement. The general format for this statement is

```
label      DC      mPLn'p'
```

where m is a valid duplication factor
P specifies packed decimal
Ln specifies a length (in bytes)
p is a decimal representation of the number to be generated

If m is omitted, a duplication factor of 1 is assumed. If Ln is omitted, the smallest field in which the number can be represented is used. A decimal point may be used in p with the same result as in the Z-type constant. (The decimal point does not affect what is generated.) C is generated for a plus sign, and D is generated for a minus sign. These points are illustrated by the following list of examples.

| | *Coded* | *Generated* |
|---|---|---|
| DC | 2P'−1' | 1D1D |
| DC | P'+.2' | 2C |
| DC | P'2' | 2C |
| DC | PL3'4' | 00004C |
| DC | 2PL2'−.12' | 012D012D |

## 5.2 THE PACK AND UNPK INSTRUCTIONS

The instructions for converting numbers between zoned and packed decimal representations are SS instructions with two lengths specified. The general format for this type of instruction, called *SS decimal,* is

```
label        mnemonic      D1(L1,B1),D2(L2,B2)
```

If implicit addressing is used, the following format applies:

```
label        mnemonic      field1(L1),field2(L2)
```

The generated instruction is of the form

$$h_0h_0h_{L1}h_{L2} \quad h_{B1}h_{D1}h_{D1}h_{D1} \quad h_{B2}h_{D2}h_{D2}h_{D2}$$

where $h_0h_0$ specifies the op code
$h_{L1}$ is the length code of the first operand
$h_{L2}$ is the length code of the second operand
$h_{B1}h_{D1}h_{D1}h_{D1}$ specifies the address of the first operand
$h_{B2}h_{D2}h_{D2}h_{D2}$ specifies the address of the second operand

Note that each length code occupies four bits. This, of course, means that 15 is the largest possible length code and 16 is the largest valid length of either operand. Thus, decimal numbers with from one to 16 digits may be represented in zoned decimal format, while decimal numbers with from one to 31 digits may be represented in packed decimal format. Another point worth noting is that if an implicit address with an unspecified length is utilized as either operand, the length attribute of the symbol will be used as an assumed length.

The instruction for converting a number from its zoned to its packed decimal representation is

```
PACK      D1(L1,B1),D2(L2,B2)          (Pack)
```

The address of the zoned decimal number to be converted is specified by the second operand, and the result is placed in the field whose address is specified by the first operand. Execution of this statement has the following effects:

- The rightmost byte of the second operand is placed in the rightmost byte of the first operand, with the zone and numeric digits reversed.
- The remaining numeric digits from the second operand are moved to the first operand, proceeding from right to left. If there are more digits in the second operand than the first operand will accommodate, the remaining leftmost digits are ignored. If the second operand has fewer numeric digits than necessary to fill the first operand, the remaining digit positions of the first operand are filled with zeros.

As an example, suppose F1 and F2 are as shown:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| F1 | 00 | 00 | 00 | 00 | | | |
| F2 | F9 | F8 | F7 | F6 | F5 | F4 | F3 |

Then, if the instruction

```
PACK     F1(4),F2(7)
```

is executed, F1 is set to 9876543F. Figure 5-1 illustrates the process.

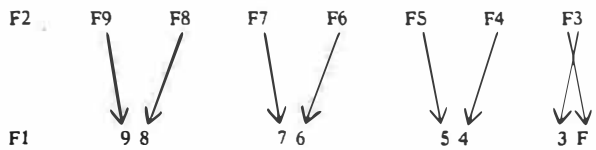



**Figure 5-1**

In a similar way, the instruction

```
PACK     F1(3),F2(7)
```

sets F1 to 76543F00, and the instruction

```
PACK     F1(4),F2(5)
```

sets F1 to 0098765F.

Note that the execution of a PACK instruction does not depend upon the second operand's being a valid zoned decimal number. For example, if F1 were as above and F2 contained

C1C2C3C4D8F101

then execution of the statement

```
PACK     F1(4),F2(7)
```

would set F1 to 12348110.

It is important to remember that the execution of a PACK instruction does not validate the number to be packed. Because of this, the hexadecimal digits in any byte may be easily swapped simply by packing the byte into itself. For example, the instruction

```
PACK     BYTE(1),BYTE(1)
```

reverses the zone and numeric digits in BYTE.

The format of the instruction for performing the reverse process (converting a packed decimal number to a zoned decimal representation) is

UNPK D1(L1,B1),D2(L2,B2) (*Unpack*)

Execution of an UNPK instruction results in the following action:

- The rightmost byte of the second operand is placed in the rightmost byte of the first operand, with the zone and numeric digits reversed.
- The four-bit hexadecimal digits of the second operand are placed in the numeric digits of the first operand. The zone digits of all but the rightmost byte of the first operand are set to F. If there are more digits in the second operand than the first operand will accommodate, the remaining leftmost digits of the second operand are ignored. If there are fewer digits in the second operand, the remaining leftmost digits of the first operand are set to F0.

For example, suppose F1 and F2 are as shown:

| | | | | | |
|---|---|---|---|---|---|
| F1 | 00 | 00 | 00 | 00 | 00 |
| F2 | 12 | 34 | 5C | | |

Then, the instruction

UNPK F1(5),F2(3)

sets F1 to F1F2F3F4C5. In a similar way, execution of the instruction

UNPK F1(1),F2(3)

sets F1 to C500000000, and execution of the instruction

UNPK F1(5),F2(2)

sets F1 to F0F0F1F243.

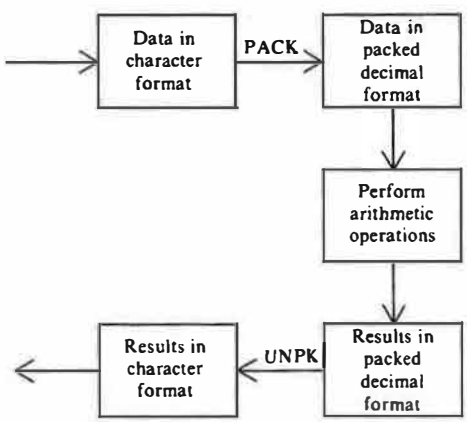



**Figure 5-2**

The principal use of the PACK and UNPK instructions occurs in situations where numeric data is to be used in decimal arithmetic operations and later printed or displayed in character format. The PACK instruction is used to convert such data into packed decimal format. In this format, the decimal instructions may be used to perform arithmetic operations on the data. The UNPK instruction may then be used to convert the results to character format for printing purposes. This process may be represented as in Figure 5-2.

Care must be exercised, however, when unpacking a numeric data item, to assure that F results as the sign digit (since F must be the zone digit of any printable numeric character). The sign may be set by using an OI instruction. This technique is discussed in Section 8.2.

As will be indicated later, the PACK and UNPK instructions may also be used in conjunction with the instructions for converting packed decimal numbers to binary numbers (and vice versa) to perform the operations for which the ASSIST instructions XDECI and XDECO were designed.

### Exercises

For each of the following exercises, show the value that would be in FLD1 after execution of the instruction.

| | *FLD1* | *FLD2* | *Instruction* | *FLD1 after Execution* |
|---|---|---|---|---|
| **1.** | 01234F | F0F1F2 | PACK FLD1,FLD2 | _____ |
| **2.** | AB | | PACK FLD1,FLD1 | _____ |
| **3.** | F1F2F3F4 | | PACK FLD1,FLD1 | _____ |
| **4.** | 000000 | ABCDEF | PACK FLD1,FLD2 | _____ |
| **5.** | 000000 | 123F | UNPK FLD1,FLD2 | _____ |
| **6.** | 1234567D | 026C | UNPK FLD1,FLD2 | _____ |
| **7.** | ABCDEF | | UNPK FLD1,FLD1 | _____ |
| **8.** | 40404040 | 4D | UNPK FLD1,FLD2 | _____ |

## 5.3 THE DECIMAL INSTRUCTIONS AP, SP, AND ZAP

In Sections 5.1 and 5.2, the packed decimal format was introduced. In this section, some of the instructions available for performing arithmetic operations on packed decimal numbers will be discussed. However, before we proceed with this discussion, consideration should be given to the desirability

of using packed decimal numbers rather than binary numbers. The principal advantage of packed decimal numbers over binary numbers is that the values represented by packed decimal numbers are more readily recognizable. Thus, when a scan of a storage dump must be made to determine the value represented by a given field, the task is much simpler if that value is represented by a packed decimal number. For example,

0123C

is a more readily distinguishable representation of +123 than is

007B

The facility gained in the debugging of programs through the use of packed decimal numbers should be obvious. Another advantage gained by the use of the arithmetic instructions for packed decimal numbers is that there is no need to convert numbers from packed decimal to binary format and back again.

The disadvantage of working with packed decimal numbers is that the execution times for the instructions for performing arithmetic operations are much greater than the execution times for the binary counterparts of these instructions. The programmer should carefully weigh this disadvantage against the advantages gained by the use of packed decimal numbers before deciding which format to employ. In general, the use of packed decimal instructions should be avoided in the coding of loops and other frequently executed sections of code. Finally, it should be noted that the use of both types of arithmetic instructions in the same program is not uncommon.

The instructions for addition, subtraction, and movement of packed decimal numbers are the AP, SP, and ZAP instructions. When these instructions are used, an error we have not previously discussed, the *data exception*, may be encountered. This error occurs when a field that is not in packed decimal format is specified as an operand of one of these instructions. Other causes of data exception errors will be noted in the discussions of individual instructions.

Another error not previously discussed that may occur with the use of these instructions is *decimal overflow*. This error has a fixed-point counterpart (the error that occurs with an A or S instruction). Here, as in the case of fixed-point overflow, a bit in the PSW determines whether or not overflow results in termination of the execution of a program; just as in the other case, an SPM instruction may be used to set that bit (bit 37) on or off. A technique for doing this will be discussed in Chapter 8.

Execution of the instruction

AP D1(L1,B1),D2(L2,B2) (*Add Decimal*)

causes the sum of the two numbers designated by D1(L1,B1) and D2(L2,B2) to be formed. This sum then replaces the first operand. If the storage occu-

pied by the first operand is insufficient to accommodate all nonzero digits of the result, overflow occurs. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The result is 0. |
| 1 | The result is < 0. |
| 2 | The result is > 0. |
| 3 | Overflow occurred. |

Note that overflow does not necessarily occur if the length of the second operand is greater than the length of the first operand. Overflow occurs only if the length of the first operand is less than that required to represent all of the nonzero digits of the result.

Execution of the instruction

```
SP      D1(L1,B1),D2(L2,B2)
```
(*Subtract Decimal*)

is analogous to the execution of AP. In this case, the difference of two numbers (rather than their sum) is calculated. For example,

```
SP      FLD1,=P '4'
```

subtracts 4 from the contents of FLD1 and puts the result into FLD1.

Execution of the instruction

```
ZAP     D1(L1,B1),D2(L2,B2)
```
(*Zero and Add Decimal*)

causes the first operand to be set to zero. The second operand is then added to it and the result replaces the first operand. Thus, the net result of executing a ZAP instruction is the movement of the second operand into the location originally occupied by the first operand. The condition code is set to the same value that would result from the execution of an AP or SP instruction. A data exception will occur only if the second operand is not a valid packed decimal number. The ZAP instruction is most frequently used for either of the following two purposes:

1. To set a field to zero. For example,

   ```
   ZAP     F1,=P'0'
   ```

   sets F1 to zero.
2. To move a packed decimal number from one field to another. Note that the condition code is set and may be used to determine whether the second operand is positive, negative, or zero.

The following examples should help to clarify the use of the AP, SP, and ZAP instructions. Suppose that F1, F2, and F3 have the indicated values:

| | | |
|---|---|---|
| F1 | 01128C | (+1128) |
| F2 | 001D | (−1) |
| F3 | 00054F | (+54) |

The execution of the following instructions would produce the indicated results:

| *Instruction* | | *Result* | | *CC* |
|---|---|---|---|---|
| AP | F1,F2 | 01127C | (in F1) | 2 |
| AP | F3,F2 | 00053C | (in F3) | 2 |
| AP | F3,=P'−100' | 00046D | (in F3) | 1 |
| AP | F2,=P'−999' | 000D | (in F2) | 3 |
| SP | F1,=P'1' | 01127C | (in F1) | 2 |
| SP | F2,F2 | 000C | (in F2) | 0 |
| SP | F2,F3 | 055D | (in F2) | 1 |
| SP | F2,=P'999' | 000D | (in F2) | 3 |
| ZAP | F1,=P'0' | 00000C | (in F1) | 0 |
| ZAP | F3,F2 | 00001D | (in F3) | 1 |
| ZAP | F2,F1 | 128C | (in F2) | 3 |

**Exercises**

For each of the following exercises, show the value that would be in FLD1 after execution of the instruction.

| | *FLD1* | *FLD2* | *Instruction* | | *FLD1 after Execution* |
|---|---|---|---|---|---|
| **1.** | 01234F | 001D | AP | FLD1,FLD2 | _____ |
| **2.** | 01234F | 00001D | SP | FLD1,FLD2 | _____ |
| **3.** | FFFF | 021F | ZAP | FLD1,FLD2 | _____ |
| **4.** | 00200D | 100F | AP | FLD1,FLD2 | _____ |
| **5.** | 00100D | 020D | SP | FLD1,FLD2 | _____ |
| **6.** | 40404040 | 000C | ZAP | FLD1,FLD2 | _____ |

## 5.4 THE DECIMAL INSTRUCTIONS MP, DP, AND CP

In this section, the repertoire of decimal arithmetic instructions is rounded out with a discussion of the decimal multiply, divide, and compare instructions. A sample program is included to illustrate the use of decimal arithmetic. The rules governing the use of the decimal multiply and divide instructions are somewhat complex and require careful examination.

Execution of the instruction

MP D1(L1,B1),D2(L2,B2) (*Multiply Decimal*)

causes the product of the two operands to be formed. The result then replaced the first operand. The condition code is unaltered. A specification exception will occur if L2 is greater than 8 or if L2 is greater than or equal

to L1. If the first L2 bytes of the first operand are not all zeros, a data exception occurs. A data exception will also occur if either of the operands is not in valid packed decimal format.

To illustrate the use of the MP instruction, suppose that F1 contains 00015C. Then the instruction

```
MP      F1,=PL1'5'
```

would leave 00075C in F1. However, the instruction

```
MP      F1,=PL2'5'
```

would cause a data exception, since the first two bytes of F1 are not 0000. A specification exception would result from execution of the instruction

```
MP      F1,=PL3'5'
```

since F1 is only three bytes in length.

Execution of the statement

```
DP      D1(L1,B1),D2(L2,B2)          (Divide Decimal)
```

results in the formation of a quotient and remainder determined by division of the first operand by the second. The first operand is then replaced by this quotient and remainder. The quotient is left in D1(L3,B1), where L3 = L1 − L2. The remainder is left in D3(L2,B1), where D3 = D1 + (L1 − L2). That is, the remainder is on the right and is exactly as long as the divisor, and the quotient occupies the remaining bytes on the left. A specification exception occurs if L2 is greater than 8 or if L2 is greater than or equal to L1. If the quotient will not fit into L1 − L2 bytes, a decimal divide exception occurs. If either of the operands is not in valid packed decimal format, a data exception error occurs.

For purposes of illustration, suppose that F1 contains 01500C. Then, execution of the instruction

```
DP      F1,=PL2'298'
```

would leave 5C010C in F1. The quotient (5C) is on the left, and the remainder (010C) is on the right. On the other hand, execution of the instruction

```
DP      F1,=PL3'298'
```

would result in a specification exception, and an attempt to execute

```
DP      F1,=PL2'15'
```

would cause a decimal divide exception (since 100C will not fit into one byte).

Execution of the statement

```
CP      D1(L1,B1),D2(L2,B2)          (Compare Decimal)
```

causes a numeric comparison of the two operands to be made, and the condition code is set as follows, to reflect the outcome of this comparison:

| *CC* | *Meaning* |
|---|---|
| 0 | The operands are equal. |
| 1 | The first operand is low. |
| 2 | The first operand is high. |
| 3 | — |

**Exercises**

For each of the following exercises, show the value that would be in FLD1 after execution of the instruction.

| | *FLD1* | *FLD2* | *Instruction* | | *FLD1 after Execution* |
|---|---|---|---|---|---|
| **1.** | 00004F | 020F | MP | FLD1,FLD2 | _____ |
| **2.** | 00013D | 9C | MP | FLD1,FLD2 | _____ |
| **3.** | 0000200D | 150D | MP | FLD1,FLD2 | _____ |
| **4.** | 01000F | 500C | DP | FLD1,FLD2 | _____ |
| **5.** | 02010D | 5D | DP | FLD1,FLD2 | _____ |
| **6.** | 0000100C | 020C | DP | FLD1,FLD2 | _____ |

## 5.5 X-TYPE CONSTANTS

To specify the patterns associated with the use of the EDit instruction, it is convenient to have a facility for generating arbitrary hexadecimal constants. This facility is provided by the following form of the DC statement:

```
label     DC     nXLm'p'
```

where n is the duplication factor
m is the length
p is a hexadecimal constant

Thus, the statement

```
          DC     3XL2'A2F1'
```

will cause a six-byte field containing A2F1A2F1A2F1 to be generated. If the duplication factor is omitted, it is assumed to be 1. Therefore, the two statements

```
          DC     XL3'12A1BF'
```

and

```
        DC      1XL3'12A1BF'
```

generate identical strings. If the indicated length of the field is more than sufficient to accommodate the digits of p, zeros are added on the left. For example, the statement

```
        DC      XL3'ABC'
```

will cause 000ABC to be generated. On the other hand, if the indicated length is insufficient to accommodate the digits in p, digits are dropped from the left. Thus, the statement

```
        DC      XL2'12345'
```

causes 2345 to be generated. The following examples should reinforce the preceding remarks.

| | *Statement* | *Generated String* |
|---|---|---|
| DC | X'FFD1' | FFD1 |
| DC | X'A' | 0A |
| DC | XL2'1' | 0001 |
| DC | 3X'5' | 050505 |
| DC | 2XL1'F12' | 1212 |

Generation of an X-type constant, unlike the F-type, does not cause an automatic boundary alignment. For example, the statement

```
TWELVE  DC      XL4'C'
```

does not necessarily generate a fullword containing a value of 12 (as DC F'12' would). The constant may or may not be generated on a fullword boundary. To force TWELVE to be generated on a fullword boundary, either of these pairs of statements could be used:

```
TWELVE  DS      0F
        DC      XL4'C'
```

or

```
        DS      0F
TWELVE  DC      XL4'C'
```

The X-type constants, like the other types, may be used in literals. When they are so used, a special rule governing the generation of literals may be taken advantage of. This rule states that all literals of length 4 are generated on fullword boundaries. Hence, instructions such as

```
        A       R1, = XL4'1'
```

and

```
L      R2, = X'FF0000FF'
```

may be used without fear of causing a specification error to occur.

## 5.6 THE ED INSTRUCTION

The EDit instruction is used to convert a packed decimal number (or a contiguous sequence of packed decimal numbers) into a form properly formatted for printed output. It provides facilities for suppressing leading zeros, inserting commas and decimal points, appending algebraic signs, and inserting text. Since so many variations are allowed, the algorithm governing the execution of this instruction is quite complex.

The format of the ED instruction is

```
label      ED      D1(L,B1),D2(B2)
```

where D1(L,B1) designates the address and length of the field that is to contain the formatted result after execution of the instruction

D2(B2) gives the address of one or more contiguous packed decimal numbers

Before the editing process can be discussed, however, some terminology must be introduced.

1. The first operand is called the *pattern*. The characters in the pattern determine the format of the edited result that will replace it. The characters in the pattern are classified as follows:
   a. 20 (that is, X'20') is called a *digit selector*.
   b. 21 is called a *significance starter*.
   c. 22 is called a *field separator*.
   d. Any other character is called a *message character*.
2. The second operand is called the *source field*, and its hexadecimal digits are called *source digits*. The source field may contain one or more packed decimal numbers. The number of source digits involved in the editing process (i.e., the length of the source field) is determined by the contents of the pattern.
3. There is a switch called the *significance indicator*, which will be either on or off. The function of this switch will become clear after the following discussion.
4. The first character of the pattern is called the *fill character*. When leading zeros or message characters are to be suppressed, they are replaced in the pattern by the fill character.

The pattern and the source field are both processed from left to right. The pattern is processed one character at a time, while the source field is processed one hexadecimal digit at a time. At the beginning of execution, the significance indicator is off. The first character of the pattern is examined and becomes the fill character. If this character is other than a digit selector or a significance starter, it is left unchanged and the next character of the pattern is examined. From this point, execution proceeds as follows:

1. If the character from the pattern is a digit selector, a digit from the source field is examined.
   a. If the significance indicator is off, and
      i) if this digit is a zero, the character in the pattern is replaced by the fill character. On the other hand,
      ii) if this digit represents a nonzero decimal digit, it is converted to zoned format by appending a leading zone digit, and the result replaces the character in the pattern. If this occurs, the significance indicator is turned on.
   b. If the significance indicator is on, this digit is converted to zoned format and replaces the character in the pattern.
2. If the character from the pattern is a significance starter, the result is the same as in the case of a digit selector except that the significance indicator is always turned on after the character in the pattern is replaced.
3. If the character from the pattern is a field separator, it is replaced by the fill character and the significance indicator is turned off.
4. If the character from the pattern is a message character, and
   a. the significance indicator is off, this character is replaced in the pattern by the fill character.
   b. the significance indicator is on, the message character in the pattern is left unchanged.

The next character in the pattern is then selected and the process is repeated until the pattern is completely processed. Each character in the pattern and each hexadecimal digit in the source field is examined only once.

In this discussion, it has been assumed that the source field is correctly formatted. An invalid packed decimal number in the source field could lead to a data exception. Of course, incorrect addresses in the instruction could cause protection or addressing errors. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The source inspected for the last field is 0. |
| 1 | The source inspected for the last field < 0. |
| 2 | The source inspected for the last field > 0. |

The following progressively more complex examples illustrate the operation of the editing algorithm:

- *Example 1.* Suppose that F1 contains 40202020 and F2 contains 123C. Then, execution of the instruction

```
ED        F1(4),F2
```

would leave 40F1F2F3 (the same as C' 123') in F1. To see this in detail, go through the algorithm carefully and note the following:

1. Since 40 (a blank) is the first character of the pattern, it becomes the fill character.
2. As each successive character of the pattern is examined, each is replaced by the character form of the corresponding source digit (since the last three pattern characters are digit selectors).

Therefore, if a three-digit decimal number is to be edited from F2 into the third through fifth bytes of PLINE, the following code could be used:

```
MVC       PLINE+1(4),=X'40202020'
ED        PLINE+1(4),F2
```

- *Example 2.* There is only one problem with Example 1; if F2 contains a zero (000C), only blanks would be put into PLINE. This would occur because the algorithm replaces leading zeros with the fill character (in this case, a blank). To remedy that problem, a significance starter should be used as follows:

```
MVC       PLINE+1(4),=X'40202120'
ED        PLINE+1(4),F2
```

In any case other than the one in which F2 contains a zero, this pattern produces exactly the same result as 40202020. However, if F2 does contain 000C, a zero is printed rather than all blanks. Note that only one zero would be printed. The significance starter will not cause the zero in its corresponding digit position to print, but subsequent zeros are printed.

- *Example 3.* Suppose that the number in F2 is to be interpreted as a number of the form X.XX. In this case, a decimal point (X'4B') should be inserted into the pattern, giving

```
MVC       PLINE+1(5),=X'40204B2020'
ED        PLINE+1(5),F2
```

Note, however, that this will not produce the desired result, if the first digit is zero; in that case, the 4B will be replaced by the fill character, 40. So again a significance starter is needed:

```
MVC       PLINE+1(5),=X'40214B2020'
ED        PLINE+1(5),F2
```

Thus, if F2 contained 012C, this last edit would cause .12 (X'40404BF1F2') to be put into PLINE.

- *Example 4.* Suppose that F2 is two bytes long but always contains at most a two-digit number. Would

```
MVC     PLINE+1(3),=X'402120'
ED      PLINE+1(3),F2
```

put the desired value into PLINE? The answer is no, but this is a mistake that programmers often make. Any field containing a single packed decimal number contains an odd number of numeric digits. The sum, therefore, of the number of digit selectors and significance starters in a pattern should probably be odd. For example, if F2 contains 010C,

```
MVC     PLINE+1(3),=X'402120'
ED      PLINE+1(3),F2
```

causes just 1 to be put into PLINE, while

```
MVC     PLINE+1(4),=X'40202120'
ED      PLINE+1(4),F2
```

causes 10 to be put into PLINE. Occasionally, only the leading digits are wanted, and so an even number of 20's and 21's may be legitimate. The point here is that the source digits should be carefully matched with the characters in the pattern when the pattern is constructed.

- *Example 5.* Suppose that F2 is a five-byte field containing a number to be printed in the form

X,XXX,XXX.XX

Naturally, leading zeros and commas should be suppressed (e.g., 000000000C should cause .00 to be put into PLINE). The pattern for this would be

```
MVC     PLINE+1(13) = X'40206B2020206B2020214B2020'
ED      PLINE+1(13),F2
```

Note that a significance starter is used.

- *Example 6.* Suppose that F2 contains a five-digit number (F2 is three bytes long) of the form

XXX.XX

where the number represents an amount of money to be printed on a check. It is often desirable that an amount such as 1.23 be printed as

**1.23

In this case, leading zeros should be replaced with asterisks rather than with blanks. This is done by specifying an asterisk as the fill character,

as follows:

```
MVC     PLINE+1(7),=X'5C2020214B2020'
ED      PLINE+1(7),F2
```

- *Example 7.* Suppose that F2 contains a three-digit number that may be negative. The easiest way to print an indication of the sign is to use the form

  XXX

  for a positive number and

  XXX–

  for a negative number. This can be done by using

```
MVC     PLINE+1(5),=X'4020212060'
ED      PLINE+1(5),F2
```

  Here the 60 (–) is a message character. When a byte whose rightmost character indicates a positive number (A, C, E, or F) is processed, the significance indicator is turned off. Hence, any message character or characters immediately following in the pattern are replaced by the fill character. If a character indicating a negative number (B or D) is encountered under the same conditions, however, the significance indicator is left on, and any message characters immediately following in the pattern are printed. These details are covered in the complete algorithm at the end of this chapter. Occasionally, the form

  XXX CR

  is preferred for a negative number. In this case, the pattern would be

```
MVC     PLINE+1(7),=X'4020212040C3D9'
ED      PLINE+1(7),F2
```

- *Example 8.* Suppose that F2 and F3 are contiguous two-byte fields, each containing a number of the form

  X.XX

  To print both numbers with one intervening blank, a field separator could be used. For example,

```
MVC     PLINE+1(10),=X'40214B202022214B2020'
ED      PLINE+1(10),F2
```

  puts both numbers into PLINE in the format

  X.XX  X.XX

- *Example 9.* Suppose that F2 and F3 contain two-digit numbers to be printed in the format

XX XX

Note that

```
MVC     PLINE+1(4),=X'40202120'
ED      PLINE+1(4),F2
MVC     PLINE+4(4),=X'40202120'
ED      PLINE+4(4),F3
```

does not produce the desired result; the pattern for F3 causes the last digit of the first number to be erased. Instead, the following code should be used:

```
MVC     PLINE+4(4),=X'40202120'
ED      PLINE+4(4),F3
MVC     PLINE+1(4),=X'40202120'
ED      PLINE+1(4),F2
```

In general, problems can be avoided by editing fields to be printed on the same line from right to left (instead of the more natural left to right).

Program 5-1 illustrates the use of the instructions introduced to this point.

**Program 5-1**

```
         TITLE 'PAYROLL EXAMPLE UTILIZING PACKED DECIMAL INSTRUCTIONS'
*****************************************************************
*
* THIS PROGRAM CALCULATES EMPLOYEES' PAY.  THE INPUT CARDS MUST
* CONFORM TO THE FOLLOWING FORMAT:
*
*        1-20  EMPLOYEE'S NAME
*        21-22 # OF HOURS WORKED
*        23-26 WAGE RATE AS $XX.XX WHERE THE '$' AND '.' DO
*              NOT APPEAR ON THE INPUT CARD
*        27-80 UNUSED
*
* IF AN EMPLOYEE WORKS OVER 40 HOURS, HE WILL BE PAID TIME
* AND A HALF ON ALL OF THE OVERTIME.  THE LOGIC OF THE
* PROGRAM IS AS FOLLOWS:
*
*   STEP 1.  CALL PRNTHDR TO PRINT THE PAGE HEADER FOR THE
*            FIRST PAGE.
*
*   STEP 2.  READ THE FIRST INPUT CARD.
*
*   STEP 3.  IF END-OF-FILE HAS OCCURRED, GO TO STEP 11.
*
*   STEP 4.  CONVERT THE FIELDS ON THE CARD TO PACKED DECIMAL.
*
*   STEP 5.  IF THE EMPLOYEE WORKED OVER 40 HOURS, GO TO STEP 7.
*
*   STEP 6.  CALCULATE THE PAY = RATE * (# HOURS WORKED).  GO
*            TO STEP 8.
*
*   STEP 7.  CALCULATE THE PAY = (RATE * 40) +
*                                ((RATE * 1.5) * (# HOURS - 40))
*
*   STEP 8.  CONSTRUCT THE PRINT LINE.
*
*   STEP 9.  CALL PRNTLINE TO PRINT THE LINE (AND A NEW HEADER, IF
*            NECESSARY).
*
*   STEP 10. READ THE NEXT INPUT CARD.  GO TO STEP 3.
*
*   STEP 11. EXIT.
*
*****************************************************************
*
PAYROLL  CSECT
         USING PAYROLL,R15
*
```

**Program 5-1 (continued)**

```
***<STEP 1>     PRINT THE PAGE HEADER FOR THE FIRST PAGE
*
         BAL    R12,PRNTHDR
*
***<STEP 2>     READ THE FIRST CARD
*
         XREAD  CARD,80
*
***<STEP 3>     IF END-OF-FILE, GO TO STEP 11.
*
TESTEND  BC     B'0100',EXIT
*
***<STEP 4>     CONVERT FIELDS TO PACKED DECIMAL
*
         PACK   HOURS,HOURSIN PACK # HOURS WORKED
         PACK   RATE,RATEIN   PACK THE PAY RATE
*
***<STEP 5>     IF OVERTIME, GO TO STEP 7.
*
         CP     HOURS,=P'40'  OVER 40 HOURS REQUIRES OVERTIME
         BH     OVERTIME
*
***<STEP 6>     CALCULATE PAY = (HOURS WORKED) * (PAY RATE)
*
         ZAP    PAY,RATE
         MP     PAY,HOURS
         B      BLDPRNT       GO BUILD THE PRINT LINE
*
***<STEP 7>     PAY = (RATE * 40) + ((RATE * 1.5) + (HOURS - 40))
*
OVERTIME ZAP    PAY,RATE
         MP     PAY,=P'40'    GET PAY FOR THE 1ST 40 HOURS
         ZAP    OVTIME,RATE   SAVE THE RATE
         MP     OVTIME,=P'15' GET 1.5 * RATE
         DP     OVTIME,=P'10'
         ZAP    OVHRS,HOURS   CALCULATE # HOURS OF OVERTIME
         SP     OVHRS,=P'40'  OVHRS <- # HOURS OVERTIME
         MP     OVTIME(6),OVHRS
         AP     PAY,OVTIME(6) PAY NOW CONTAINS THE TOTAL
*
***<STEP 8>     CONSTRUCT THE PRINT LINE
*
BLDPRNT  MVC    NAMEOUT,NAMEIN
         MVC    RATEOUT,=X'402020214B2020'
         ED     RATEOUT,RATE
*
         MVC    HOURSOUT,=X'40202120'
         ED     HOURSOUT,HOURS
*
         MVC    PAYOUT,=X'4020206B2020214B2020'
         ED     PAYOUT,PAY+1
*
*
***<STEP 9>     CALL PRNTLINE TO PRINT THE LINE
*
         BAL    R12,PRNTLINE
*
***<STEP 10>    READ THE NEXT CARD AND GO BACK TO STEP 3.
*
         XREAD  CARD,80
         B      TESTEND
*
***<STEP 11>    EXIT.
*
EXIT     BR     R14
*
*
*****************************************************************
*
* THIS ROUTINE IS CALLED TO PRINT A LINE.  IF NECESSARY, PRNTHDR
* WILL BE CALLED TO START A NEW PAGE.  THE LOGIC IS
*
*   STEP 1.  IF THE LINECTR IS LESS THAN OR EQUAL TO 50, GO TO STEP 3.
*
*   STEP 2.  CALL PRNTHDR TO PRINT PAGE HEADERS AND RESET THE LINECTR.
*
*   STEP 3.  PRINT THE LINE (AND SET CARRIAGE CONTROL TO ' ' FOR THE
*            NEXT LINE).
*
*   STEP 4.  EXIT.
*
*****************************************************************
```

**Program 5-1 (continued)**

```
*
PRNTLINE STM   R0,R15,PRNTSAVE    SAVE CALLER'S REGISTERS
*
***<STEP 1>    CHECK LINECTR TO SEE IF HEADERS ARE REQUIRED
*
         CP    LINECTR,=P'50'
         BNH   PRINTNOW          BRANCH IF ROOM ON PAGE
*
***<STEP 2>    CALL PRNTHDR TO PRINT PAGE HEADERS
*
         BAL   R12,PRNTHDR
*
***<STEP 3>    NOW PRINT THE LINE & INCREMENT THE LINECTR
*
PRINTNOW XPRNT PLINE,133
         AP    LINECTR,=P'1'      INCR LINECTR
         MVI   PLINE,C' '         SET CC FOR NEXT LINE
*
***<STEP 4>    EXIT
*
         LM    R0,R15,PRNTSAVE    RESTORE CALLER'S REGISTERS
         BR    R12                RETURN
*
PRNTSAVE DS    16F                SAVE CALLER'S REGISTERS HERE
*
*****************************************************************
*
* THIS ROUTINE JUST PRINTS THE PAGE HEADER, RESETS THE LINECTR,
* AND SETS THE CARRIAGE CONTROL IN PLINE TO CAUSE THE NEXT LINE
* TO BE DOUBLE-SPACED.  THE LOGIC IS
*
*   STEP 1.  PRINT THE HEADER.
*
*   STEP 2.  RESET THE LINECTR TO 3 (NEXT LINE PRINTED IS 3TH OF PAGE)
*
*   STEP 3.  SET CARRIAGE CONTROL TO DOUBLE-SPACE.
*
*   STEP 3.  EXIT.
*
*****************************************************************
*
***<STEP 1>    PRINT THE HEADERS
*
PRNTHDR  XPRNT COLHDR,133
*
***<STEP 2>    RESET THE LINECTR
*
         ZAP   LINECTR,=P'3'
*
***<STEP 3>    SET CARRIAGE CONTROL FOR DOUBLE-SPACE
*
         MVI   PLINE,C'0'
*
***<STEP 4>    EXIT
*
         BR    R12
*
*****************************************************************
*
         LTORG
*
CARD     DS    CL80               IO AREA FOR THE INPUT CARD
         ORG   CARD
NAMEIN   DS    CL20          EMPLOYEE'S NAME
HOURSIN  DS    CL3           HOURS WORKED
RATEIN   DS    CL4           PAY RATE (XX.XX)
         ORG
*
COLHDR   DC    CL133'1'      PAGE HEADER
         ORG   COLHDR+4
         DC    C'NAME'
         ORG   COLHDR+23
         DC    C'HRS.'
         ORG   COLHDR+31
         DC    C'RATE'
         ORG   COLHDR+38
         DC    C'TOTAL PAY'
         ORG
```

**Program 5-1 (continued)**

```
*
PLINE     DC    CL133' '        PRINT LINE
          ORG   PLINE+1
NAMEOUT   DS    CL20            EMPLOYEE'S NAME
          ORG   PLINE+22
HOURSOUT  DS    CL4             HOURS WORKED
          ORG   PLINE+28
RATEOUT   DS    CL7             PAY RATE
          ORG   PLINE+35
PAYOUT    DS    CL10            CALCULATED PAY FOR THIS WEEK
          ORG
*
LINECTR   DS    PL2                  NEXT LINE OF PAGE
*
HOURS     DS    PL2             HOURS WORKED
OVHRS     DS    PL2             OVERTIME HOURS
RATE      DS    PL3             RATE OF PAY (XXX.XX)
PAY       DS    PL5             TOTAL PAY FOR THE WEEK
OVTIME    DS    PL8             OVERTIME PAY

*
R0        EQU   0
R1        EQU   1
R2        EQU   2
R3        EQU   3
R4        EQU   4
R5        EQU   5
R6        EQU   6
R7        EQU   7
R8        EQU   8
R9        EQU   9
R10       EQU   10
R11       EQU   11
R12       EQU   12
R13       EQU   13
R14       EQU   14
R15       EQU   15
          END   PAYROLL
```

## Exercises

Examine the following patterns and source fields. Then fill in the values that are left blank. The first line has been completed as an illustration.

| *Patterns* | | *Numbers* | |
|---|---|---|---|
| P1: | 40 20 20 20 | F1: | 12 3C |
| P2: | 40 20 21 20 | F2: | 00 0C |
| P3: | 5C 20 21 20 | F3: | 01 2C |
| P4: | 40 20 4B 20 20 | F4: | 12 34 56 7C |
| P5: | 40 21 4B 20 20 | F5: | 00 00 12 3C |
| P6: | 40 20 20 6B 20 20 21 4B 20 20 | F6: | 00 00 00 0C |
| P7: | 40 20 20 6B 20 20 21 4B 20 20 40 C3 D9 | F7: | 00 01 23 4D |

| *Instruction* | *Resulting Pattern Value* | *Character String* |
|---|---|---|
| ED P1(4),F1 | 40 F1 F2 F3 | 123 |
| **1.** ED P1(4),F2 | — — — — | _____ |
| **2.** ED P1(4),F3 | — — — — | _____ |
| **3.** ED P2(4),F1 | — — — — | _____ |
| **4.** ED P2(4),F2 | — — — — | _____ |
| **5.** ED P2(4),F3 | — — — — | _____ |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **6.** | ED | P3(4),F1 | — | — | — | — | | | | | | | | | | |
| **7.** | ED | P3(4),F2 | — | — | — | — | | | | | | | | | | |
| **8.** | ED | P3(4),F3 | — | — | — | — | | | | | | | | | | |
| **9.** | ED | P4(5),F1 | — | — | — | — | — | | | | | | | | | |
| **10.** | ED | P4(5),F2 | — | — | — | — | — | | | | | | | | | |
| **11.** | ED | P4(5),F3 | — | — | — | — | — | | | | | | | | | |
| **12.** | ED | P5(5),F1 | — | — | — | — | — | | | | | | | | | |
| **13.** | ED | P5(5),F2 | — | — | — | — | — | | | | | | | | | |
| **14.** | ED | P5(5),F3 | — | — | — | — | — | | | | | | | | | |
| **15.** | ED | P6(10),F4 | — | — | — | — | — | — | — | — | — | — | | | | |
| **16.** | ED | P6(10),F5 | — | — | — | — | — | — | — | — | — | — | | | | |
| **17.** | ED | P6(10),F6 | — | — | — | — | — | — | — | — | — | — | | | | |
| **18.** | ED | P7(13),F4 | — | — | — | — | — | — | — | — | — | — | — | — | — | |
| **19.** | ED | P7(13),F5 | — | — | — | — | — | — | — | — | — | — | — | — | — | |
| **20.** | ED | P7(13),F6 | — | — | — | — | — | — | — | — | — | — | — | — | — | |
| **21.** | ED | P7(13),F7 | — | — | — | — | — | — | — | — | — | — | — | — | — | |

## 5.7 THE SRP INSTRUCTION

The SRP instruction can be used to shift a packed decimal number. A left shift is equivalent to multiplying by a power of 10, and a right shift can be used to calculate the result of dividing by a power of 10. Furthermore, the SRP can be used to round off the result on a right shift. To understand the operation performed by this instruction, it is necessary to know how the direction and number of digits involved in a shift are encoded in a six-bit binary number. This encoding is done as follows:

- A left shift of up to 31 positions is represented by a binary number that designates the number of positions. For example, a left shift of 10 digits is encoded as 001010.
- A right shift of from 1 to 32 positions is specified by subtracting the number of positions from 64 and representing the result as a six-bit binary number. For example, a right shift of 1 may be encoded as

$$\begin{array}{r} 64 \\ -1 \\ \hline 63 = 111111 \end{array}$$

With this in mind, the following detailed description of the SRP instruction should be clear.

Execution of the instruction

SRP D1(L,B1),D2(B2),i (*Shift and Round Decimal*)

causes the contents of the field designated by the first operand to be shifted. The direction and number of positions involved in the shift are determined by doing the following:

- Calculate the address represented by D2(B2).
- Use the rightmost six bits of this address as the encoded form described above.

The sign is not altered unless the result is zero; in this case, the sign is always made positive. If the shift is to the right, the value i (which should be in the range 0 to 9) is used as a rounding factor. That is, i is added to the leftmost digit shifted off the right and, if the result is greater than 9, 1 is added to the result after the shift. If a left shift occurs and nonzero digits are lost, a decimal overflow occurs (which normally causes termination of program execution). The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The result is 0. |
| 1 | The result is negative. |
| 2 | The result is positive. |
| 3 | Overflow occurred. |

Thus, execution of the instruction

```
SRP     RATE,B'000100',0
```

would result in a left shift of four positions, and execution of the instruction

```
SRP     TIME,B'111111',5
```

would result in a right shift of one position, with a rounding factor of 5. Execution of the instruction

```
SRP     WAGE,0(R2),0
```

can cause a shift right or left (depending on the contents of the rightmost six bits of R2).

When the second operand does not involve a register, a decimal value can be specified. In this case, the decimal value is converted to the binary equivalent by the assembler. This leads to the following conventions:

- A left shift of n positions is represented by n.
- A right shift of n positions is represented by (64 − n).

Thus, the first two SRP examples cited earlier could have been coded as follows:

```
SRP     RATE,4,0
```

and

```
SRP     TIME,(64-1),5
```

**Exercises**

For each of the following exercises, show the value that would be in FLD1 after execution of the instruction.

| *FLD1* | *Instruction* | *FLD1 after Execution* |
|---|---|---|
| **1.** 00004F | SRP FLD1,4,0 | _____ |
| **2.** 00013D | SRP FLD1,2,0 | _____ |
| **3.** 0000262C | SRP FLD1,(64-2),5 | _____ |
| **4.** 01925F | SRP FLD1,(64-3),0 | _____ |
| **5.** 02654C | SRP FLD1,(64-2),5 | _____ |
| **6.** 0000168C | SRP FLD1,2,5 | _____ |
| **7.** 0000168D | SRP FLD1,(64-4),5 | _____ |

## 5.8 THE CVB AND CVD INSTRUCTIONS

In the examples given in the text so far, the pseudo-instructions XDECI and XDECO have been used to convert numbers in character format to binary representations and vice versa. These pseudo-instructions are not available on most assemblers. In this section, the instructions for converting numbers in packed decimal format to their binary representations and for converting from binary to packed decimal format are introduced. Then, the standard methods for converting between binary and character representations of numbers are indicated.

Execution of the instruction

```
CVB     r,D(X,B)        (Convert to Binary)
```

causes the contents of r to be replaced by the binary representation of the packed decimal number at the address D(X,B). If D(X,B) is not the address of a doubleword (i.e., is not a multiple of 8), a specification exception occurs. If D(X,B) is the address of a doubleword that does not contain a valid packed decimal number, a data exception occurs. Finally, if the packed decimal number at D(X,B) is too large to be represented in 32 bits, a fixed-point divide exception occurs.

Assume, for example, that DWORD is a doubleword whose contents are 000000000000010F. The execution of the instruction

```
CVB     R1,DWORD
```

will cause the contents of R1 to be replaced by 0000000A.

Execution of the instruction

CVD r,D(X,B) *(Convert to Decimal)*

causes the contents of the doubleword at D(X,B) to be replaced by the packed decimal representation of the binary number in r. If D(X,B) is not the address of a doubleword, a specification exception will occur.

Thus, if R1 contains FFFFFFFF, execution of the instruction

CVD R1,DWORD

replaces the contents of D(X,B) with 000000000000001D. (Actually, a determination of which valid negative sign is to be used must be made. It is sufficient, however, for the reader to assume only that some valid negative sign is used.)

The standard technique for converting the character representation of a number to the binary representation of that number is first to convert the number to packed decimal format by use of a PACK instruction and then to convert the resulting packed decimal number to binary by use of a CVB instruction. Essentially the reverse of this process—utilizing a CVD instruction and then an UNPK instruction—is used to convert from binary to character representations. These processes are illustrated in Figure 5-3.

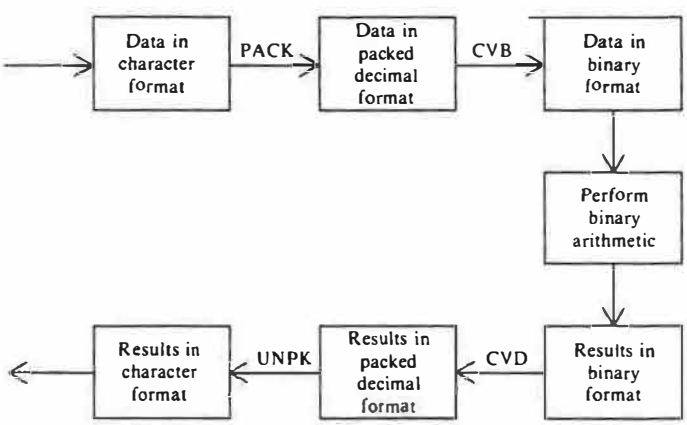



**Figure 5-3**

The reader is again cautioned that the UNPK instruction actually converts a number to zoned decimal representation and that an OI instruction should be used to assure that the sign digit is F if character format is desired.

## 5.9 THE EDMK INSTRUCTION

The EDMK instruction provides all of the facilities provided by the ED instruction and, in addition, sets a pointer to the first nonzero digit of an edited number string under the proper conditions. The general format of this instruction is

```
EDMK      D1(L,B1), D2(B2)          (Edit and Mark)
```

Execution of this instruction has precisely the same effect on the first operand as does the execution of the corresponding ED instruction. Further, let x be the last character of the result such that the following conditions are met:

- x was formed by the replacement of a 20 or 21 by a source digit.
- The significance indicator was off before the replacement occurred (i.e., the significance indicator was turned from off to on with the creation of x).

In this case, the rightmost three bytes of R1 are set to the address of x. If no such x exists, R1 is left unaltered. Normally, since there will be at most one character that fulfills the above conditions, the last such character is usually the first such character as well.

To illustrate the effect of the execution of an EDMK instruction, suppose that

F1 contains 402020214B2020
F2 contains 01230F
F3 contains 00097F

Then, execution of the instruction

```
EDMK      F1,F2
```

sets the contents of F1 to 4040F1F24BF3F0 and places the address of F1 + 2 in the rightmost three bytes of R1. The leftmost byte of R1 is unaltered. On the other hand, execution of the instruction

```
EDMK      F1,F3
```

replaces the contents of F1 with 404040404BF9F7 and R1 is unaltered. In this case, the significance indicator is turned on because of the presence of the 21 (the significance starter).

The two most common uses of the EDMK are to insert a dollar sign in front of a number representing a cash amount and to insert a minus sign in front of a negative number. As a specific example, suppose that F2 is a three-byte field containing a valid positive packed decimal number and that F1

contains the same pattern as in the previous example. Then, if the packed decimal number in F2 has three or more significant digits (i.e., has fewer than three leading zeros), execution of the instruction

```
EDMK    F1,F2
```

leaves the address of the first nonblank in the right three bytes of R1. What is really necessary, however, is that R1 point to the first nonblank character under all conditions. This may be accomplished by means of the following two instructions:

```
LA      R1,F1+4
EDMK    F1,F2
```

Execution of the first of these instructions puts the eventual address of the period into R1. If R1 is not altered by execution of the EDMK instruction, the period is the first nonblank character in F1. A complete sequence of instructions to put the number and the dollar sign into F1 is as follows:

```
LA      R1,F1+4
EDMK    F1,F2
BCTR    R1,R0          SUBTRACT 1 FROM R1
MVI     0(R1),C'$'     PUT IN THE $
```

Although numbers are sometimes converted to printable form through the use of an UNPK and an OI instruction, an ED or an EDMK instruction should be used in most cases. This concludes the discussion on the subject of editing output. It will be assumed from this point on that you are equipped to edit all of your output.

Program 5-2 illustrates a variety of the techniques discussed up to this point. You should study it carefully, along with the sample output in Table 5-1, before continuing.

Table 5-1 is an example of the output of GROWTH, given an initial balance of $10,000, a target balance of $20,000, an interest rate of 10 percent, and four interest periods per year.

**Table 5-1**

| INTEREST PERIOD | BEGINNING BALANCE | INTEREST | END BALANCE |
|---|---|---|---|
| 1 | 10,000.00 | 250.00 | 10,250.00 |
| 2 | 10,250.00 | 256.25 | 10,506.25 |
| 3 | 10,506.25 | 262.66 | 10,768.91 |
| 4 | 10,768.91 | 269.22 | 11,038.13 |
| 5 | 11,038.13 | 275.95 | 11,314.08 |
| 6 | 11,314.08 | 282.85 | 11,596.93 |
| 7 | 11,596.93 | 289.92 | 11,886.85 |

**Table 5-1 (continued)**

| INTEREST PERIOD | BEGINNING BALANCE | INTEREST | END BALANCE |
|---|---|---|---|
| 8 | 11,886.85 | 297.17 | 12,184.02 |
| 9 | 12,184.02 | 304.60 | 12,488.62 |
| 10 | 12,488.62 | 312.22 | 12,800.84 |
| 11 | 12,800.84 | 320.02 | 13,120.86 |
| 12 | 13,120.86 | 328.02 | 13,448.88 |
| 13 | 13,448.88 | 336.22 | 13,785.10 |
| 14 | 13,785.10 | 344.63 | 14,129.73 |
| 15 | 14,129.73 | 353.24 | 14,482.97 |
| 16 | 14,482.97 | 362.07 | 14,845.04 |
| 17 | 14,845.04 | 371.13 | 15,216.17 |
| 18 | 15,216.17 | 380.40 | 15,596.57 |
| 19 | 15,596.57 | 389.91 | 15,986.48 |
| 20 | 15,986.48 | 399.66 | 16,386.14 |
| 21 | 16,386.14 | 409.65 | 16,795.79 |
| 22 | 16,795.79 | 419.89 | 17,215.68 |
| 23 | 17,215.68 | 430.39 | 17,646.07 |
| 24 | 17,646.07 | 441.15 | 18,087.22 |
| 25 | 18,087.22 | 452.18 | 18,539.40 |
| 26 | 18,539.40 | 463.49 | 19,002.89 |
| 27 | 19,002.89 | 475.07 | 19,477.96 |
| 28 | 19,477.96 | 486.95 | 19,964.91 |
| 29 | 19,964.91 | 499.12 | 20,464.03 |

AVG INTEREST = $360.83

**Program 5-2**

```
        TITLE 'A PROGRAM TO SHOW THE GROWTH OF AN INVESTMENT'
*****************************************************************
*
* THIS PROGRAM PRODUCES A TABLE WHICH SHOWS THE GROWTH OF A PRINCIPLE
* AMOUNT OF MONEY WHICH IS INVESTED AT A FIXED RATE OF INTEREST.  THE
* INPUT WILL INDICATE THE BEGINNING PRINCIPLE, THE TARGET AMOUNT, THE
* INTEREST RATE, AND THE NUMBER OF PERIODS FOR WHICH THE INTEREST IS
* COMPOUNDED EACH YEAR.  THE OUTPUT WILL BE A TABLE WHICH WILL INDICATE
* FOR EACH PERIOD
*
*       THE BEGINNING BALANCE
*       THE INTEREST FOR THE PERIOD
*       THE FINAL BALANCE FOR THE PERIOD
*
* THE CALCULATION IS TERMINATED WHEN THE PRINCIPLE AT THE END OF A
* PERIOD EQUALS OR EXCEEDS THE TARGET AMOUNT.
*
* THE PROGRAM ACCEPTS A SINGLE INPUT CARD CONFORMING TO THE FOLLOWING
* FORMAT:
*
*       COLUMNS         CONTENTS
*
*         1-7           BEGINNING PRINCIPLE (IN CENTS)
*         9-15          TARGET AMOUNT (IN CENTS)
*        17-22          ANNUAL INTEREST RATE (TO FOUR DECIMAL PLACES)
*        24-25          THE # OF INTEREST PERIODS PER YEAR
*
```

**Program 5-2 (continued)**

```
* THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*   STEP 1.  READ THE INPUT CARD AND GET THE VALUES OFF IT.
*
*   STEP 2.  CALL PRNTHDRS TO PRINT THE HEADERS FOR THE FIRST PAGE.
*
*   STEP 3.  IF THE CURRENT PRINCIPLE HAS REACHED THE TARGET AMOUNT,
*            GO TO STEP 8.
*
*   STEP 4.  CALCULATE THE VALUES FOR THE NEXT INTEREST PERIOD.
*
*   STEP 5.  CALL PRNTLINE TO PRINT THE LINE FOR THE NEXT PERIOD.
*
*   STEP 6.  ADD THE INTEREST FOR THE PERIOD TO THE TOTAL INTEREST.
*
*   STEP 7.  ADD THE INTEREST FOR THE PERIOD TO THE CURRENT PRINCIPLE
*            AND GO BACK TO STEP 3.
*
*   STEP 8.  CALCULATE THE AVERAGE INTEREST PER PERIOD.
*
*   STEP 9.  PRINT THE FINAL LINE.
*
*   STEP 10. EXIT.
*
*****************************************************************
*
GROWTH   CSECT
         USING GROWTH,R15
*
***<STEP 1>    READ THE INPUT AND GET THE STARTING VALUES
*
         XREAD CARD,80              READ THE CARD
         PACK  CURPRIN,BEGPRIN      GET THE 1ST PRINCIPLE
         PACK  TARGPRIN,TARGAMNT    AND THE TARGET AMOUNT
*
         PACK  WORK,ANNULINT        CALCULATE INTEREST PER PERIOD
         SRP   WORK,3,0             ANNUAL RATE * 1000
         PACK  NUMPERYR,INTPERDS
         DP    WORK,NUMPERYR        DIVIDED BY # PERIODS PER YEAR
         SRP   WORK(6),(64-3),5     DIVIDED BY 1000, ROUNDED
         ZAP   INTPER,WORK(6)       THE INTEREST PER PERIOD
*
***<STEP 2>    PRINT HEADERS FOR THE FIRST PAGE
*
         BAL   R12,PRNTHDRS
*
***<STEP 3>    TEST FOR END OF THE CALCULATION
*
CALCLOOP CP    CURPRIN,TARGPRIN     HAS PRINCIPLE REACHED TARGET?
         BNL   PRNTLAST             YES -> BRANCH
*
***<STEP 4>    CALCULATE THE INTEREST FOR THE NEXT PERIOD & BUILD LI
*
         ZAP   WORK,CURPRIN
         MP    WORK,INTPER          PRINCIPLE * INTEREST
         SRP   WORK,(64-6),5        GET IT IN CENTS ROUNDED
         ZAP   CURINT,WORK
*
         ZAP   NEWPRIN,CURPRIN      BAL AT END OF PERIOD = STARTING BA
         AP    NEWPRIN,CURINT                              + INTEREST
*
         AP    PERIOD,=P'1'
         MVC   OINTPER,=X'40202120'
         ED    OINTPER,PERIOD       PUT IN THE NUMBER OF THE PERIOD
*
         MVC   OBEGBAL,=X'4020206B2020214B2020'
         ED    OBEGBAL,CURPRIN      PUT IN THE BEGINNING BALANCE
*
         MVC   OINTERST,=X'4020206B2020214B2020'
         ED    OINTERST,CURINT      PUT IN THE INTEREST FOR THE PERIOD
*
         MVC   OENDBAL,=X'4020206B2020214B2020'
         ED    OENDBAL,NEWPRIN      PUT IN THE NEW PRINCIPLE
*
***<STEP 5>    CALL PRNTLINE TO PRINT THE LINE
*
         BAL   R12,PRNTLINE
*
***<STEP 6>    ACCUMULATE TOTAL INTEREST
*
         AP    TOTINT,CURINT
*
***<STEP 7>    RESET CURRENT PRINCIPLE TO NEW VALUE (ADD IN INTEREST
*
         ZAP   CURPRIN,NEWPRIN
         B     CALCLOOP
```

**Program 5-2 (continued)**

```
*
***<STEP 8>     CALCULATE AVERAGE INTEREST PER PERIOD
*
PRNTLAST SRP    TOTINT,1,0          MULT TOTAL INT * 10
         DP     TOTINT,PERIOD
         SRP    TOTINT(6),(64-1),5 GET AVG PER PERIOD
*
         LA     R1,AVGINT+7
         MVC    AVGINT,=X'4020206B2020214B2020'
         EDMK   AVGINT,TOTINT+2
         BCTR   R1,0
         MVI    0(R1),C'$'          R1 POINTS JUST TO LEFT OF 1ST DIGIT
*
***<STEP 9>     PRINT FINAL LINE
*
         XPRNT LASTLINE,35
*
***<STEP 10>    EXIT
*
         BR     R14
*
*****************************************************************
*
* THIS ROUTINE IS CALLED TO PRINT A LINE.  IF NECESSARY, PRNTHDRS
* WILL BE CALLED TO START A NEW PAGE.  THE LOGIC IS
*
*   STEP 1.  IF THE LINECTR IS LESS THAN OR EQUAL TO 50, GO TO STEP 3.
*
*   STEP 2.  CALL PRNTHDRS TO PRINT PAGE HEADERS AND RESET THE LINECTR.
*
*   STEP 3.  PRINT THE LINE (AND SET CARRIAGE CONTROL TO ' ' FOR THE
*            NEXT LINE).
*
*   STEP 4.  EXIT.
*
*****************************************************************
*
PRNTLINE STM    R0,R15,PRNTSAVE     SAVE CALLER'S REGISTERS
*
***<STEP 1>     CHECK LINECTR TO SEE IF HEADERS ARE REQUIRED
*
         CP     LINECTR,=P'50'
         BNH    PRINTNOW            BRANCH IF ROOM ON PAGE
*
***<STEP 2>     CALL PRNTHDRS TO PRINT PAGE HEADERS
*
         BAL    R12,PRNTHDRS
*
***<STEP 3>     NOW PRINT THE LINE & INCREMENT THE LINECTR
*
PRINTNOW XPRNT PLINE,133
         AP     LINECTR,=P'1'       INCR LINECTR
         MVI    PLINE,C' '          SET CC FOR NEXT LINE
*
***<STEP 4>     EXIT
*
         LM     R0,R15,PRNTSAVE     RESTORE CALLER'S REGISTERS
         BR     R12                 RETURN
*
PRNTSAVE DS     16F                 SAVE CALLER'S REGISTERS HERE
*
*****************************************************************
*
* THIS ROUTINE JUST PRINTS THE PAGE HEADERS, RESETS THE LINECTR,
* AND SETS THE CARRIAGE CONTROL IN PLINE TO CAUSE THE NEXT LINE
* TO BE DOUBLE-SPACED.  THE LOGIC IS
*
*   STEP 1.  PRINT THE 2 HEADERS.
*
*   STEP 2.  RESET THE LINECTR TO 4 (NEXT LINE PRINTED IS 4TH OF PAGE)
*
*   STEP 3.  SET CARRIAGE CONTROL TO DOUBLE-SPACE.
*
*   STEP 4.  EXIT.
*
*****************************************************************
*
***<STEP 1>     PRINT THE HEADERS
*
PRNTHDRS XPRNT COLHDR1,133
         XPRNT COLHDR2,133
*
***<STEP 2>     RESET THE LINECTR
*
         ZAP    LINECTR,=P'4'
*
```

```
***<STEP 3>     SET CARRIAGE CONTROL FOR DOUBLE-SPACE
*
         MVI    PLINE,C'0'
*
***<STEP 4>     EXIT
*
         BR     R12
*
*****************************************************************
*
         LTORG
*
CARD     DS     CL80                IO AREA FOR THE INPUT CARD
         ORG    CARD
BEGPRIN  DS     CL7                 BEGINNING PRINCIPLE IN CENTS
         ORG    CARD+8
TARGAMNT DS     CL7                 END WHEN THIS VALUE IS REACHED
         ORG    CARD+16
ANNULINT DS     CL6                 ANNUAL INTEREST TO 4 DEC PLACES
         ORG    CARD+23
INTPERDS DS     CL2                 INTEREST PERIODS PER YEAR
         ORG
*
COLHDR1  DC     CL133'1'            FIRST PAGE HEADER
         ORG    COLHDR1+2
         DC     C'INTEREST'
         ORG    COLHDR1+25
         DC     C'BEGINNING'
         ORG    COLHDR1+40
         DC     C'INTEREST'
         ORG    COLHDR1+55
         DC     C'END BALANCE'
         ORG
*
COLHDR2  DC     CL133' '
         ORG    COLHDR2+2
         DC     C'PERIOD'
         ORG    COLHDR2+26
         DC     C'BALANCE'
         ORG
*
PLINE    DC     CL133' '            PRINT LINE
         ORG    PLINE+1
OINTPER  DS     CL4                 INTEREST PERIOD
         ORG    PLINE+23
OBEGBAL  DS     CL10                STARTING BALANCE
         ORG    PLINE+38
OINTERST DS     CL10                INTEREST FOR PERIOD
         ORG    PLINE+53
OENDBAL  DS     CL10                NEW BALANCE
         ORG
*
LASTLINE DC     C'0'
         DC     CL10' '
         DC     C'AVG INTEREST ='
AVGINT   DS     CL10
*
*
CURINT   DS     PL4                 INTEREST FOR PERIOD
CURPRIN  DS     PL4                 CURRENT PRINCIPLE
NEWPRIN  DS     PL4                 NEW PRINCIPLE
TARGPRIN DS     PL4                 TARGET PRINCIPLE
*
INTPER   DS     PL4                 INTEREST PER PERIOD (TO 4 DEC PLACES)
PERIOD   DC     PL2'0'              INTEREST PERIOD (FROM 1)
NUMPERYR DS     PL2                 INTEREST PERIODS PER YEAR
*
TOTINT   DC     PL8'0'              TOTAL INTEREST
*
WORK     DS     PL8                 A WORK AREA
LINECTR  DS     PL2                 NEXT LINE OF PAGE
*
R0       EQU    0
R1       EQU    1
R2       EQU    2
R3       EQU    3
R4       EQU    4
R5       EQU    5
R6       EQU    6
R7       EQU    7
R8       EQU    8
R9       EQU    9
R10      EQU    10
R11      EQU    11
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
         END    GROWTH
```

## Exercises

Each of the following two dumps was produced by a data exception. What can you deduce about what went wrong?

**1.**

```
PSW:  FF000000 CF00082C

R0-7 :F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000008B0 000008F8 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      47F0F810   F5F5F5F5   F5F5F5F5   F5F5F5F5      *.08.555555555555*
000010      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000010 - 0007C0    ARE IDENTICAL
0007D0      F5F5F5F5   00003000   033F0500   002FF5F5      *5555..........55*
0007E0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   0007E0 - 000800    ARE IDENTICAL
000810      E000F855   00504740   F852F259   F7D4F855      *\.8..&. 8.2.7M8.*
000820      F235F7DA   F85FFC53   F7D4F7DA   E020F854      *2.7.8...7M7.\.8.*
000830      0051D207   F849F8A8   DE07F849   F7D6E020      *..K.8.8y..8.7O\.*
000840      F8480009   47F0F810   F04040F0   F0F0F0F8      *8....08.0  00008*
000850      F0F507FE   F0F0F0F0   F3F0F0F0   F0F3F3F5      *05..000030000335*
000860      F0F0F0F0   F2404040   40404040   40404040      *00002           *
000870      40404040   40404040   40404040   40404040      *                *
            LINES:   000870 - 000890    ARE IDENTICAL
0008A0      40404040   40F5F5F5   40212020   20202020      *     555 .......*
0008B0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**2.**

```
PSW:  FF000000 CF0005BC

R0-7 :F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000630 00000678 00000000

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      4700F5D3   0050F259   F558F5D3   47F0F594      *..5L.&2.5.5L.05m*
000010      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000010 - 000540    ARE IDENTICAL
000550      F5F5F5F5   F5F5F5F5   00000000   880C0002      *55555555....h...*
000560      0FF5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *.555555555555555*
000570      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000570 - 000580    ARE IDENTICAL
000590      F5F5F5F5   E000F5D3   00504740   F5D0F224      *5555\.5L.&. 5}2.*
0005A0      F55EF5D3   FB52F558   F55EE020   F5D20051      *5;5L..5.5;\.5K..*
0005B0      D207F5C7   F628DE07   F5C7F550   E020F5C6      *K.5G6...5G5&\.5F*
0005C0      000947F0   F594F040   21202020   202020F5      *...05m0 .......5*
0005D0      07FEF0F0   F0F0F2F0   40404040   40404040      *..000020        *
0005E0      40404040   40404040   40404040   40404040      *                *
            LINES:   0005E0 - 000610    ARE IDENTICAL
000620      404040F5   F5F5F5F5   40212020   20202020      *   55555 .......*
000630      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

At this point, you should be capable of obtaining input values without using XDECI and converting output values to character format without using XDECO. Therefore, neither of these instructions should be utilized in the following exercises.

**3.** Write a program that produces summary reports for weather. The program should read in records conforming to the following format:

| *Positions* | *Contents* |
|---|---|
| 1–6 | Date (MMDDYY) |
| 7–10 | High temperature in Fahrenheit (to 1 decimal place) |
| 11–14 | Low temperature |
| 15–18 | Normal low |

The program should produce the following report, where all values are properly rounded:

TEMPERATURE SUMMARY

| DATE | LOW(F) | HIGH(F) | LOW(C) | HIGH(C) | NORMAL LOW(F) | DIFF |
|---|---|---|---|---|---|---|
| 6/16/89 | 62.3 | 76.7 | 16.8 | 24.8 | 62.6 | .3– |
| 6/17/89 | 64.6 | 79.3 | 18.1 | 26.3 | 62.8 | 1.8 |
| . | . | . | . | . | | |
| . | . | . | . | . | | |
| AVERAGES: | 63.5 | 78.1 | 17.5 | 25.6 | | |

The program should utilize the packed decimal format for all of the conversions and computation of averages.

**4.** There are many different forms of money used in the world. If you travel, you will find yourself exchanging currencies (for example, you might find that you could exchange $100 US for 13,894 Japanese yen). The relative values of currencies fluctuate. Occassionally, this leads to situations where, by exchanging several currencies, you could actually end up with slightly more money than you started with. For example, you might trade $100 for 13,894 yen, which could be traded for 144,775 Italian lira, which could finally be traded for $100.47 US. Such trades are called "arbitrage." Clearly, such situations can only last for a short time, since traders will immediately start taking advantages of the small price advantages, causing the prices to become "consistent" (in the sense that the undervalued currencies will be bid up slightly, and the overvalued currencies will drop slightly in value). With the use of computers, it has become possible to spot such opportunities almost

instantly. In this assignment, you are to read in the "conversion factors" for 6 separate currencies. The currencies will be those of the Italy, West Germany, Japan, Britain, Colombia and the United States. Input to the program will be 21 records conforming to the following format:

| *Position* | *Contents* |
|---|---|
| 1–3 | country code 1 (ITA, WGR, JAP, BRT, or USA) |
| 4–6 | country code 2 |
| 7–16 | the factor to multiply by when converting currency from country 2 to currency from country 1 (xxxx.xxxxxx) |

Note that the factor to convert from country 1's currency to country 2's can be calculated as (1 / (the factor for going from country 2 to country 1)). As sample input, you could use

```
ITAWGR0731123911
ITAJAP0010370317
ITABRT2324207400
ITACOL0003946685
ITAUSA1440922103
WGRJAP0000014183
WGRBRT0003178952
WGRCOL0000005396
WGRUSA0001970832
JAPBRT0224121170
JAPCOL0000380565
JAPUSA0138946780
BRTCOL0000001699
BRTUSA0000619963
COLUSA0365096745
```

From this input, your program should first print a table similar to the following:

CURRENCY EXCHANGE VALUES

| | ITA | WGR | JAP | BRT | COL | USA |
|---|---|---|---|---|---|---|
| ITA | | 001368 | .096429 | .000430 | .253377 | .000694 |
| WGR | 731.123911 | | 70.506944 | .314569 | 185.322460 | .507400 |
| . | . | . | . | . | . | . |
| . | . | . | . | . | . | . |
| USA | 1440.922103 | 1.970832 | 138.946780 | .619963 | 365.096745 | |

That is, it should compute the complementary conversion factors and print the whole table (you should create a 6 × 6 table of these factors). Then, your program should look for "opportunities." That is, it should search for 3 currencies (call them, A, B, and C) such that you could convert A → B → C → A and end up with significantly more money than you started with. To determine what "significantly more" means, your program should read in one last record which contains a percent in positions 1–5 (x.xxxx). Significantly more will be taken to mean that the final result exceeds the original value by at least the given percentage. For example, if your input percentage were

00500 (i.e., 0.05%)

then the trade

BRT → JAP → COL → BRT should be reported (along with the percentage increase)

To search for these opportunities, your program will need to use an algorithm similar to the following:

```
for (each of the 6 countries)
    Call the chosen country A
    for (each of the remaining 5 countries)
        Call the chosen country B
          for (each of the remaining 4 countries)
            Call the chosen country C
            If (A → B → C → A would produce a significant
                increase)
                report on the A → B → C → A opportunity
```

Note that 6 × 5 × 4 = 120 possible trades must be considered.

**5.** Write a program to calculate the average cost per square foot of a plot of land. Specifically, your program should perform the following tasks:

a. The program should read in a set of records in the following format:

| *Positions* | *Contents* |
|---|---|
| 1–4 | Width (in feet) of a plot of land |
| 5–8 | Length (in feet) of the plot |
| 9–15 | Price (in dollars) of the plot |

As the records are read, a report similar to the following should be produced:

| WIDTH | LENGTH | AREA | COST | COST/SQ. FT. |
|---|---|---|---|---|
| 100 | 50 | 5000 | 9,000 | 1.80 |
| 150 | 200 | 30000 | 6,000 | .20 |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |

b. At end-of-file, a single line conforming to the following format should be produced:

TOTAL AREA = 84,000 TOTAL COST = $202,000 AVG. COST/SQ. FT. = $2.40

All arithmetic operations should be done with decimal arithmetic instructions.

**6.** Write a program that will produce an amortization table for an installment loan. The input will indicate the principal of the loan, the nominal annual interest rate, and the monthly payment. The output from your program will be a table that will indicate, for each month of the life of the loan, the payment number, the payment, the portion of the payment applied to principal repayment, and the outstanding principal at the end of the month. All arithmetic operations should be done with decimal instructions.

Your program should read a single input record conforming to the following format:

| *Positions* | *Contents* |
|---|---|
| 1–7 | The principal (in cents) |
| 10–15 | The nominal annual interest rate (to four decimal places) |
| 20–25 | Monthly payment |

For example, a loan of $1000.00 at an annual interest rate of 6 percent (.5 percent per month) with monthly payments of $100.00 would be represented as follows:

```
Col.  123456789012345678901234567890123456789012345678901234 5. . .
      0100000  060000    010000
```

The table produced should contain five columns as follows:

*Col. 1:* The payment number, beginning with zero
*Col. 2:* The payment (in the last period, the payment required may be less than a full regular payment)

*Col. 3:* The interest for the month, computed as principal at the beginning of the month multiplied by one-twelfth the annual interest rate, rounded to the nearest cent

*Col. 4:* The portion of the monthly payment applied to the repayment of the principal, computed as the difference between the monthly payment and the interest

*Col. 5:* The principal outstanding at the end of the month after suitable adjustment for the monthly payment transaction, obtained by subtraction

For example, the output produced for the loan described as sample input might be:

| PAYMENT NUMBER | PAYMENT | INTEREST | PRINCIPAL REPAYMENT | OUTSTANDING PRINCIPAL |
|---|---|---|---|---|
| 0 | | | | 1,000.00 |
| 1 | 100.00 | 5.00 | 95.00 | 905.00 |
| 2 | 100.00 | 4.53 | 95.47 | 809.53 |
| 3 | 100.00 | 4.05 | 95.95 | 713.58 |
| 4 | 100.00 | 3.57 | 96.43 | 617.15 |
| 5 | 100.00 | 3.09 | 96.91 | 520.24 |
| 6 | 100.00 | 2.60 | 97.40 | 422.84 |
| 7 | 100.00 | 2.11 | 97.89 | 324.95 |
| 8 | 100.00 | 1.62 | 98.38 | 226.57 |
| 9 | 100.00 | 1.13 | 98.87 | 127.70 |
| 10 | 100.00 | .64 | 99.36 | 28.34 |
| 11 | 28.48 | .14 | 28.34 | 0.00 |

**7.** Frequently, it is necessary to store information into a table so that it can be retrieved and possibly altered at a later time. For example, an automobile parts supply firm might keep a table of parts. Each table entry would contain a parts number and the number of units in stock. In this case, as in many other common cases, the information in one entry of the table is composed of two parts, a key (the part number) and data associated with the key (the number of units in stock).

A variety of efficient techniques can be used to store and retrieve information based on a key. This exercise requires the implementation of one of the more unusual (but highly efficient) of these techniques.

The basic idea of *hashing* is to take a key and convert it through some fixed process to a number in the range from 0 to $n - 1$. The resulting number can then be used to determine which entry in a table should be used to store the data item associated with the key.

In particular, given a key KEY, we compute a hash function HASH(KEY) = X (a number) and use this value as the index into the table where the search is to begin. We shall assume a table with $n$ locations or entries for storing "key-data" pairs. These table entries will be numbered, $0, 1, 2, \ldots, n - 1$. Hash addressing, then, consists of arithmetically converting the KEY of a key-data pair to a number X = HASH(KEY) where $0 \leq X \leq n - 1$. This number is used as an index into the table where the key and the data are to be stored. The number X is said to be obtained by "hashing" the key.

As long as no two keys hash to the same number, the time involved to search for a particular key is the time spent doing the hashing. To enter data having a particular key, the hash function is evaluated and the data is stored in the appropriate table entry. To search the table, the hash function is again evaluated and the computed index indicates the location of the sought data item in the table. Trouble occurs, however, when two keys hash to the same table entry. This situation is called *collision.* Since only one key-data pair may be stored in an entry of the table, it is necessary to find another location for the second (or subsequent) key-data pairs hashing to a particular entry.

Collision problems can be handled by means of the *linear probe.* If upon attempting to enter the key and data into the table, it is found that a collision occurs at an entry X, consecutive entries $X+1, X+2, \ldots$, down the table are searched until an empty entry is found, and the key and data are entered there. If an empty entry is not found before the end of the table is reached, the search is continued at the top of the table.

It should now be clear how a table is searched for a particular key. The key is hashed to obtain the index of the entry X where the key-data should appear in the table. Then the given key is compared with the keys in the table at consecutive entries $X, X+1, X+2, \ldots$, until a match is established. If an empty entry is found before a match is established, the given key is not in the table.

In this exercise, you are to construct a table for looking up the current balance of checking accounts. Use the hash addressing technique discussed above to construct a table of up to 100 entries, each containing a 7-digit account number (a 4-byte packed decimal field) and a 9-digit current balance (a 5-byte packerd decimal field).

The current balance is allowed to go negative.

The program should accept as input three types of records:

1. A "new account" record is used to create a new entry in the hash table. The format of a new account record will be

| | |
|---|---|
| 1-7 | account number |
| 8 | 'N' |
| 9-17 | starting balance |

2. A "processed check" record is used to decrement the current balance. The format of such a record is

| | |
|---|---|
| 1-7 | account number |
| 8 | 'C' |
| 9-17 | amount of the check |

3. A "deposit" record is used to increment the current balance:

| | |
|---|---|
| 1-7 | account number |
| 8 | 'D' |
| 9-17 | amount of the deposit |

Your program should process a sequence of such records, producing a report similar to the following:

CHECKING ACCOUNT TRANSACTION REPORT

| TYPE | ACCOUNT | AMOUNT | BALANCE | ERROR |
|---|---|---|---|---|
| N | 843-1778 | 532.47 | 532.47 | |
| N | 637-0011 | 1,342.00 | 1,342.00 | |
| C | 771-0011 | 1,800.00 | | NO SUCH ACCOUNT |
| N | 771-0011 | 2,500.00 | 2,500.00 | |
| D | 843-1778 | 640.00 | 1,172.47 | |
| C | 637-0011 | 1,500.00 | 158.00- | OVERDRAWN |

TOTALS:
# ACCOUNTS = 24
# CHECKS = 17
# DEPOSITS = 9
AVERAGE CHECK AMOUNT = $187.63
AVERAGE DEPOSIT AMOUNT = $1,101.87

**8.** In the first paragraph of Exercise 7, a table containing keyed entries was introduced. Read that paragraph before reading the rest of this exercise.

One of the more efficient ways to access information stored in a table involves a technique referred to as a *binary search*. To use a binary search to retrieve information in a table, the entries in the table must be sorted into either ascending or descending order, based on the keys in the entries. Since the table that will be constructed by the program described in this exercise will contain entries in ascending order, the following discussion will presume such an ordering.

Assume that a table exists such that all of the entries in the table occur in ascending order, based on their keys.

The precise logic to find the "relevant table entry," given a key K is as follows:

```
LOCATE:  Proc (TABLE,N,K,RELEVANT)
         LOW ← 1

      HIGH ← N
      Do While (HIGH > LOW)
            MID ← (HIGH − LOW) / 2 (rounded down)
            If (K > the MIDth entry of TABLE)
               LOW ← MID + 1
            else
               HIGH ← MID
            Endif
      Enddo
      RELEVANT = HIGH
Endproc
```

---

When this procedure exists, assuming that N was greater than 0, RELEVANT will contain the subscript of the first entry in the table with a key greater than or equal to K.

This technique is slightly slower than the use of a hash table (see previous exercise), but it does allow you to conveniently display the table entries in a sorted order.

This exercise is very similar to the previous exercise; you are to write a program to maintain balances for checking accounts. However, in this version, you are to use a sequential table of up to 100 entries. For each transaction, you will need to locate the relevant entry using a binary search. For new accounts, you will need to "shift" entries in the table to make room for the new entry. Produce a report similar to the one presented in the previous assignment, with the following addition: once all of the transactions have been processed, and the totals have been printed, display all of the existing table entries (in ascending order based on their keys).

## 5.10 THE EDIT ALGORITHM

For completeness, an overview flowchart (Figure 5-4), a detailed flowchart (Figure 5-5), and a step algorithm for the edit process are included here. These should be comprehensible to the reader who has a thorough understanding of the material covered in Section 5.6.

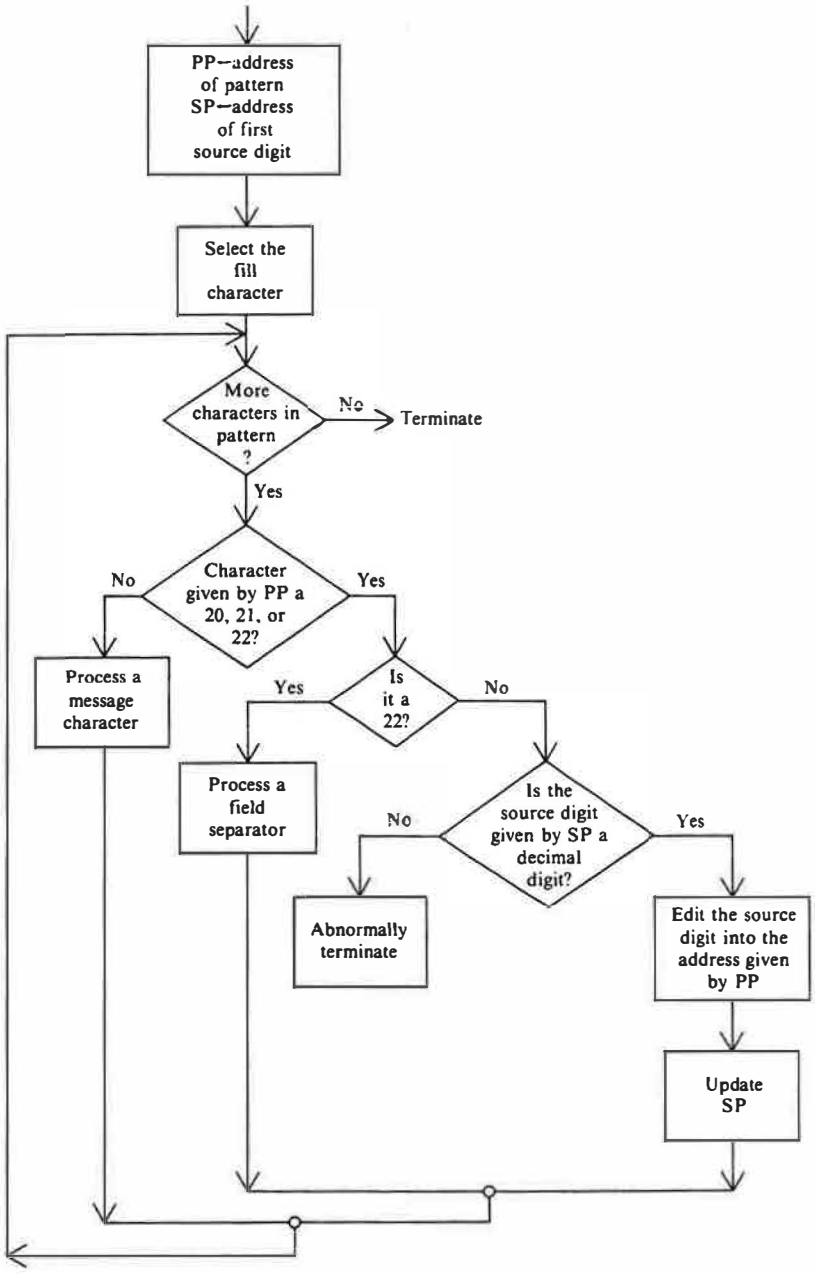

PP—address of pattern
SP—address of first source digit
Select the fill character
More characters in pattern ?
No
Terminate
Yes
Character given by PP a 20, 21, or 22?
No
Yes
Process a message character
Is it a 22?
Yes
No
Process a field separator
Is the source digit given by SP a decimal digit?
No
Yes
Abnormally terminate
Edit the source digit into the address given by PP
Update SP

Figure 5-4

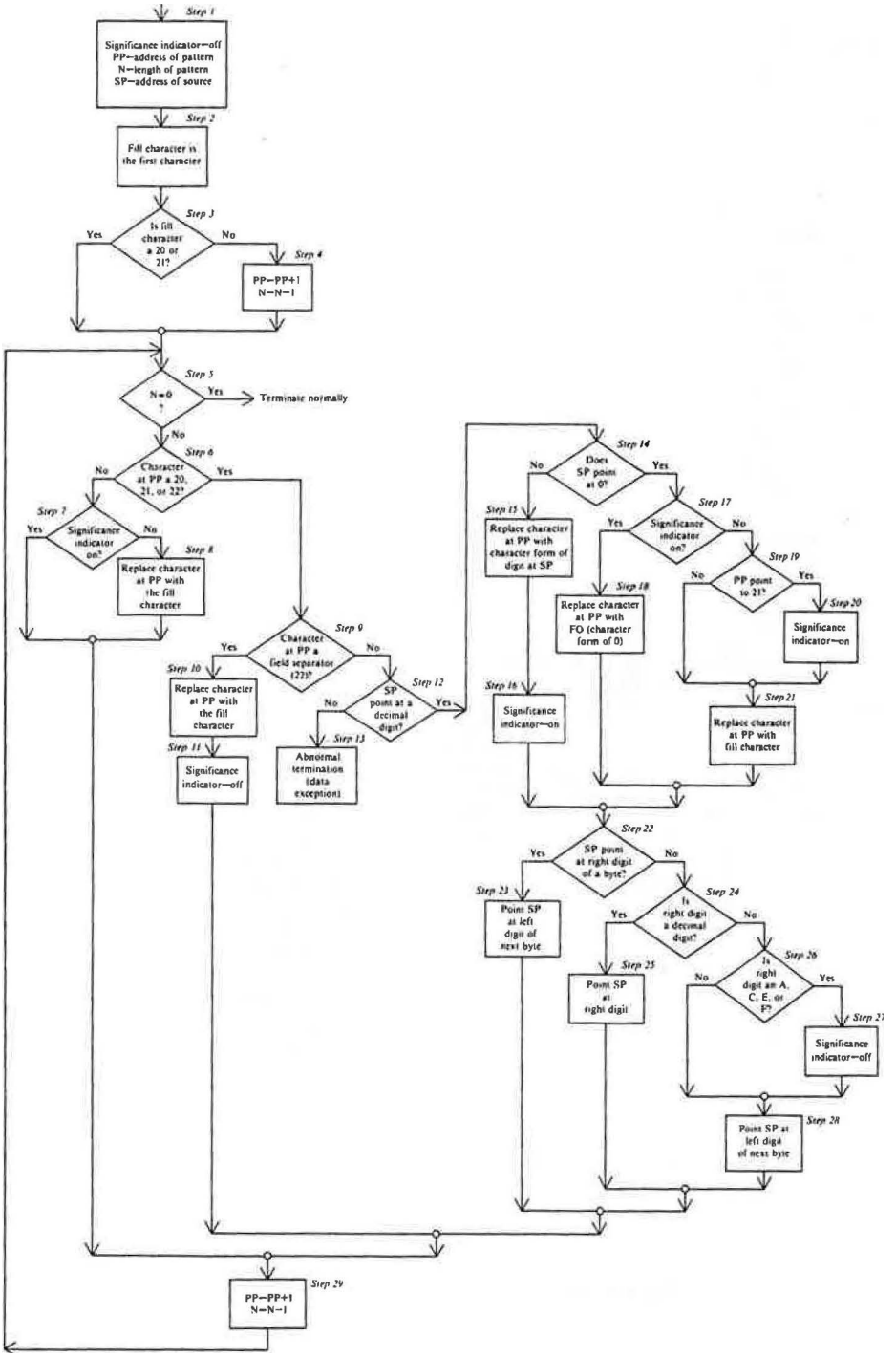

Step 1
Significance indicator—off
PP—address of pattern
N—length of pattern
SP—address of source
Step 2
Fill character is the first character
Step 3
Is fill character a 20 or 21?
Yes
No
Step 4
PP—PP+1
N—N−1
Step 5
N=0 ?
Yes
Terminate normally
No
Step 6
Character at PP a 20, 21, or 22?
No
Yes
Step 7
Significance indicator on?
Yes
No
Step 8
Replace character at PP with the fill character
Step 9
Character at PP a field separator (22)?
Yes
No
Step 10
Replace character at PP with the fill character
Step 11
Significance indicator—off
Step 12
SP point at a decimal digit?
No
Yes
Step 13
Abnormal termination (data exception)
Step 14
Does SP point at 0?
No
Yes
Step 15
Replace character at PP with character form of digit at SP
Step 16
Significance indicator—on
Step 17
Significance indicator on?
Yes
No
Step 18
Replace character at PP with F0 (character form of 0)
Step 19
PP point to 21?
No
Yes
Step 20
Significance indicator—on
Step 21
Replace character at PP with fill character
Step 22
SP points at right digit of a byte?
Yes
No
Step 23
Point SP at left digit of next byte
Step 24
Is right digit a decimal digit?
Yes
No
Step 25
Point SP at right digit
Step 26
Is right digit an A, C, E, or F?
No
Yes
Step 27
Significance indicator—off
Step 28
Point SP at left digit of next byte
Step 29
PP—PP+1
N—N−1

**Figure 5-5**

*Step 1.* Set the significance indicator off. Point PP at the leftmost byte of the pattern. Set N equal to the length of the pattern.

*Step 2.* Call the character pointed at by PP (the first character in the pattern) the *fill character*. The fill character is determined just once; it will not change throughout the execution of the algorithm.

*Step 3.* If the fill character is 20 or 21, go to Step 5.

*Step 4.* Move PP past the fill character (add 1 to PP), and decrement the count of characters in the pattern that have not been processed. (Subtract 1 from N.)

*Step 5.* If N is 0, terminate normally.

*Step 6.* If the next character in the pattern (pointed to by PP) is a 20, 21, or 22, go to Step 9.

*Step 7.* If the significance indicator is on, go to Step 29 (leaving the character in the result).

*Step 8.* Since the significance indicator is off, replace the character in the pattern with the fill character. Go to Step 29.

*Step 9.* If the next character in the pattern (pointed to by PP) is not a field separator (22), go to Step 12.

*Step 10.* Replace the character in the pattern with the fill character.

*Step 11.* Set the significance indicator off. Go to Step 29.

*Step 12.* If the next character in the source field (pointed to by SP) is a decimal digit, go to Step 14.

*Step 13.* At this point, a data exception has occurred, so the algorithm terminates abnormally.

*Step 14.* If the next digit in the source field (pointed to by SP) is a 0, go to Step 17.

*Step 15.* Replace the character in the pattern (the line 20 or 21) with the character form of the digit in the source field (pointed to by SP).

*Step 16.* Turn the significance indicator on. Go to Step 22.

*Step 17.* If the significance indicator is off, go to Step 19.

*Step 18.* Replace the pattern character with F0 (character form of 0). Go to Step 22.

*Step 19.* If the pattern character is not a 21, go to Step 21.

*Step 20.* Turn the significance indicator on.

*Step 21.* Replace the pattern character (the 21) with the fill character.

*Step 22.* If SP points at the left digit of a byte, go to Step 24.

*Step 23.* Point SP at the left digit of the next byte. Go to Step 29.

*Step 24.* If the right digit of the same byte in the source field does not contain a decimal digit, go to Step 26.

*Step 25.* Point SP at the right digit of the byte. Go to Step 29.

*Step 26.* If the right digit is B or D, go to Step 28.

*Step 27.* Turn the significance indicator off.

*Step 28.* Point SP at the left digit of the next byte.

*Step 29.* Move to the next character in the pattern. (Add 1 to PP, and subtract 1 from N.) Go back to Step 5.

# 6

# External Subroutines and DSECTs

## 6.1 FUNCTIONS OF THE ASSEMBLER AND LOADER

The process normally utilized to convert an assembler-language program to executable (machine-language) code is depicted in Figure 6-1.

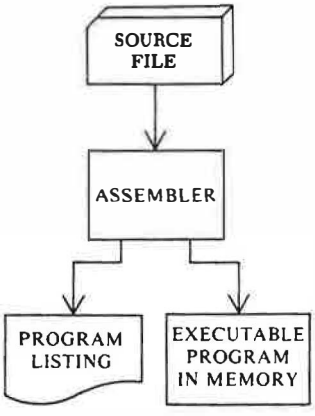



**Figure 6-1**

The *source file*, the assembler-language program, is translated by the assembler into an executable version of the program. If no errors are detected in the source deck during the process of assembly, execution of the translated form of the program may begin immediately. This is certainly the most direct approach to the execution of a program, and it is satisfactory for most short programs that are intended to be executed once or, at most, a few times. However, in a normal industrial environment, the typical program is intended to be executed many, many times. In such cases, it is essential to avoid the

necessity of using the assembler to translate the source file each time a particular program is to be executed. Thus, most industrial computing centers employ a procedure similar to the one illustrated in Figure 6-2.

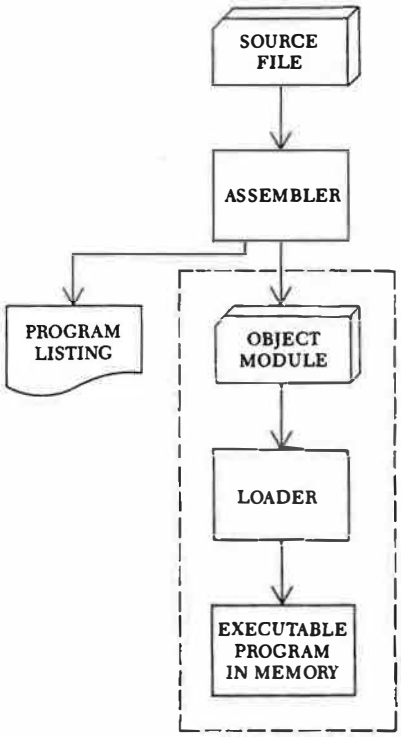



**Figure 6-2**

In this procedure, the output (an executable version of the program) from the assembler is retained in the form of an *object module*. The function of the *loader* is to copy the translated code from the object module into storage so that execution of the program can begin.

Thus, once a completely debugged source file has been obtained, it is necessary to utilize the entire procedure depicted in Figure 6-2 only on the first occasion that the program is executed. On all subsequent occasions, execution of the program may be accomplished simply by utilizing the part of the procedure that is enclosed in broken lines. That is, once an object module has been created, the program may be readied for execution just by utilizing the loader to copy the translated code from the object module into storage.

To understand the discussion of external subroutines that begins in Section 6.2, it will be necessary for the reader to keep in mind the procedure represented by Figure 6-2.

## 6.2 AN INTRODUCTION TO EXTERNAL SUBROUTINES

The reader should, by this time, be well aware of the advantages that may be gained through the use of subroutines. The creation of general subroutines that can be invoked from any point in a program may serve to accomplish the following:

- simplify the logic of the program
- significantly reduce the amount of code required
- facilitate the task of debugging

The subroutines that have been considered to this point are called *internal subroutines*, because they are themselves part of the programs by which they are invoked. It is possible, however, to produce subroutines that may be invoked by any program. Such subroutines are called *external subroutines*, because they may be created and maintained separately from the programs by which they will be invoked.

Two important factors make the general use of external subroutines possible:

1. The source file for an external subroutine may be assembled separately to produce an object module. The resulting object module may then be entered into an object module library, which is simply a collection of object modules residing on some mass storage device such as a disk pack.
2. The loader may accept as input not only an object module but an object module library as well. From this input, the loader will construct an executable program that employs any required external subroutines from the object module library.

The use of external subroutines leads to an extended version of the procedure presented in Figure 6-2. This extended procedure is illustrated in Figure 6-3.

Consideration of Figure 6-3 should indicate the complete independence of the external subroutine from the main program. Thus, external subroutines that perform commonly required tasks may be created and entered into the object module library and made available to any number of programmers. Just how useful it can be to a programmer to have a common set of thoroughly debugged subroutines available should become apparent when the specific examples presented in this chapter are considered.

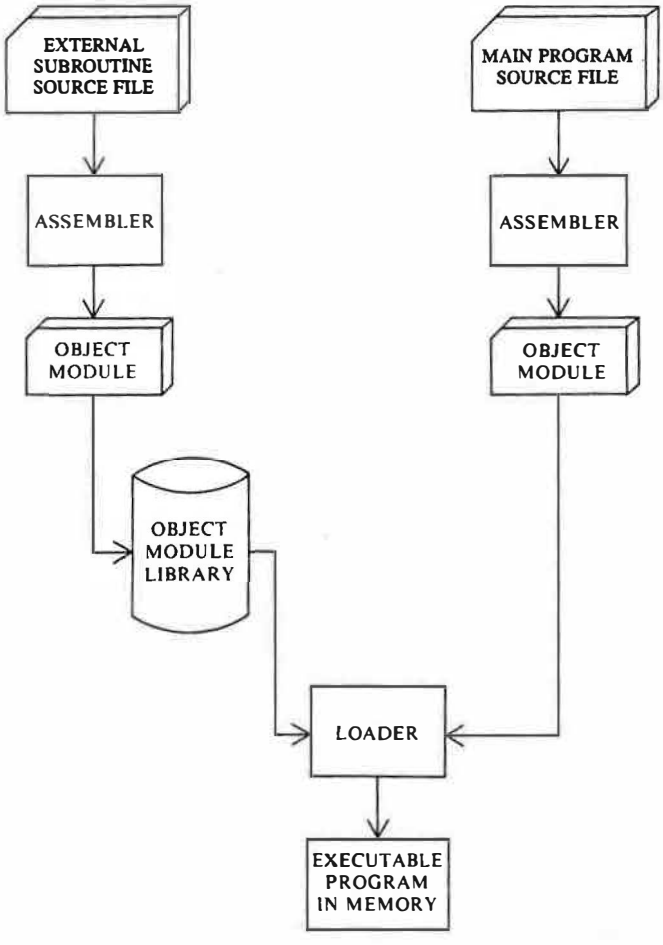



**Figure 6-3**

## 6.3 CODING AND INVOKING EXTERNAL SUBROUTINES

In Section 6.2, we presented an overview of external subroutines. Here, we will discuss the details of the techniques used to code and invoke external subroutines.

Each external subroutine should begin with a statement of the form

```
name        CSECT
```

where name is the label by which the subroutine will be called. The CSECT statement defines the beginning of a *control section*, which is a block of code

that may be assembled and relocated independently of other blocks of code. For our present purpose, it will be useful to think of each control section as constituting a separate subroutine.

As discussed in Section 6.2, once a subroutine has been debugged it is usually assembled into a separate object module. In such cases, the source file for the subroutine will resemble in most respects the source files with which you are familiar. During debugging stages, however, several external subroutines are frequently included in the same source deck with a program by which they are called. Such a source file has the following form:

```
MAINPROG    CSECT
            .
            .
            .
            LTORG
SUBRT1      CSECT
            .
            .
            .
            LTORG
SUBRT2      CSECT
            .
            .
            .
            LTORG
            END   MAINPROG
```

Here, the beginning of each subroutine is determined by the positioning of the CSECT statements. Each new control section will begin on a doubleword boundary. The LTORG statements should be included to ensure that the literals for each subroutine are not assembled as part of the first control section (in this case, MAINPROG) but, rather, are grouped with the subroutine of which they are intended to be a part.

The problem of invoking (or calling) an external subroutine from a main program or another external subroutine is slightly more complex than it may at first appear. For example, assume that SUBRTN is an external subroutine. If SUBRTN has been assembled separately from the calling routine, the statement

```
BAL     R14,SUBRTN
```

will not suffice to invoke SUBRTN. When this statement is encountered by the assembler, SUBRTN will be identified as an undefined symbol. A similar comment applies to the statements

```
        L       R15,=A(SUBRTN)
        BALR    R14,R15
```

In this case, SUBRTN will again be declared an undefined symbol if SUBRTN has been assembled separately. The address of SUBRTN must be obtained before this subroutine can be invoked. This is accomplished through the use of a V-type constant. The format for specifying a V-type constant is

```
label       DC      V(ext-symbol)
```

where ext-symbol is normally the label of a CSECT statement. The referenced CSECT may occur in the same source file or it may be assembled separately. In either event, the actual value generated by this statement is a fullword containing 00000000. The address of the referenced subroutine is filled in by the loader when the executable program is constructed in storage. Thus, the statement

```
SUBADDR     DC      V(SUBRTN)
```

will cause 00000000 to be generated when the program is assembled, but SUBADDR will contain the address of SUBRTN when execution of the program begins. From this discussion, it should be clear that the statements

```
        L       R15,SUBADDR
        BALR    R14,R15
                .
                .
                .
SUBADDR     DC      V(SUBRTN)
```

could be used to call SUBRTN. The call can be made more conveniently through the use of a V-type literal, as follows:

```
        L       R15,=V(SUBRTN)
        BALR    R14,R15
```

Consideration of the use of external subroutines should naturally give rise to the following questions:

- What registers may be altered by the subroutines?
- How should parameters be passed on to the subroutines?
- How should results be passed back to the calling routine?

Before a subroutine can be of use to a large number of programmers, answers to these questions must be carefully documented. To facilitate the creation of common subroutines, a set of basic, standardized linkage conventions have evolved. These are as follows:

1. When control is passed to an external subroutine, R15 should contain the address of the first instruction in the subroutine, and R14 should contain

the address in the calling routine to which control is to be returned. Hence, if the statements

```
        L       R15,=V(SUBRTN)
        BALR    R14,R15
```

were used to call SUBRTN, both R14 and R15 would contain the appropriate values.

2. Critical parameters to be passed to a subroutine are normally passed through a parameter list. A *parameter list* is a set of contiguous fullwords, each of which contains an address. Upon entry to the subroutine, R1 should contain the address of the parameter list. For example, to pass the address of a table to be sorted and the address of a field containing the number of entries in the table to an external subroutine called SORTTAB, the following code could be used:

```
                LA      R1,PARMLIST
                L       R15,=V(SORTTAB)
                BALR    R14,R15
                .
                .
                .
PARMLIST        DC      A(TABLE,NUM)
NUM             DC      F'20'
```

The exact format of the parameter list should be included in the documentation for the subroutine. If only a few parameters are to be passed to a subroutine, these may be passed through registers. For example, the statements

```
        LM      R2,R3,=A(TABLE,20)
        L       R15,=V(SORTTAB)
        BALR    R14,R15
```

could be used to call the subroutine, if it is assumed that the parameters for SORTTAB would be extracted from R2 and R3 rather than from a parameter list. In cases where the number of words in the parameter list can vary, it is common practice to set the leftmost bit of the last word in the list to 1. This allows the called routine to easily determine the number of words in the list.

3. Values to be returned from the subroutine to the calling routine are normally stored in areas designated in the parameter list. However, if just a single value is to be returned, it is frequently passed back in R0.

4. It is the responsibility of the subroutine to store the contents of the registers upon entry to the subroutine and to restore these original values to the registers before returning control to the calling routine. It is the

responsibility of the calling program to place into R13 the address of an 18-fullword area, called a *register save area,* which the called subroutine may utilize to store the original contents of the registers. The format of the register save area is illustrated in Figure 6-4.

| |
|---|
| ignored |
| Backward pointer |
| Forward pointer |
| R14 |
| R15 |
| . . . |
| R12 |

**Figure 6-4**

The uses of the second and third words in the register save area will be discussed later in this section. Words 4 through 18 are used to store the original contents of registers 14, 15, 0, 1, . . . 12. Thus, the statement

```
        STM     R14,R12,12(R13)
```

should be the first instruction executed upon entry to a subroutine. The statements

```
        LM      R14,R12,12(R13)
        BR      R14
```

should be used to restore the original contents of the registers and to return control to the calling routine.

5. Because of the frequent use of R1, R14, and R15 in subroutine calls, these registers should not be used as base registers. For this reason, each external subroutine should contain a section of code that establishes a base register for use in calculating addresses within that routine. For example, the statements

```
                BALR    R12,0
                USING   BASEPT,R12
BASEPT          DS      0H
```

could be used to establish R12 as a base register. The BALR statement simply causes the address of the next executable statement to be placed in R12. (No branch occurs, because the second operand is R0.) The DS statement serves only as a means of establishing an address corresponding to the label BASEPT. (No storage area is reserved, since none is requested.)

The details of the process by which the *operating system* initiates the execution of a program are well beyond the scope of this book. There is one point, however, that should be mentioned in this regard. A save area for utilization by the main program is provided and the register linkage conventions that apply to external subroutines are in effect. Thus, the convention that R15 should contain the address of the first executable instruction of the called routine upon entry to that routine should explain why it has been possible to assume that R15 was properly prepared for use as a base register in all of the examples presented to this point. Likewise, the convention pertaining to R14 should explain why those programs could be exited by branching to the address in R14.

To adhere to the linkage conventions that we have just outlined, each external subroutine (or main program) that calls no external subroutines should begin with a section of code similar to

```
ROUTINE   CSECT
          STM     R14,R12,12(R13)
          BALR    R12,0
          USING   BASEPT,R12
BASEPT    DS      0H
```

This causes the contents of the calling routine's registers to be saved in the save area provided by the calling routine (or operating system) and establishes R12 as the base register. In the interior of the routine, neither the base register nor R13 should be altered. The routine should exit with the instructions

```
          LM      R14,R12,12(R13)
          BR      R14
```

This restores the original contents of the calling routine's registers and returns control to that routine.

Program 6-1, which calls no external subroutines, illustrates the proper linkage to the calling program (or to the operating system).

**Program 6-1**

```
*********************************************************************
*
* THIS PROGRAM READS DATA CARDS, EACH OF WHICH CONTAINS TWO
* NUMBERS.  THE SUM OF THE TWO NUMBERS IS PRINTED.
*
*********************************************************************
*
SUMUP    CSECT
         STM   R14,R12,12(R13)     SAVE CALLER'S REGISTERS
         BALR  R12,0
         USING BASEPT,R12
BASEPT   DS    OH
*
         XPRNT HEADING,28          PRINT A PAGE HEADING
*
         XREAD CARD,80             READ THE FIRST CARD
*
CHECKEOF BC    B'0100',EXIT        BRANCH ON EOF
*
         XDECI R2,CARD             WE ASSUME THAT BOTH NUMBERS
         XDECI R3,0(R1)            ARE VALID
*
         AR    R2,R3               CALCULATE THE SUM
*
         XDECO R2,OUTPUT           PUT PRINTABLE FORM INTO PRINT LINE
*
         XPRNT CRG,13              PRINT THE SUM (SINGLE SPACED)
*
         XREAD CARD,80             TRY TO READ THE NEXT CARD
         B     CHECKEOF            GO CHECK FOR EOF
*
EXIT     LM    R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
         BR    R14                 EXIT
*
CARD     DS    CL80                CARD INPUT AREA
*
CRG      DC    C' '                SINGLE SPACE CARRIAGE CONTROL
OUTPUT   DS    CL12                OUTPUT THE SUM HERE
*
HEADING  DC    C'1THIS IS THE OUTPUT OF SUMUP'
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   SUMUP
```

The situation is somewhat more complex in the case of a main program or subroutine that calls an external subroutine. For purposes of illustration, suppose SUBRTN1 has called SUBRTN2 and that SUBRTN2 is to call SUBRTN3 in turn. Then SUBRTN2 should do the following:

- Establish a save area for use by SUBRTN3.
- Doubly link this save area to the save area provided by SUBRTN1.
- Place the address of this save area in R13.

This can be accomplished by a sequence of instructions similar to

```
LA      R14,SAVEAREA
ST      R14,8(R13)
ST      R13,4(R14)
LR      R13,R14
```

The first ST instruction fills in the forward pointer in the save area in SUBRTN1 with the address of the save area in SUBRTN2. The second ST instruction fills in the backward pointer in the save area in SUBRTN2 with the address of the save area in SUBRTN1. Finally, the LR instruction places the address of the save area in SUBRTN2 into R13.

Program 6-2 illustrates the use of these conventions. In this example, two subroutines, READTAB and SORTTAB, are called by MAIN. Study the listing of this program carefully before proceeding.

**Program 6-2**

```
         TITLE 'EXAMPLE OF A PROGRAM CALLING AN EXTERNAL SUBROUTINE'
*****************************************************************
*
* THIS PROGRAM CALLS THE SUBROUTINE 'READTAB' TO READ IN A TABLE
* OF INTEGERS, XDUMPS THE TABLE, CALLS 'SORTTAB' TO SORT THE
* TABLE, AND THEN XDUMPS THE SORTED TABLE.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  CALL READTAB TO READ IN A TABLE OF INTEGERS.
*
*   STEP 2.  XDUMP THE TABLE OF UNSORTED INTEGERS
*
*   STEP 3.  CALL SORTTAB TO SORT THE TABLE.
*
*   STEP 4.  XDUMP THE TABLE OF SORTED INTEGERS.
*
*   STEP 5.  EXIT.
*
*****************************************************************
*
MAIN     CSECT
         STM    R14,R12,12(R13)     SAVE CALLER'S REGISTERS
         BALR   R12,0               ESTABLISH THE BASE REGISTER
         USING  BASEPT,R12
BASEPT   DS     OH
         LA     R14,SAVEAREA        NOW LINK UP THE SAVE AREAS
         ST     R14,8(R13)
         ST     R13,4(R14)
         LR     R13,R14             POINT R13 AT NEW SAVE AREA
*
***<STEP 1>     CALL READTAB TO READ IN A TABLE OF INTEGERS
*
         LA     R1,=A(TABLE,NUMENT)
         L      R15,=V(READTAB)
         BALR   R14,R15             CALL READTAB
*
***<STEP 2>     XDUMP THE UNSORTED TABLE
*
         XDUMP  TABLE,200
*
***<STEP 3>     CALL SORTTAB TO SORT THE TABLE
*
         LA     R1,=A(TABLE,NUMENT)
         L      R15,=V(SORTTAB)
         BALR   R14,R15
*
***<STEP 4>     XDUMP THE SORTED TABLE
*
         XDUMP  TABLE,200
```

**Program 6-2 (continued)**

```
*
***<STEP 5>     EXIT
*
          L     R13,4(R13)          R13 NOW POINTS AT OLD SAVE AREA
          LM    R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
          BR    R14                 RETURN TO CALLER
*
          LTORG
*
SAVEAREA  DS    18F                 REGISTER SAVE AREA
TABLE     DS    50F                 TABLE TO HOLD THE INTEGERS
NUMENT    DS    F                   SET TO CONTAIN THE NUMBER
*                                   OF ENTRIES IN THE TABLE

*
*****************************************************************
*
* 'READTAB' IS AN EXTERNAL SUBROUTINE THAT READS IN A TABLE OF
* INTEGERS.  THE PARAMETER LIST TO READTAB MUST CONTAIN
*
*        THE ADDRESS OF THE TABLE
*        THE ADDRESS OF A WORD THAT GETS SET TO THE NUMBER OF
*           ENTRIES IN THE TABLE
*
* THE LOGIC OF READTAB IS AS FOLLOWS:
*
*   STEP 1.  SET A POINTER TO THE FIRST ENTRY IN THE TABLE.
*
*   STEP 2.  READ THE FIRST CARD.
*
*   STEP 3.  IF END-OF-FILE HAS OCCURRED, GO TO STEP 6.
*
*   STEP 4.  PUT THE NUMBER INTO THE TABLE.
*
*   STEP 5.  READ THE NEXT CARD AND GO TO STEP 3.
*
*   STEP 6.  CALCULATE THE NUMBER OF ENTRIES, STORE IT, AND
*            RETURN TO THE CALLER.
*
*****************************************************************

*
READTAB  CSECT
         STM   R14,R12,12(R13)     SAVE CALLER'S REGISTERS
         BALR  R12,0               SET UP A NEW BASE REGISTER
         USING READBASE,R12
READBASE DS    OH
*
         LM    R2,R3,0(R1)         R2 <- A(TABLE)
*                                  R3 <- A(NUMBER OF ENTRIES)
*
***<STEP 1>    SET POINTER THAT ALWAYS POINTS TO NEXT ENTRY
*
         LR    R4,R2               R4 POINTS AT NEXT OPEN ENTRY
*
***<STEP 2>    READ THE FIRST CARD
*
         XREAD CARD,80
*
***<STEP 3>    IF ENF-OF-FILE HAS OCCURRED, GO TO STEP 6.
*
TESTEND  BC    B'0100',EXIT
*
***<STEP 4>    PUT THE NUMBER IN TO THE NEXT TABLE ENTRY
*
         XDECI R5,CARD
         ST    R5,0(R4)            STORE NUMBER INTO THE TABLE
         LA    R4,4(R4)            POINT TO NEXT TABLE ENTRY
*
***<STEP 5>    READ THE NEXT NUMBER AND GO BACK TO STEP 3.
*
         XREAD CARD,80
         B     TESTEND
*
***<STEP 6>     SAVE THE NUMBER OF TABLE ENTRIES AND RETURN
*
EXIT      SR    R4,R2
          SRA   R4,2                R4 HAS THE NUMBER OF ENTRIES
          ST    R4,0(R3)            RETURN ANSWER TO CALLER
*
          LM    R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
          BR    R14                 RETURN TO CALLER
*
          LTORG
*
CARD      DS    CL80                CARD INPUT AREA
*
```

**Program 6-2 (continued)**

```
*****************************************************************
*
* 'SORTTAB' CAN BE CALLED TO SORT A TABLE OF INTEGERS INTO
* ASCENDING ORDER.  THE PARAMETER LIST MUST CONTAIN
*
*        THE ADDRESS OF THE TABLE TO BE SORTED
*        THE ADDRESS OF A WORD CONTAINING THE NUMBER OF ENTRIES
*           IN THE TABLE
*
* TO SEE HOW THE ALGORITHM WORKS, THINK OF THE TABLE AS BEING
* DIVIDED INTO A SORTED PART (ON THE LEFT) AND AN UNSORTED
* PART.  THE NUMBERS IN THE SORTED PART ARE IN ASCENDING ORDER.
* INITIALLY, ONLY THE LEFTMOST NUMBER IS IN THE SORTED PART.
* NOW PICK UP THE FIRST UNSORTED NUMBER.  NOW SHIFT OVER ANY
* OF THE SORTED NUMBERS THAT ARE LARGER THAN IT, MAKING ROOM
* FOR THE NUMBER IN THE SORTED LIST.  PUT IT INTO THE LIST.
* THUS, WE MOVE ONE NUMBER AT A TIME INTO THE SORTED LIST.
* CONTINUE MOVING NUMBERS FROM THE UNSORTED SECTION INTO THE
* SORTED LIST UNTIL ALL THE NUMBERS HAVE BEEN MOVED.  THEN THE
* SORT IS COMPLETE.  THIS LOGIC GOES AS FOLLOWS:
*
*   STEP 1.  SET A POINTER TO THE SECOND WORD OF THE TABLE (FIRST
*            ELEMENT IN THE UNSORTED SECTION).  GET THE NUMBER
*            OF WORDS IN THE UNSORTED SECTION.
*
*   STEP 2.  IF THERE ARE NO MORE WORDS IN THE UNSORTED SECTION,
*            GO TO STEP 8.
*
*   STEP 3.  PICK UP THE FIRST WORD IN THE UNSORTED SECTION.
*
*   STEP 4.  IF THERE ARE NO MORE NUMBERS TO THE LEFT OF IT,
*            OR IF THE NUMBER JUST TO THE LEFT IS SMALLER, GO
*            TO STEP 6.
*
*   STEP 5.  MOVE ONE NUMBER IN THE SORTED SECTION TO THE RIGHT,
*            AND DECREMENT THE POINTER TO THE NEXT WORD TO LOOK
*            AT.  GO BACK TO STEP 4.
*
*   STEP 6.  STORE THE # AT THE CORRECT SPOT IN THE SORTED
*            LIST.
*
*   STEP 7.  MOVE THE POINTER TO THE FIRST UNSORTED NUMBER OVER
*            ONE POSITION TO THE RIGHT.  GO TO STEP 2.
*
*   STEP 8.  RETURN TO CALLER.
*
*****************************************************************
*
SORTTAB  CSECT
         STM   R14,R12,12(R13)     STORE CALLER'S REGISTERS
         BALR  R12,0
         USING SORTBASE,R12
SORTBASE DS    OH
*
***<STEP 1>    GET POINTER TO 1ST UNSORTED AND COUNT OF UNSORTED
*
         LM    R2,R3,0(R1)         R2 <- A(TABLE)
*                                  R3 <- A(# WORDS IN TABLE)
         LA    R4,4(R2)            R4 <- A(1ST UNSORTED)
         L     R5,0(R3)
         BCTR  R5,0                R5 <- # WORDS IN UNSORTED SECTION
*
***<STEP 2>    IF NO MORE UNSORTED, GO TO STEP 8
*
CHECKEND S     R5,=F'1'
         BM    SORTEXIT            BRANCH IF NO MORE UNSORTED
*
***<STEP 3>    PICK UP FIRST UNSORTED WORD
*
         L     R6,0(R4)            R6 <- FIRST UNSORTED WORD
*
         LR    R7,R4
         S     R7,=F'4'            R7 <- A(WORD TO LOOK AT NEXT)
*
***<STEP 4>    IF NO MORE WORDS SHOULD BE SHIFTED, GO TO STEP 6.
*
CHECK1   CR    R7,R2
         BL    GOTSPOT             BRANCH IF NO MORE WORDS
*
         C     R6,0(R7)
         BNL   GOTSPOT             BRANCH IF WORD DOESN'T GET SHIFTED
*
***<STEP 5>    SHIFT ONE OVER AND GO BACK TO STEP 4.
*
         MVC   4(4,R7),0(R7)
         S     R7,=F'4'
         B     CHECK1
```

**Program 6-2 (continued)**

```
*
***<STEP 6>     PUT THE NUMBER INTO ITS CORRECT SPOT
*
GOTSPOT  ST     R6,4(R7)
*
***<STEP 7>     INCREMENT POINTER INTO UNSORTED SECTION
*
         LA     R4,4(R4)
         B      CHECKEND
*
***<STEP 8>     RETURN TO CALLER
*
SORTEXIT LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
         BR     R14                 EXIT
*
         LTORG
R0       EQU    0
R1       EQU    1
R2       EQU    2
R3       EQU    3
R4       EQU    4
R5       EQU    5
R6       EQU    6
R7       EQU    7
R8       EQU    8
R9       EQU    9
R10      EQU    10
R11      EQU    11
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
         END    MAIN
```

The following facts are relevant to observance of the register linkage conventions and should be remembered:

- R13 should always contain the address of a register save area and, hence, should not be used for normal computations.
- R1, R14, and R15 should not be used as base registers and, because of their frequent use in subroutine calls, should never be loaded with values that are considered to be more or less permanent.

Although the register linkage conventions may seem complex, observance of them breaks down into two rather simple cases:

1. A routine that calls no external subroutines should begin with a section of code similar to

```
ROUTINE   CSECT
          STM     R14,R12,12(R13)
          BALR    R12,0
          USING   BASEPT,R12
BASEPT    DS      0H
```

   This causes the original contents of the registers to be saved and establishes R12 has a base register. (Recall that a BALR instruction with R0 as second operand simply loads the link register with the address of the next instruction.) In the interior of the routine, neither the base register nor R13 should be altered. The routine should exit with the instructions

```
         LM      R14,R12,12(R13)
         BR      R14
```

2. A routine that may invoke one or more external subroutines should begin with a sequence of instructions similar to

```
ROUTINE  CSECT
         STM     R14,R12,12(R13)
         BALR    R12,0
         USING   BASEPT,R12
BASEPT   LA      R14,SAVEAREA
         ST      R14,8(R13)
         ST      R13,4(R14)
         LR      R13,R14
```

In this case, the routine should exit with the

```
         L       R13,4(R13)
         LM      R14,R12,12(R13)
         BR      R14
```

In concluding this section, it should be noted that it is possible to use R13 simultaneously as a save area pointer and a base register. This has the advantage of leaving an additional register free for computational uses. The following section of code accomplishes this purpose:

```
ROUTINE  CSECT
         STM     R14,R12,12(R13)
         BAL     R14,80(R15)
SAVEAREA DS      18F
         ST      R13,4(R14)
         ST      R14,8(R13)
         LR      R13,R14
         USING   SAVEAREA,R13
```

This particular section of code should be studied carefully. It is not difficult to comprehend how this code works, if one understands that the instruction

```
         BAL     R14,80(R15)
```

loads the address of SAVEAREA in R14 and causes a branch around SAVEAREA to the instruction

```
         ST      R13,4(R14)
```

It must be remembered that, according to convention, R15 contains the address of the first instruction of the routine at the time the routine is entered.

## Exercises

The following two dumps were produced by programs that conformed to standard linkage conventions.

**1.** This dump occurred while executing a subroutine that set up its own savearea (i.e., it was not a "lowest level" subroutine). R13 was used as a base register in the routine. The routine took four parameters as input:

a. the address of a string,
b. the address of a fullword containing the lengths of the strings,
c. the address of a second string, and
d. the address of a 1-byte field which should get set to 'Y' if the strings are identical, or to 'N' if they are not.

What were the values of the first three parameters (presumably, the dump occurred before the 1-byte answer got set)? Can you figure out what went wrong?

```
PSW:  FF000000 AF000003

R0-7 :F4F4F4F4 00000120 000000CC 0000011C 0000007C 0000011A 00000006 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 8F000140 8F000140 00000138


USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      47ECD00C   45EF0050   F5F5F5F5   000001C8      *..}....&5555...H*
000010      8F000140   4F000070   00000138   F4F4F4F4      *... ........4444*
000020      00000120   F4F4F4F4   F4F4F4F4   F4F4F4F4      *....444444444444*
000030      F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4      *4444444444444444*
            LINES:   000030 - 000040    ARE IDENTICAL
000050      50DE0004   50ED0008   18DEE000   D0C20050      *&...&.....\.}B.&*
000060      E000D072   00504110   D11858F0   D12805EF      *\.}..&..J..0J...*
000070      58DD0004   98ECD00C   07FEC1C2   E7C4C5C6      *....q.}...ABXDEF*
000080      C7C84040   40404040   40404040   40404040      *GH              *
000090      40404040   40404040   40404040   40404040      *                *
            LINES:   000090 - 0000B0    ARE IDENTICAL
0000C0      40404040   40404040   4040C1C2   C3C4C5C6      *          ABCDEF*
0000D0      C7C84040   40404040   40404040   40404040      *GH              *
0000E0      40404040   40404040   40404040   40404040      *                *
            LINES:   0000E0 - 000100    ARE IDENTICAL
000110      40404040   40404040   4040D5F5   00000008      *          N5....*
000120      000000CA   0000011C   0000007A   0000011A      *............:...*
000130      00000138   F5F5F5F5   90ECD00C   45EF0050      *....5555..}....&*
000140      F5F5F5F5   8F000008   F5F5F5F5   F5F5F5F5      *5555....55555555*
000150      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
            LINES:   000150 - 000170    ARE IDENTICAL
000180      F5F5F5F5   F5F5F5F5   50DE0004   50ED0008      *55555555&...&...*
000190      18DE9825   10005863   0000D500   40002000      *..q.......N. ...*
0001A0      4780D06C   92D55000   47F00003   41440001      *..}%kN&..0......*
0001B0      41220001   4660D05A   92E85000   58DD0004      *.....-}!kY&.....*
0001C0      98ECD00C   07FEF5F5   F5F5F5F5   F5F5F5F5      *q.}...5555555555*
0001D0      8F000008   00000210   00000000   F4F4F4F4      *............4444*
0001E0      F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4      *4444444444444444*
            LINES:   0001E0 - 000200    ARE IDENTICAL
000210      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**2.** The following dump occurred while executing a subroutine that was a "lowest level" subroutine. The subroutine took three parameters:

a. the address of a string,
b. the address of where to place a reversed copy of the string, and
c. the address of a fullword containing the length of the string.

What parameters were passed? Can you figure out where the subroutine was located? How many characters got reversed? What went wrong?

```
PSW:  FF000000 6F000150

R0-7 :F4F4F4F4 00000120 0000007B 000000D2 0000000A F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 4F000136 8F000008 4F000070 00000130

USER STORAGE:   CORE ADDRESSES SPECIFIED - 000000 to 000A8C

000000      47ECD00C   45EF0050   F5F5F5F5   00000160      *..}....&5555...-*
000010      F5F5F5F5   4F000070   00000130   F4F4F4F4      *5555........4444*
000020      00000120   F4F4F4F4   F4F4F4F4   F4F4F4F4      *....444444444444*
000030      F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4      *4444444444444444*
            LINES:   000030 - 000040    ARE IDENTICAL
000050      50DE0004   50ED0008   18DEE000   D0C20050      *&...&.....\.}B.&*
000060      E000D072   00504110   D11858F0   D12405EF      *\.}..&..J..0J...*
000070      58DD0004   98ECD00C   07FEC1C2   E7C4C5C6      *....q.}...ABXDEF*
000080      C7C84040   40404040   40404040   40404040      *GH              *
000090      40404040   40404040   40404040   40404040      *                *
            LINES:   000090 - 0000B0    ARE IDENTICAL
0000C0      40404040   40404040   4040C1C2   C3C4C5C6      *          ABCDEF*
0000D0      C7C840C1   40404040   40404040   40404040      *GH A            *
0000E0      40404040   40404040   40404040   40404040      *                *
            LINES:   0000E0 - 000100    ARE IDENTICAL
000110      40404040   40404040   4040F5F5   0000000A      *          55....*
000120      0000007A   000000CA   0000011C   00000130      *...:............*
000130      90ECD00C   05C09824   10005A34   00000630      *..}..{q...!.....*
000140      58440000   D2003000   20004122   00010639      *....K...........*
000150      4640C00E   98ECD00C   07FEF5F5   F5F5F5F5      *. {.q.}...555555*
000160      F5F5F5F5   F5F5F5F5   8F000008   000001A8      *55555555.......y*
000170      00000000   F4F4F4F4   F4F4F4F4   F4F4F4F4      *....444444444444*
000180      F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4      *4444444444444444*
            LINES:   000180 - 000190    ARE IDENTICAL
0001A0      F4F4F4F4   F4F4F4F4   F5F5F5F5   F5F5F5F5      *4444444455555555*
0001B0      F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5      *5555555555555555*
```

**3.** In this assignment, you are to write a program that reads in a string and a short pattern. The program invokes a subroutine INDEX that takes in four parameters:

a. the address of the short pattern,
b. the address of a word containing the length of the pattern,
c. the address of the string to search, and
d. the address of a word containing the length of the string to search.

The routine sets R0 to the address of the first occurrence of the pattern (or to 0, if the pattern does not occur in the string).

For example, if INDEX were called with

| | |
|---|---|
| ABGTAXDRK*&CGTSOOHT | as the string and |
| XDRK | as the pattern, |

then R0 would be set to reference the sixth byte of the string.

There is a remarkably fast algorithm for searching a string for a pattern, called the Boyer-Moore string searching algorithm. It works roughly as follows (using the string and pattern above as the example input):

- First, since the pattern is 4 characters long, check the fourth character of the string. Since it is T, and since T does not occur in the pattern, you know that the pattern cannot match before the fifth character.
- To look for a match starting at the fifth character or beyond, we again look four characters past the point where a match might occur; that is, we look at the R that occurs in the string. Since it does occur in the pattern, but not as the last character, we move ahead by the distance of the R in the pattern from the end of the pattern (1 character)
- Now we look at the fourth character from where the pattern might match, and we find a K. Since K is the last character of the pattern, we proceed to perform a full match and find that we actually have an occurrence of the pattern.

A more precise version of the algorithm is given by the following pseudo-code:

```
INDEX: Proc(STRING,SLEN,PATTERN,PLEN)
    Create a 256 character table TAB, in which every
        character is initialized to PLEN.
    I ← 1
    Do while (I <= PLEN)
        C ← Ith character of the PATTERN
        Set the Cth entry of TAB (i.e., TAB[C]) to PLEN-I
        I ← I+1
    Enddo

    MATCH ← 0
    I ← 1
    Do while ((I <= (SLEN-PLEN)) and (MATCH = 0)
        C ← the (I+PLEN-1)th character of STRING
        If (TAB[C] = 0)
            If (PATTERN matches STRING at Ith location)
              MATCH ← I
```

```
            else
                I ← I+1
            Endif
        else
            I ← I + TAB[C]
        Endif
    Enddo

    return MATCH
Endproc
```

This algorithm is somewhat complex, and (as presented above) there is a significant initialization cost. However, the initialization cost can be dramatically reduced (how?), and on strings that are fairly long, the gain in speed over the more straightforward approaches is dramatic.

**4.**

**a.** Write a subroutine NEXTWORD to find the next "word" in a string. For the purposes of this exercise, you may consider any sequence of characters up to the next blank (or the end of the string) as a word. The parameter list to the subroutine should have the following format:

- address of a string of characters (delimited by a X'00')
- address of a fullword set to point to the first nonblank in the string (0, if there are no more nonblanks)
- address of a fullword set to the address of the first character past the word (the address of the delimiting character, which should be a space or a X'00')

**b.** Write a subroutine that counts the number of characters and words in a line. The routine should accept as input the following parameter list:

- address of a string (delimited by a X'00')
- address of a fullword that should be set to the number of characters in the line (do not include the 00)
- address of a fullword that should be set to the number of words in the line

**5.** Write a subroutine that removes the duplicates from a table of integers. The routine should accept as input the following parameter list:

- address of a table of integers
- address of a word that contains the number of entries in the table

The subroutine should remove duplicate values and reset the count to the updated value.

**6.** This is the same as Exercise 5, except that in this case you should assume that the values in the table occur in ascending order.

**7.** The SHELL sort algorithm is a more efficient sorting algorithm than the sort shown in Section 6.3. Code a subroutine, SHELL, that takes the following parameter list:

- address of a table of integers
- address of a word containing the number of entries in the table

Suppose that the table is called V and that N contains the number of entries in V. Then, SHELL should use the following sort algorithm to order the entries in V:

*Step 1.* Set GAP ← N/2, GAPDIS ← GAP*4, and ENDPT ← the address of the last entry in V.
*Step 2.* If GAP = 0, go to Step 11. (The table is sorted.)
*Step 3.* NEXTEL ← address of V+GAPDIS. NEXTEL references the (GAP+1)st entry in V.
*Step 4.* If NEXTEL > ENDPT, go to Step 10.
*Step 5.* SORTEL ← NEXTEL−GAPDIS
*Step 6.* If SORTEL < V, or the entry pointed to by SORTEL <= the entry at SORTEL+GAPDIS, go to Step 9.
*Step 7.* Exchange the entry at SORTEL with the entry at SORTEL+GAPDIS.
*Step 8.* SORTEL ← SORTEL−GAPDIS. Go to Step 6.
*Step 9.* NEXTEL ← NEXTEL+4. Go to Step 4.
*Step 10.* GAP ← GAP/2. GAPDIS ← GAP*4. Go to Step 2.
*Step 11.* Exit.

The whole algorithm is much clearer if vector notation is used along with pseudo-code. In this case, the algorithm is as follows:

```
SHELL: PROCEDURE (V,N)
    GAP ← N/2
    Do while (GAP > 0)
        NEXTEL ← GAP + 1
        Do while (NEXTEL <= N)
            SORTEL ← NEXTEL − GAP
            Do while (SORTEL > 0 and V(SORTEL) > V(SORTEL+GAP))
                Exchange V(SORTEL) and V(SORTEL+GAP)
                SORTEL ← SORTEL − GAP
            Enddo
            NEXTEL ← NEXTEL + 1
        Enddo
        GAP ← GAP/2
    Enddo
Endproc
```

Write a program that reads in a table of integers, prints the table, calls SHELL to sort the table, and prints the sorted table.

## 6.4 LINKAGES BETWEEN BAL AND HIGH-LEVEL LANGUAGES

The facility to write subroutines that can be assembled and kept in a library is of fundamental importance. This facility allows the creation of powerful service routines that any other assembler program can conveniently invoke. Fortunately, assembler subroutines can be easily invoked from many high-level languages as well. In particular, the linkages between FORTRAN, COBOL, and assembler routines are all straightforward. To use a PL/I routine from any of these languages or to invoke a subroutine in these languages from PL/I is not quite as easy. The details for all of these interfaces can be found in the IBM manuals. (Normally, the programmer's guide for a high-level language discusses the interfaces to subroutines in other languages.) In this section, we give a brief overview of how assembler routines can be interfaced to FORTRAN and COBOL routines.

To invoke an assembler routine from COBOL or FORTRAN, the CALL statement is used. Thus, to invoke SORTTAB from FORTRAN

```
CALL SORTTAB(V,N)
```

could be used, where V is assumed to be a vector of fullword integers and N is a single integer. This requires that V and N be declared as INTEGER*4. The exact storage format of the FORTRAN data types is given in the FORTRAN Programmer's Guide. To invoke SORTTAB from COBOL,

```
CALL 'SORTTAB' USING V N
```

would be used, where V and N are declared in the data division of the program as

```
01 V.
   05     TABEL PIC S9(5)
          USAGE IS COMP OCCURS 50 TIMES.

01 N      PIC 9(5) USAGE IS COMP.
```

To allow SORTTAB to be called in this way from FORTRAN or COBOL programs, it must be modified to observe two linkage conventions required by these languages. These are:

1. R15 is used as a *return code*. Normally, it should be set to 0 by the subroutine. We recommend always setting R15 to 0 in subroutines called from high-level language programs.
2. Before exiting, the thirteenth byte of the save area (12(R13)) must be set to X'FF'.

Hence, SORTTAB would have to be modified to use the following code to exit:

```
EXIT     LM     R14,R12,12(R13)
         MVI    12(R13),X'FF'
         SR     R15,R15
         BR     R14
```

These slight changes are all that is required to make a subroutine accessible from either COBOL or FORTRAN.

Although it is common to invoke assembler routines from COBOL or FORTRAN, it is much less common to invoke a high-level language routine from assembler language. Occasionally, however, it is very convenient. For example, in Chapter 10, two COBOL service routines are used to perform floating-point conversions. Calling high-level language subroutines normally requires that a standard initialization subroutine be invoked before actually calling the service routines. (The name of the initialization module depends on the compiler.) The actual call to the subroutine follows standard linkage conventions. Thus, in the example presented in Chapter 10, the assembler program first uses

```
         L      R15,=V(ILBOSTP0)
         BALR   R14,R15
```

to initialize the variables used by the COBOL subroutines. Then, to invoke the COBOL service routine to convert a floating-point number from external to internal format,

```
         LA     R1,=A(EXTNUM,INTNUM)
         L      R15,=V(FLETOI)
         BALR   R14,R15
```

is used.

The preceding discussion is necessarily brief. However, the interested reader can find a complete discussion of linkages between BAL and high-level languages in the language reference and programmer's guide manuals.

## 6.5 DUMMY SECTIONS (DSECTs)

A *dummy section*, or DSECT, begins with a statement of the form

```
label        DSECT
```

The end of the dummy section is delimited by the occurrence of a CSECT statement, another DSECT statement, or an END statement. The statements in the body of a dummy section specify a format, but these statements do not cause any object code to be generated. As an example, the following

DSECT describes a three-word area:

```
PARMLIST   DSECT
TABLADDR   DS      A   ADDRESS OF THE TABLE
KEYADDR    DS      A   ADDRESS OF A KEY
NUMENT     DS      F   NUMBER OF ENTRIES
*                      IN THE TABLE
```

The format described by a DSECT may be associated with a particular area in storage. The labels on the DSECT statements may then be used to specify addresses in that area in assembler statements that cause object code to be generated. Therefore, the register that is to contain the address of the area must be specified before the assembler statements that use labels from the dummy section to reference fields in that area are assembled. Unexpected or erroneous results may still occur, if the specified register does not contain the correct address at execution time. A statement of the form

```
USING   dsect,r
```

indicates to the assembler that the area at the address specified by the contents of the register r conforms to the format specified by the dummy section designated by the first operand. The assembler utilizes the information from the USING statement to convert any addresses specified by labels from the dummy section to addresses specified by displacements from the address in register r. As an example, consider the following section of code:

```
USING   PARMLIST,R1
L       R2,NUMENT
L       R5,KEYADDR
```

Since the USING statement conveys that during execution R1 will contain the address of an area in storage that conforms to the format specified by the dummy section PARMLIST, the word to be loaded into R2 is located eight bytes from the address in R1. Thus, the first Load instruction is encoded as 5820 1008. Similarly, the reference to KEYADDR is converted to four bytes from the address in R1. The actual code generated by the previous example is displayed in the assembler listing presented in Program 6-3.

At least two significant advantages can be gained through the use of DSECTs:

- The readability of a program can be markedly improved. For example,

```
L       R2,NUMENT
```

  is far clearer than

```
L       R2,8(R1)
```

- A program that employs a DSECT is more easily alterable than one in which explicit addresses are used exclusively.

To illustrate the second advantage, suppose that the program to invoke SEARCH has been coded with the parameters defined in a different order. This situation could be corrected in the subroutine containing the PARMLIST dummy section by simply reordering the statements in the dummy section. Then, when SEARCH is reassembled, all of the addresses will be converted to the correct values. If, however, explicit addressing had been used, it would have been necessary to alter each statement that referenced a field in the parameter list, before reassembling the program.

In the previous example, the DSECT is used to describe the format of a single area. However, a DSECT may be used to reference more than one area in storage during the execution of a program. This is illustrated in the complete listing of SEARCH presented in Program 6-4. In this case, each individual area to be referenced must conform to the format described in the dummy section, and the register specified in the USING statement must be adjusted to contain the address of a specific area, before fields in that area are actually referenced. In SEARCH, the dummy section TABENTRY is used to specify the format of an entry in the table, and R3 is used as a pointer to the entry. Thus, by altering R3 (referred to as the base register for TABENTRY), the labels in the dummy section can be made to apply to any specific entry in the table.

One further aspect of the use of dummy sections requires examination: Different base registers may be used with a dummy section in different parts of a program. Thus, in one section of code, the statement

```
USING     AREA,R5
```

could be used to indicate that R5 is to be the base register for AREA, while the statement

```
USING     AREA,R4
```

could occur in another section of the same program. To make it clear which register the assembler is to use in converting implicit addresses to explicit addresses, the effect of one USING statement should be canceled before another is issued. This is accomplished through the use of the DROP statement, which has the following format:

```
DROP      r1,r2, . . . ,rn
```

This statement simply serves to inform the assembler that registers $r_1, r_2, \ldots, r_n$ are no longer to be used as base registers in calculating explicit addresses.

## Program 6-3

```
        CSECT EXAMPLE - SUBROUTINE TO SEARCH TABLE

  LCC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT

 000000                             34 PARMLIST DSECT
                                    35 * THIS DSECT GIVES THE FORMAT OF THE INPUT PARAMETER LIST.
 000000                             36 TABLADDR DS    A                 ADDRESS OF THE TABLE TO SEARCH
 000004                             37 KEYADDR  DS    A                 ADDRESS OF THE KEY TO SEARCH FOR
 000008                             38 NUMENT   DS    F                 NUMBER OF ENTRIES IN THE TABLE

 000000                             40 SEARCH   CSECT

                                    42 ***<STEP 1>    SAVE REGS AND ESTABLISH A BASE REG
 000000 90EC D00C          0000C    43          STM   R14,R12,12(R13)   STORE CALLER'S REGISTERS
 000004 05C0                        44          BALR  R12,R0            SET UP BASE REGISTER
 000006                             45          USING *,R12

                                    47 ***<STEP 2>    SCAN TABLE FOR DESIRED ENTRY
 000000                             48          USING PARMLIST,R1       R1 CONTAINS ADDRESS OF INPUT PARM.S
 000006 5820 1008          00008    49          L     R2,NUMENT         LOAD # ENTRIES IN THE TABLE
 00000A 5850 1004          00004    50          L     R5,KEYADDR        LOAD ADDRESS OF THE KEY
 00000E 5830 1000          00000    51          L     R3,TABLADDR       LOAD ADDRESS OF THE TABLE
```

As an illustration, consider the following section of code:

```
AREA      DSECT
FIELD1    DS    CL10
FIELD2    DS    H
FIELD3    DS    F
MAIN      CSECT
          .
          .
          .
          USING AREA,R5
          .
          .
          .
          USING AREA,R4
          L     R1,FIELD3
          .
          .
          .
```

Here, it is not clear whether FIELD3 should be converted to 12(R5) or to 12(R4). However, if the statement

```
DROP    R5
```

were inserted immediately preceding the second USING statement, R5 would not be used as a base register for AREA in any following statement unless so specified by another USING statement. Thus, FIELD3 could then be unambiguously converted to 12(R4). It is sound practice always to drop the base register of a given dummy section at the end of any sequence of code that references labels in that particular dummy section. This assures that the desired base register will be selected by the assembler when implicit addresses are to be converted to explicit addresses.

## Program 6-4

```
        CSECT EXAMPLE - SUBROUTINE TO SEARCH TABLE                                                    PAGE    1

  LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                     2 * THE FOLLOWING SUBROUTINE CAN BE CALLED TO SEARCH A TABLE OF THE
                                     3 * FOLLOWING FORMAT:
                                     4 *
                                     5 *          KEY    +0(6)       THE KEY UPON WHICH THE TABLE IS SEARCHED
                                     6 *          PRODN  +6(5)       THE PRODUCT NUMBER
                                     7 *          PRICE  +11(4)      THE PRICE WHICH IS STORED AS PACKED DECIMAL
                                     8 *                             IN THE FORM (XXXXX.XX)
                                     9 *          STOCK  +15(4)      THE NUMBER OF UNITS IN STOCK (PACKED DECIMAL)
                                    10 *
                                    11 * THE INPUT TO THE SUBROUTINE IS A PARAMETER LIST SPECIFYING AN ENTRY
                                    12 * WHICH SHOULD BE PRINTED.  THE FORMAT OF THE PARAMETER LIST IS:
                                    13 *
                                    14 *          TABLE  +0(4)       ADDRESS OF THE TABLE TO SEARCH (FORMATTED AS
                                    15 *                             SHOWN ABOVE)
                                    16 *          KEY    +4(4)       ADDRESS OF THE KEY TO USE IN THE SEARCH
                                    17 *          *      +8(4)       NUMBER OF ENTRIES IN THE TABLE
                                    18 *
                                    19 * HERE +N(M) MEANS AN M-BYTE FIELD AT A DISPLACEMENT OF N BYTES.
                                    20 *
                                    21 * THE LOGIC OF THE SUBROUTINE IS:
                                    22 *
                                    23 *          STEP 1.  SAVE CALLER'S REGISTERS AND SET UP A BASE REG.
                                    24 *
                                    25 *          STEP 2.  SEARCH TABLE FOR THE SOUGHT ENTRY.  IF IT'S FOUND, GO
                                    26 *                   TO STEP 4.  ELSE, GO TO STEP 3.
                                    27 *
                                    28 *          STEP 3.  PRINT AN ERROR MESSAGE - ENTRY NOT IN TABLE.
                                    29 *                   GO TO STEP 5.
                                    30 *
                                    31 *          STEP 4.  PRINT THE MATCHED ENTRY.
                                    32 *
                                    33 *          STEP 5.  EXIT.

 C00000                             35 PARMLIST DSECT
                                    36 * THIS DSECT GIVES THE FORMAT OF THE INPUT PARAMETER LIST.
 C00000                             37 TABLADDR DS    A                 ADDRESS OF THE TABLE TO SEARCH
 000004                             38 KEYADDR  DS    A                 ADDRESS OF THE KEY TO SEARCH FOR
 C00008                             39 NUMENT   DS    F                 NUMBER OF ENTRIES IN THE TABLE

 C00000                             41 SEARCH   CSECT

                                    43 ***<STEP 1>    SAVE REGS AND ESTABLISH A BASE REG
 000000 90EC D00C          0000C    44          STM   R14,R12,12(R13)   STORE CALLER'S REGISTERS
 000004 05C0                        45          BALR  R12,R0            SET UP BASE REGISTER
 C00006                             46          USING *,R12

                                    48 ***<STEP 2>    SCAN TABLE FOR DESIRED ENTRY
 0C0000                             49          USING PARMLIST,R1       R1 CONTAINS ADDRESS OF INPUT PARM.S
 000006 5820 1008          00008    50          L     R2,NUMENT         LOAD # ENTRIES IN THE TABLE
 00000A 5850 1004          00004    51          L     R5,KEYADDR        LOAD ADDRESS OF THE KEY
 00000E 5830 1000          00000    52          L     R3,TABLADDR       LOAD ADDRESS OF THE TABLE
```

**Program 6-4 (continued)**

```
        DSECT EXAMPLE - SUBROUTINE TO SEARCH TABLE                                                    PAGE    2

  LOC   OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT
 CC0000                                 53          USING TABENTRY,R3
 000012 D505 3000 5000 00000 00000      54 SRCHLP   CLC   TABKEY,0(R5)        COMPARE KEY WITH THE KEY IN 1 ENTRY
 0C0018 4780 C02E            00034      55          BE    GOTENTRY
 0C001C 4130 3013            00013      56          LA    R3,TANXTENT         LOAD ADDRESS OF THE NEXT ENTRY
 0C0020 4620 C00C            00012      57          BCT   R2,SRCHLP           BRANCH IF MORE ENTRIES TO TRY

                                        59 ***<STEP 3>    PRINT AN ERROR MESSAGE
 0C0024 0205 C076 5000 0007C 00000      60          MVC   ERRKEY,0(R5)        MOVE KEY TO ERROR MESSAGE
 00002A E020 C075 0023 00078            61          XPRNT ERRLINE,35          PRINT ERROR MESSAGE
 0C0030 47F0 C058            0005E      62          B     LEAVE

                                        64 ***<STEP 4>    PRINT THE MATCHED ENTRY
 000034 D205 C099 3000 00090 00000      65 GOTENTRY MVC   PRNTKEY,TABKEY      MOVE KEY TO PRINT LINE
 0C003A 0204 C0A1 3006 000A7 00006      66          MVC   PRNTPROD,TABPROD#   MOVE PRODUCT NUMBER TO PRINT LINE
 0C0040 C208 C0A8 C06C 000AE 00072      67          MVC   PRNTPRIC,=X'4020202020214820 20'
 000046 DE08 C0A8 3008 000AE 00008      68          ED    PRNTPRIC,TABPRICE   EDIT IN THE PRICE
 0C004C D209 C0B3 C062 00089 00068      69          MVC   PRNTSTCK,=X'4020682020206820 2120'
 0C0052 DE09 C0B3 300F 00089 0000F      70          ED    PRNTSTCK,TABSTOCK   EDIT IN THE # OF UNITS OF STOCK
 CC0058 E020 C098 0025 0009E            71          XPRNT PRNTLINE,37

                                        73 ***<STEP 5>    EXIT
 C0C05E 98EC D00C            0000C      74 LEAVE    LM    R14,R12,12(R13)
 000062 07FE                            75          BR    R14
                                        76          LTORG
 0CCC68 4020682020206820                77                =X'4020682020206820 2120'
 000072 4020202020214820                78                =X'4020202020214820 20'
 CC0078 F0                              79 ERRLINE  DC    C'0'                CARRIAGE CONTROL
 00007C                                 80 ERRKEY   DS    CL6                 KEY VALUE WHICH WASN'T FOUND
 0C0082 406040C5D5E3D9E8                81          DC    C' - ENTRY IS NOT IN THE TABLE'
 0C009E F0                              82 PRNTLINE DC    C'0'                CARRIAGE CONTROL
 00C09F                                 83 PRNTKEY  DS    CL6                 KEY OF MATCHED ENTRY
 0000A5 4040                            84          DC    CL2' '
 CC00A7                                 85 PRNTPROD DS    CL5                 PRODUCT NUMBER OF MATCHED ENTRY
 0C00AC 4040                            86          DC    CL2' '
 0000AE                                 87 PRNTPRIC DS    CL9                 PRICE OF MATCHED ENTRY
 0C00B7 4040                            88          DC    CL2' '
 C00089                                 89 PRNTSTCK DS    CL10                NUMBER OF UNITS IN STCCK
 CC0000                                 90 R0       EQU   0
 0C0001                                 91 R1       EQU   1
 C00002                                 92 R2       EQU   2
 CC0003                                 93 R3       EQU   3
 CC0005                                 94 R5       EQU   5
 00000C                                 95 R12      EQU   12
 CC000D                                 96 R13      EQU   13
 CC00E                                  97 R14      EQU   14
 CCC0CF                                 98 R15      EQU   15
 CC0000                                 99 TABENTRY DSECT
                                       100 * THIS DSECT GIVES THE FORMAT OF AN ENTRY IN THE TABLE
 CC0000                                101 TABKEY   DS    CL6                 THE KEY
 CC00C6                                102 TABPROD# DS    CL5                 PRCDUCT NUMBER
 000008                                103 TABPRICE DS    PL4                 PRICE AS XXXXX.XX
 CC000F                                104 TABSTOCK DS    PL4                 UNITS OF STOCK ON HANC
 000013                                105 TANXTENT DS    0X                  ADDRESS OF THE NEXT ENTRY

                                       107          END
```

# 7

# Input/Output under OS and DOS

## 7.1 INTRODUCTION

Throughout Chapters 1–6, the tacit assumption was made that all input and output of data was to be accomplished using the pseudo-instructions XREAD and XPRNT. This approach offers the following major advantages over more conventional approaches:

1. The complexities involved in the standard techniques used for the input and output of data are avoided initially. Therefore:
   a. Complete programs can be introduced very early.
   b. Full concentration can be focused on the assembler-language instructions and their use in manipulating data.
2. Student programs may be processed under ASSIST. Therefore:
   a. As much as 75 percent of processing time can be saved.
   b. Abbreviated dumps with excellent diagnostics can save paper and time spent debugging programs.

There is a major disadvantage, of course, if the learning process stops here. The student might have gained a rather thorough knowledge of the assembler-language instruction set but still has no idea of how input and output are handled in a conventional setting.

The purpose of this chapter is to introduce some of the basic notions involved in data organization that are prerequisite to any discussion of input and output and then to introduce one of the widely used methods of handling the input and output of data.

## 7.2 SEQUENTIAL FILES

All electronic high-speed digital computers (the IBM machines are prime examples) can be thought of as devices used for the manipulation of data.

This data is normally stored on external storage media such as punched cards, magnetic tape, and magnetic disks. Data is transferred from these media to the main storage of the computer and from computer storage to these media by input and output (I/O) devices. The I/O devices that are relevant to this discussion include the card reader, printer, magnetic tape drive, and magnetic disk drive.

Areas in computer storage into which data is input from external media and from which data is output to external media are called *buffers*. The amount of data transferred in a single I/O operation is normally the amount required to fill a buffer and is referred to as a *physical record*. The *length* of a physical record is the number of bytes the record contains.

For data to be manipulated by the execution of a user program, the data must be passed from an input buffer to the program; likewise, data that is to be output must be passed from the user program to an output buffer. The amount of data passed from a buffer to a user program or from a user program to a buffer in a single operation is referred to as a *logical record*.

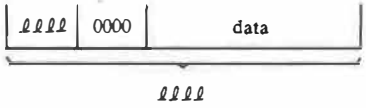
A *file* is an organized collection of related data records. In the case of the card and printer files with which the reader is familiar, the distinction between logical and physical records is not crucial, since in either case the length of a logical record and the length of a physical record are the same. Furthermore, the lengths of these records are fixed; for example, all records in a card file have a length of 80 bytes. In Sections 7.3 and 7.4, however, it will become apparent that these notions take on added significance when tape or disk files are under consideration.

A *sequential file* is made up of records that must be processed serially (one after another in some fixed order). Card files and printed files are excellent examples of sequential files. In each case, the ordering of the file is apparent. With a card file, each card in the file must be processed in the order in which it occurs; likewise, with a printed file, the lines directed to the printer must be printed in some fixed order.

Although file organizations other than sequential (for example, indexed sequential and random access) are commonly used on most modern data processing equipment, the discussion in this chapter will, for the sake of simplicity, be confined to the processing of sequential files.

As indicated earlier, the logical records in a card file or a printed file are all the same length. In general, however, when processing files that reside on magnetic tapes or magnetic disk packs, a programmer can choose either to force all the records in the file to be the same length or to allow the lengths of the individual records to vary. In the first case, the records in the file are said to conform to the *fixed-length format;* in the second case, the records are said to be in the *variable-length format*. The fixed-length format is particularly simple, since no control information must be added to a record to indicate the length of the record. Variable-length records, however, require a means of designating the length of each logical record.

The standard format for a variable-length logical record is




Here, the first two bytes are reserved for the length of the record; the third and fourth bytes are normally set to 0000. The four-byte field of control information is called the *Record Descriptor Word (RDW)* and must be included in each record in a file of variable-length logical records.

## 7.3 TAPE FILES

A magnetic tape drive is similar in several respects to a common tape recorder/player. In both cases, information can be stored on magnetic tapes for future retrieval and the tapes are normally rewound between uses. Of course, in one instance the data is a sound image, while in the other it consists of images of strings of binary bits.

The tapes utilized by magnetic tape drives are normally as long as 2400 feet, and the storage capacity of these tapes is, literally, enormous. A single reel of tape can be used to store several files, each containing thousands of records. It is not uncommon for one reel of tape to contain 30 million characters of data.

The files on a reel of tape are numbered, starting with 1. Several special records normally precede the data records in each file; these records, called *label records*, contain information about the file. For example, the format of the records in a file is a part of the information stored in the label records for that file. Thus, it is possible to determine the format of the records in a file as well as a variety of other information about the file by simply examining the label records in that file.

When data is stored on a magnetic tape, a gap is left between the individual data records. This gap, or empty space, is referred to as an *interrecord gap*. Although such a gap is only .60 to about .75 inches wide, this can exceed the length of tape necessary to store a 100-character record by a factor of as much as 10, because data is so densely packed on the tape. A typical density factor is 1600 characters per inch. In addition, each interrecord gap represents a place where the tape must be physically stopped and restarted. A typical time for starting and stopping a tape is approximately five times as long as the time required to read a 100-character record.

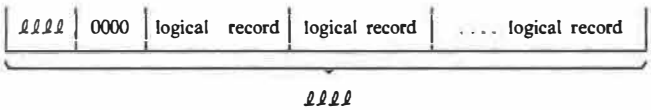
By applying a little arithmetic, the reader can easily determine that, if individual 100-character records were stored on a tape, the tape could be 90

percent blank spaces and the time occupied in starting and stopping this tape could be 80 percent of the time required to read the tape. To alleviate this situation, it is common to store more than one logical record between interrecord gaps. This technique is called *blocking*. The set of records stored between gaps is called a *block*, and the number of these records is called the *blocking factor*.

From this information the reader can easily calculate the effect that a blocking factor of 10 would have on the length of tape required to store and the length of time required to read a lengthy file of 100-character records. Assume, for example, that such a file contained 10,000 records. Blocking reduces the number of interrecord gaps from 10,000 to 1000. This effectively reduces the length of tape required to store the file by 5400 inches; the amount of time required to read the file is about one-sixth of what it would have been without blocking.

When magnetic tape drives are used for the input or output of data, a physical record (the amount of data transferred in a single I/O operation) is the data recorded between two adjacent interrecord gaps. Thus, a block and a physical record are the same. If a blocking factor of 1 is used, a logical record and a physical record have the same length. However, if, as in the previous example, 100-byte logical records are blocked using a blocking factor of 10, a logical record has a length of 100 bytes while a physical record has a length of 1000 bytes. The advantages gained by using a large blocking factor must always be weighed against the expense of the computer storage required to store large blocks of data.

Before we leave the topic of tape files, one more aspect of blocking must be discussed. When logical records in variable-length format are blocked, the lengths of the blocks may vary because of the variation in the lengths of the logical records. In this case, control information must be added to the beginning of each block of records to indicate the length of the block. The format of a block of variable-length records is




where the two bytes $\ell\ell\ell\ell$ indicate the length of the block.

## 7.4 DISK FILES

A *direct-access device* is an I/O device that permits any single physical record stored on the device to be accessed without having to access any other physical record stored on the device. There are a variety of direct-access devices

in common use. However, in this section, only the magnetic moving-head disk drive will be considered. A typical moving-head disk pack (the recording medium for a disk drive) has six disks that are mounted on a vertical shaft. There are five movable arms, each controlling two read-write heads used to record or read information from the inside surfaces of the disks. These arms move in unison.

If the read-write heads are not moved during the time required for the disk pack to rotate once, each of the read-write heads will have moved past an area of a disk that forms a ring on the surface of that disk. There is a fixed number of positions—say, 200—to which the read-write heads can be moved. Thus, for each disk in the disk pack, there are 200 concentric rings that can be used to store data on each surface in contact with a read-write head. Each such ring is called a *track*. Each track has the same storage capacity, which is a function of the particular model or type of disk pack under consideration.

Suppose that as the disk pack revolves, the read-write heads are not moved. Then, the collection of tracks that passes under the individual read-write heads is called a *cylinder*. The tracks in a cylinder are naturally related, since data can be stored on or read from all the tracks in that cylinder without intermediate movement of the read-write heads.

One common moving-head disk drive in use at this writing has 30 recording surfaces. Such a disk pack is capable of storing more than 300 million characters of data.

This discussion of magnetic disk drives is confined to a consideration of sequential files. The following sequence describes the basic order in which physical records in a sequential file are stored on a disk pack.

1. The read-write heads are first positioned to the cylinder in which the file is to begin.
2. Physical records are stored in all the tracks in the current cylinder until this cylinder is filled. Then, all the read-write heads are moved to the next adjacent cylinder where storage is continued.

As in the case of files stored on magnetic tape, label records are normally associated with disk files. However, with disk files, these records are not stored at the beginning of the file to which they are related. Instead, for each file, the position of that file on the disk pack and the label records associated with the file are stored in the *volume table of contents (VTOC)*. There is one VTOC per pack, and it is used to store information pertinent to each file stored on that pack.

The records stored on a track of a disk pack resemble the records stored on a magnetic tape. In each case, relatively large gaps occur between physical records. For this reason, blocking is used with disk files just as with tape files. With a disk file, however, the size of the blocks should be chosen

to conform to the storage capacity of a track: The block size should be chosen so as to avoid an unnecessarily large gap at the end of the track.

For example, if the storage capacity of a track were equal to two blocks of $n$ characters each, it would be wasteful to choose a blocking factor resulting in a physical record size of $2n$-$n/2$ bytes, as this would result in a gap of $n/2$ bytes at the end of each track. For most types of disk packs, charts are available that give suggested block sizes. These charts should be consulted before the block size is selected for any disk file.

## 7.5 AN OVERVIEW OF THE QUEUED SEQUENTIAL ACCESS METHOD (QSAM)

The routines required to effect the reading of a record or the printing of a line are incredibly complex. The routines required to access records on tape or disk files are even more complex, because the logical records must be extracted from the physical records or blocks. Since the problems posed by accessing and creating files are so substantial, routines for performing these functions are available on most computer systems. These routines may be invoked by the application programmer through appropriate macro instructions.

The details concerning the definition of macros are deferred to Chapter 9. For now, the reader may think of a macro instruction simply as a single instruction that will cause a sequence of assembler instructions to be generated. Specifically, when a module is required to perform a given function, a macro instruction can be used to generate the instructions necessary to call the module.

A complete set of macros and modules for performing I/O functions is referred to as an *access method*. Only one such access method, the *queued sequential access method* (QSAM), will be considered here. The basic services provided by QSAM are presented in this section; the specific details of the macro instructions available to the application programmer for invoking the modules to perform these services are deferred to Section 7.6.

1. In the case of *output files* (files created by a user program), QSAM provides modules that can be invoked to do the following:

   a. Open the file. This service must be performed before any attempt is made to transfer a record to the file. Such a module performs initialization tasks, such as readying an output device to receive the file and inserting label records on a tape file.

   b. Transfer a record to a buffer. When a module of this type is invoked, a record is transferred from the application program to a buffer. When the last record in a block has been transferred to the buffer, the block is output to the appropriate recording medium through an I/O device. Thus, with a tape file that consists of fixed-length records grouped

ten to a block, the module invoked will cause a physical record to be output every tenth time it is invoked. On the other hand, with an unblocked file (such as a printer file), a physical record is output each time the module is invoked.

c. Close the file. Such a module must be invoked after the last of the records in a file has been transferred to a buffer. This module causes the last block assembled to be output and a variety of necessary "clean-up" operations to be performed.

2. In the case of *input files*, QSAM provides modules that can be invoked to do the following:

   a. Open the file. Such a module initiates the input of the first block of the file to a buffer so that it will be available when the application program makes a request for a record from the file.

   b. Pass a record to the application program. When such a module is invoked, a record is made available to the user program from a buffer residing in memory. The buffer is automatically replenished with physical records. When an attempt is made to pass a record after the file has been exhausted, control is transferred to a routine in the application program that processes end-of-file.

   c. Close the file. This routine is normally invoked by the user program before termination.

Before discussing QSAM macro instructions, we need to discuss a few details of the existing methods for passing records back and forth between the user program and buffers. Two basic methods are available in QSAM for accomplishing this. These are represented by the *move mode* and the *locate mode*.

When an input file is processed using QSAM in the move mode, one logical record is actually transferred from a buffer to an area specified by the user program whenever an input record is requested. However, when the locate mode is employed, the address of the record is returned in a register and no actual movement of data takes place. When an output file is processed using QSAM in the move mode, each output request causes a logical record to be transferred to a buffer. On the other hand, if the locate mode is specified, the address of the location to which the record should be moved is returned to the application program in a register and no actual movement of data takes place.

## 7.6 INVOKING QSAM SERVICES IN AN OS ENVIRONMENT

The services offered by QSAM are sketchily outlined in Section 7.5. In this section, the QSAM macro instructions used to invoke the routines that perform these services are discussed.

The DCB macro instruction is used to generate a storage area where information about the characteristics and status of a particular file is retained. Such a storage area is called a *data control block (DCB)*. There must be a DCB instruction for each file processed by a program. Since no executable statements are generated, the DCB instructions are normally placed at the end of a program, along with the DC and DS statements. The DCB macro instruction has numerous keyword operands. The following format contains the most commonly used operands:

```
label      DCB      DSORG=PS
                    DDNAME=ddname
                    RECFM=recfm
                    LRECL=lrecl
                    BLKSIZE=blksize
                    EODAD=eodad
                    MACRF=macrf
```

The meanings of these operands are as follows:

- DSORG=PS specifies that the file is a sequential file.
- DDNAME=ddname specifies the name by which the file will be described in the Job Control Language statements when the program is executed. Although this topic is beyond the scope of this text, we will give brief attention to it at the end of this chapter. Suffice it to say here that any symbol acceptable as a label for an assembler-language statement can be used.
- RECFM=recfm specifies the format of the records in the file. The most common specifications and formats are:

| *Recfm* | *Meaning* |
|---|---|
| F | Fixed-length, unblocked records |
| V | Variable-length, unblocked records |
| FB | Fixed-length, blocked records |
| VB | Variable-length, blocked records |
| FA | Fixed-length records with a carriage control character in the first byte |

The FA value is normally specified only for files that are to be printed.

- LRECL=lrecl specifies the length of logical records in the file. In the case of variable-length records, lrecl should be the maximum length of a record (including the Record Descriptor Word).
- BLKSIZE=blksize specifies the maximum size of a block in the file. For example, if LRECL=80 and RECFM=FB were specified, BLKSIZE=800

would be used to indicate that 10 logical records are included in each block. With variable-length records, the block size must be at least 4 larger than lrecl, to allow for the Block Descriptor Word.

- EODAD=eodad specifies the label of a routine to which control is to be passed if a record is requested after the file has been exhausted. When the routine gains control, registers R2–R13 will contain the same values that they contained when the request was made.
- MACRF=macrf specifies whether the file is an input or an output file and whether locate or move mode will be used in processing the file. The normal values are:

| *Macrf* | *Meaning* |
|---|---|
| GL | Input file using locate mode |
| GM | Input file using move mode |
| PL | Output file using locate mode |
| PM | Output file using move mode |

The following examples should help to clarify the use of the DCB macro instruction:

- *Example 1.* A DCB for a card input file might be specified as follows:

```
CARDIN    DCB  DSORG=PS,DDNAME=CARDFL,RECFM=F,      X
               LRECL=80,BLKSIZE=80,EODAD=EOF,       X
               MACRF=GM
```

In this case, move mode will be used and, when end-of-file occurs, control will be passed to the routine EOF.

- *Example 2.* A DCB for a file that is to be printed could be specified as follows:

```
PRINTOUT DCB  DSORG=PS,DDNAME=REPORT,RECFM=FA,     X
              LRECL=133,BLKSIZE=133,MACRF=PM
```

In this case, move mode is specified. The first character of each record is to be interpreted as a carriage control character (just as the first character is used as a carriage control character when a line is printed using XPRNT). Note that every record in the file must be 133 bytes long; using XPRNT, the length can range from 1 to 133 bytes.

- *Example 3.* A DCB for a payroll master file of variable-length records that will be read from a disk or tape using locate mode might be coded as follows:

```
PAYROLL   DCB  DSORG=PS,DDNAME=PAYMAST,RECFM=VB,   X
               LRECL=428,BLKSIZE=3520,              X
               EODAD=PAYEOF,MACRF=GL
```

The OPEN macro instruction is used to invoke a routine that causes one or more files to be opened. The format for this instruction is

```
label        OPEN    (entry1,entry2, . . .)
```

where each entry is of the form

```
dcblabel,(INPUT)
```

or

```
dcblabel,(OUTPUT)
```

For example, the macro instruction

```
OPEN        (CARDIN,(INPUT),PRINTOUT,(OUTPUT))
```

could be used to initialize the processing of two files with DCBs labeled CARDIN and PRINTOUT.

The GET macro instruction is used to invoke a routine that will obtain a record from an open input file. The format for the GET macro instruction, using move mode, is

```
label        GET       dcblabel,area
```

Execution of the called module will cause one record to be moved from the input file with the DCB labeled dcblabel to be moved to the area specified by the second operand. For example, the macro instruction

```
GET       CARDIN,CARD
```

could be used to move the contents of a card into an area labeled CARD. If end-of-file occurs, the next instruction executed in the user program is determined by the label specified in the EODAD operand in the DCB CARDIN. If a file is to be accessed using locate mode, only the first operand of the GET macro instruction should be specified. As a result, the address of the desired record will be placed in R1. Thus, the macro instruction

```
GET       PAYROLL
```

could be used to insert into R1 the address of the next record from the file with the DCB PAYROLL.

The PUT macro instruction is used to invoke a routine for passing records from the user program to an output file. The two alternate formats for the PUT macro instruction are

```
label        PUT       dcblabel,area
```

and

```
label        PUT       dcblabel
```

When the first format is used, the record is actually moved from the location designated by the second operand to an output buffer. When the second format is used, the address to which the record should be moved is returned in R1 and no data transfer occurs. The first format is far more common than the second.

The CLOSE macro instruction is used to invoke a routine that will cause the processing of one or more files to be terminated. The format for this instruction is

```
label        CLOSE (entry1,entry2, . . .)
```

where each entry has the form

```
dcblabel,,
```

Thus, the macro instruction

```
CLOSE (CARDIN,,PRINTOUT,,PAYROLL)
```

could be used to close the three files with DCBs labeled CARDIN, PRINTOUT, and PAYROLL. The adjacent commas are used to specify that a parameter designating possible options is omitted. The reader should consult the appropriate IBM manual to determine what options are available and when they should be used.

Two details concerning the use of IBM macros should be carefully noted before leaving this discussion of QSAM:

1. The use of almost any IBM-supplied macro can cause the destruction of the contents of R0, R1, R14, and R15.
2. A register save area should be established before any QSAM routine is invoked.

Programs 7-1 through 7-4 illustrate the use of the QSAM macro instructions. Study these examples carefully.

The reader should note that, although these examples illustrate I/O using QSAM services, the programs are certainly not structured. The main problem in writing a structured program that utilizes QSAM involves the EODAD address. When writing structured programs, the EODAD address should be set up as follows:

```
INFILE   DCB   ...EODAD=EODRTN,...
EODRTN   MVI   EOFFLAG,C'Y'        SET END-OF-FILE FLAG
         BR    R14                 GO TO INSTRUCTION FOLLOWING GET
EOFFLAG  DC    C'N'                SET TO 'Y' AT END-OF-FILE
```

**Program 7-1**

```
HOW TO READ CARDS AND PRINT LINES WITH QSAM                                                          PAGE    1

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                              16 JUN 75

                                  2 * THIS SHORT PROGRAM IS DESIGNED TO ILLUSTRATE THE STEPS REQUIRED
                                  3 * TO READ CARDS AND/OR PRINT LINES USING QSAM.
                                  4 *
                                  5 * THE PROGRAM SIMPLY 80-80 LISTS A DECK OF CARDS, SKIPPING
                                  6 * TO THE TOP OF A PAGE AFTER EVERY 50 LINES.
                                  7 *
                                  8 * THE LOGIC IS AS FOLLOWS:
                                  9 *
                                 10 *         STEP 1.  OBSERVE NORMAL OS LINKAGE CONVENTIONS.
                                 11 *
                                 12 *         STEP 2.  OPEN THE DCBS.
                                 13 *
                                 14 *         STEP 3.  SET THE COUNTER OF LINES LEFT TO PRINT ON THE
                                 15 *                  CURRENT PAGE TO 50.
                                 16 *
                                 17 *         STEP 4.  GET A CARD.  IF END-OF-FILE OCCURS AN AUTOMATIC
                                 18 *                  BRANCH TO STEP 8 WILL OCCUR.
                                 19 *
                                 20 *         STEP 5.  PRINT OUT THE CARD JUST READ.
                                 21 *
                                 22 *         STEP 6.  SET THE CARRIAGE CONTROL TO SINGLE SPACE, AND
                                 23 *                  DECREMENT THE COUNT OF LINES LEFT FOR THIS PAGE.
                                 24 *                  IF THE COUNT IS NOT 0, GO TO STEP 4.
                                 25 *
                                 26 *         STEP 7.  SET THE CARRIAGE CONTROL FOR SKIP TO TOP OF PAGE
                                 27 *                  BEFORE PRINTING, AND GO BACK TO STEP 3.
                                 28 *
                                 29 *         STEP 8.  CLOSE THE DCBS, AND EXIT.
                                 30 *
000000                           31 LISTPROG CSECT
                                 32          PRINT NOGEN
                                 33 *
                                 34 ***<STEP 1>     FOLLOW NORMAL LINKAGE CONVENTIONS
000000 90EC 000C        00000C   35          STM   R14,R12,12(R13)      STORE CALLER'S REGISTERS
000004 45EF 0050        00050    36          BAL   R14,80(R15)          BRANCH AROUND THE SAVE AREA
000008                           37          DS    18F                  REGISTER SAVE AREA
00005C 50ED 0008        00008    38          ST    R14,8(R13)           NOW LINK THE SAVE AREAS
000054 50DE 0004        00004    39          ST    R13,4(R14)
000058 18DE                      40          LR    R13,R14              R13 WILL BE THE BASE REGISTER
                        00008    41          USING LISTPROG+8,R13
                                 42 *
                                 43 *
                                 44 ***<STEP 2>     OPEN THE DCBS.
00005A                           45          OPEN  (CARDDCB,(INPUT),PRINTDCB,(OUTPUT))
                                 53 *
                                 54 ***<STEP 3>     SET THE COUNT OF LINES LEFT ON THE PAGE TO 50.
00006A 4120 0032        00032    55 STARTPG  LA    R2,50                R2 <- # LINES LEFT ON PAGE
                                 56 *
```

## Program 7-1 (continued)

```
        HOW TO READ CARDS AND PRINT LINES WITH QSAM                                                    PAGE    2

 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                              16 JUN 75

                                  57 ***<STEP 4>     READ A CARD.
000006E                           58 READLOOP GET    CARDDCB,CARD        READ A CARD
                                  63 *
                                  64 ***<STEP 5>     PRINT IT.
000007C                           65          PUT    PRINTDCB,CARD-1     PRINT IT

                                  70 *
                                  71 ***<STEP 6>     SET CARRIAGE CONTROL TO SINGLE SPACE. IF MORE LINES LEFT
                                  72 *               ON THE PAGE, GO BACK TO STEP 4.
000008A 9240 D0AC     00084       73          MVI    CARD-1,C' '         SET FOR SINGLE SPACING
000008E 4020 D066           0006E 74          BCT    R2,READLOOP         BRANCH UNLESS PAGE BREAK OCCURS
                                  75 *
                                  76 ***<STEP 7>     SET CARRIAGE CONTROL TO SKIP TO TOP OF PAGE.
000092 92F1 D0AC      00084       77          MVI    CARD-1,C'1'         SET CARRIAGE CONTROL TO
                                  78 *                                   SKIP TO TOP OF PAGE BEFORE PRINTING
000096 47F0 D062            0006A 79          B      STARTPG             GO SET THE LINE COUNTER
                                  80 *
                                  81 ***<STEP 8>     CLOSE FILES AND EXIT.
00009A                            82 EOFRT    CLOSE (CARDDCB,,PRINTDCB) CLOSE THE FILES
0000AA 58DD 0004            00004 90          L      R13,4(R13)
0000AE 98EC 000C            0000C 91          LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTER'S
0000B2 07FE                       92          BR     R14
                                  93 *
0000B4 F1                         94          DC     C'1'                CARRIAGE CONTROL
0000B5                            95 CARD     DS     CL80                CARDS ARE READ INTO THIS AREA
                                  96 *
                                  97 CARDDCB  DCB    DSORG=PS,DDNAME=INPUTFL,MACRF=GM,EODAD=EOFRT,          X
0001D5                                               RECFM=F,BLKSIZE=80,LRECL=80
                                 151 *
                                 152 PRINTDCB DCB    DSORG=PS,DDNAME=OUTPUT,MACRF=PM,RECFM=FA,             X
0001E8                                               LRECL=81,BLKSIZE=81
                                 206 *
0001C0                           207          LTORG
                                 208          EQUREGS
000000                           225          END    LISTPROG
```

**Program 7-2**

```
COPYFILE - COPY AND DISPLAY A SEQUENTIAL FILE                                                    PAGE    1

LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                                        16 JUN 75

                                   2 * THIS PROGRAM ILLUSTRATES THE USE OF QSAM TO READ AND
                                   3 * WRITE SEQUENTIAL FILES.  IN THIS PARTICULAR CASE A FILE
                                   4 * OF 100-BYTE RECORDS IS COPIED.  THE RECORDS ARE BLOCKED
                                   5 * INTO BLOCKS OF 1600 BYTES.  THE PROGRAM ALSO DISPLAYS THE
                                   6 * CONTENTS OF EACH RECORD (IT IS ASSUMED THAT THE RECORDS
                                   7 * CONTAIN DATA WHICH IS ALL IN CHARACTER FORMAT.)  THE
                                   8 * INPUT FILE IS PROCESSED IN LOCATE MODE, WHILE BOTH OUPUT
                                   9 * FILES UTILIZE MOVE MODE.  THE LOGIC OF COPYFILE IS AS FOLLOWS:
                                  10 *
                                  11 *          STEP 1.  OBSERVE NORMAL OS SAVE AREA LINKAGE CONVENTIONS.
                                  12 *
                                  13 *          STEP 2.  OPEN THE DCBS.
                                  14 *
                                  15 *          STEP 3.  SET THE COUNT OF LINES LEFT TO PRINT ON THE CURRENT
                                  16 *                   PAGE TO 50.
                                  17 *
                                  18 *          STEP 4.  READ A RECORD FROM THE INPUT FILE.  SINCE PROCESSING
                                  19 *                   IS BEING DONE USING LOCATE MODE, THE ADDRESS OF THE
                                  20 *                   RECORD IS RETURNED IN R1 (RATHER THAN MOVING THE
                                  21 *                   RECORD TO A WORK AREA IN THE USER'S ROUTINE).
                                  22 *
                                  23 *          STEP 5.  WRITE THE RECORD OUT TO THE NEW FILE USING MOVE MODE.
                                  24 *                   NOTE THAT THE ADDRESS OF THE RECORD IS SPECIFIED AS
                                  25 *                   THE VALUE IN A REGISTER.
                                  26 *
                                  27 *          STEP 6.  PRINT THE RECORD.  THIS REQUIRES FIRST MOVING IT TO
                                  28 *                   A WORK AREA SO THAT CARRIAGE CONTROL CAN BE INSERTED.
                                  29 *
                                  30 *          STEP 7.  SET THE CARRIAGE CONTROL TO SINGLE SPACE.  IF THERE
                                  31 *                   ARE MORE LINES LEFT TO PRINT ON THE CURRENT PAGE, GO
                                  32 *                   BACK TO STEP 4.
                                  33 *
                                  34 *          STEP 7.  SET CARRIAGE CONTROL FOR SKIP TO 1 BEFORE PRINTING,
                                  35 *                   AND RETURN TO STEP 3.
                                  36 *
                                  37 *          STEP 7.  PRINT END OF LIST MESSAGE, CLOSE THE FILES, AND EXIT.
                                  38 *
                                  39 *
000000                            40 COPYFILE CSECT
                                  41          PRINT NOGEN
                                  42 ***<STEP 1>     FOLLOW NORMAL LINKAGE CONVENTIONS
000000 90EC 000C        000C      43          STM   R14,R12,12(R13)     STORE CALLER'S REGISTERS
000004 45EF 0050        0050      44          BAL   R14,80(R15)         BRANCH AROUND THE SAVE AREA
000008                            45          DS    18F                 REGISTER SAVE AREA
00005C 50ED 0008        0008      46          ST    R14,8(R13)          NOW LINK THE SAVE AREAS
000054 50DE 0004        0004      47          ST    R13,4(R14)
000058 18DE             0008      48          LR    R13,R14             R13 WILL BE THE BASE REGISTER
                                  49          USING COPYFILE+8,R13
                                  50 *
                                  51 *
```

**Program 7-2 (continued)**

```
COPYFILE - COPY AND DISPLAY A SEQUENTIAL FILE                                                    PAGE    2

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                          16 JUN 75

                                  52 ***<STEP 2>    OPEN THE DCBS
000005A                           53          OPEN  (FILEIN,(INPUT),FILEOUT,(OUTPUT),LIST,(OUTPUT))
                                  63 *

                                  64 ***<STEP 3>    SET COUNT OF LINES LEFT ON PAGE TO 50.
000006E 4120 0032          00032  65 STARTPG  LA    R2,50                R2 <- # LINES LEFT ON PAGE
                                  66 *
                                  67 ***<STEP 4>    READ A RECORD FROM THE INPUT FILE.
000072                            68 READLOOP GET   FILEIN               THIS RETURNS ADDRESS OF REC. IN R1
00007C 1831                       72          LR    R3,R1                SAVE ADDRESS IN REGISTER WHICH
                                  73 *                                   DOESN'T GET DESTROYED
                                  74 *
                                  75 ***<STEP 5>                         WRITE THE RECORD OUT TO THE NEW FILE.
00007E                            76          PUT   FILEOUT,(3)
                                  81 * NOTE THAT THE SECOND OPERAND IS USED TO GIVE THE ADDRESS OF
                                  82 * THE RECORD TO WRITE OUT, AND THAT OPERAND MAY BE SPECIFIED AS
                                  83 * THE VALUE IN A REGISTER BY JUST ENCLOSING THE REGISTER NUMBER
                                  84 * WITH PARENTHESES.
                                  85 *
                                  86 ***<STEP 6>    PRINT THE RECORD.
00008A D263 D001 3000 00009 00000 87          MVC   RECORD+1(100),0(R3) MOVE RECORD TO WORK AREA
000090                            88          PUT   LIST,RECORD            PRINT OUT THE RECORD
                                  93 *
                                  94 ***<STEP 7>    SET CARRIAGE CONTROL FOR SINGLE SPACE, AND
                                  95 *              TEST FOR MORE LINES LEFT ON PAGE.
000096 9240 D000       000D8      96          MVI   RECORD,C' '            SET CARRIAGE CONTROL FOR SINGLE SPACE
00009A 4620 006A           00072  97          BCT   R2,READLOOP            BRANCH UNLESS PAGE BREAK OCCURS
                                  98 *
                                  99 ***<STEP 8>    SET CARRIAGE CONTROL FOR SKIP TO TOP OF PAGE.
0000A6 92F1 D000       000D8     100          MVI   RECORD,C'1'
0000AA 47F0 006E           0006E 101          B     STARTPG                BRANCH TO RESET LINE COUNTER
                                 102 *
                                 103 ***<STEP 9>    PRINT END OF LIST, CLOSE DCBS, AND EXIT.
0000AE                           104 EOFRT    PUT   LIST,ENDMESS
0000BC                           109          CLOSE (LIST,,FILEIN,,FILEOUT)
0000CE 58DD 0004           00004 119          L     R13,4(R13)
0000D2 98EC D00C           0000C 120          LM    R14,R12,12(R13)        RESTORE CALLER'S REGISTERS
0000D6 07FE                      121          BR    R14                    EXIT
                                 122 *
0000D8 F140404040404040          123 RECORD   DC    CL101'1'               AREA FOR 1 RECORD AND CARR. CONTROL
000139 F05C5C5C5C5C40C5          124 ENDMESS  DC    CL101'0***** END OF LISTING *****'
                                 125 *
                                 126 LIST     DCB   DDNAME=LIST,DSORG=PS,MACRF=PM,BLKSIZE=101,RECFM=FA,      X
0001A2                                             LRECL=101
                                 180 FILEIN   DCB   DSORG=PS,DDNAME=FILEIN,MACRF=GL,EODAD=EOFRT,RECFM=FB,    X
000204                                             BLKSIZE=1600,LRECL=100
                                 234 FILEOUT  DCB   DSORG=PS,DDNAME=FILEOUT,MACRF=PM,RECFM=FB,               X
000264                                             BLKSIZE=1600,LRECL=100
                                 288 *
0002C8                           289          LTORG
                                 290          EQUREGS
000000                           307          END   COPYFILE
```

**Program 7-3**

```
VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE    1

LCC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                16 JUN 75

                                  2 * THIS SIMPLE PROGRAM IS DESIGNED TO ILLUSTRATE THE USE OF VARIABLE
                                  3 * LENGTH RECORDS.  THE PROGRAM READS CARDS, EACH OF WHICH CONTAINS
                                  4 *
                                  5 *         A STUDENT'S SOCIAL SECURITY NUMBER IN COL.S 1-9 AND
                                  6 *         A TEST SCORE (0-100) IN COLUMNS 11-13.
                                  7 *
                                  8 * ALL OF THE CARDS FOR A GIVEN STUDENT OCCUR TOGETHER IN THE CARD
                                  9 * INPUT FILE.  THE PROGRAM CREATES 1 VARIABLE-LENGTH RECORD FOR
                                 10 * EACH STUDENT; THE RECORD CONTAINS ALL OF THE STUDENT'S TEST
                                 11 * SCORES IN PACKED DECIMAL FORMAT.  THE PRECISE FORMAT OF THE
                                 12 * GENERATED RECORDS IS
                                 13 *
                                 14 *         +0(4)      RDW (2 BYTES OF LENGTH, 2 BYTES OF 0000)
                                 15 *         +4(9)      SOCIAL SECURITY NUMBER
                                 16 *         +13(UP TO 40)  THE STUDENT'S SCORES
                                 17 *                     EACH SCORE WILL BE IN A 2-BYTE PACKED DEC. FIELD
                                 18 *
                                 19 * THUS, THE MAXIMUM LENGTH OF ONE OF THE GENERATED RECORDS IS 53,
                                 20 * AND THIS WOULD REQUIRE 20 CONSECUTIVE TEST SCORES FOR THE
                                 21 * SAME STUDENT.  THE LOGIC OF THE PROGRAM IS
                                 22 *
                                 23 *         STEP 1.  OBSERVE NORMAL OS LINKAGE CONVENTIONS.
                                 24 *
                                 25 *         STEP 2.  OPEN BOTH DCBS.
                                 26 *
                                 27 *         STEP 3.  READ THE FIRST RECORD AND SAVE ITS ADDRESS.
                                 28 *
                                 29 *         STEP 4.  PUT THE SOC. SEC. # INTO THE NEW RECORD.  ALSO,
                                 30 *                  PACK IN THE SCORE OFF THE 1ST CARD.
                                 31 *
                                 32 *         STEP 5.  READ CARDS,PACKING THE SCORES INTO THE DISK RECORD,
                                 33 *                  UNTIL A CARD WITH A NEW SOC. SEC. # IS READ OR END-
                                 34 *                  OF-FILE OCCURS.  IF END-OF-FILE OCCURS, A BRANCH TO
                                 35 *                  STEP 7 WILL TAKE PLACE AUTOMATICALLY.
                                 36 *
                                 37 *         STEP 6.  CALL 'PUTREC' TO PUT IN THE RDW AND WRITE OUT THE
                                 38 *                  CONSTRUCTED RECORD.  GO TO STEP 4 (SINCE THE 1ST
                                 39 *                  RECORD FOR THE NEXT GUY HAS BEEN READ ALREADY).
                                 40 *
                                 41 *         STEP 7.  CALL 'PUTREC' TO WRITE OUT THE LAST RECORD.
                                 42 *
                                 43 *         STEP 8.  CLOSE THE FILES AND EXIT.
                                 44 *
                                 45          PRINT NOGEN
000000                           46 VARBUILD CSECT
```

**Program 7-3 (continued)**

```
VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE    2

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                              16 JUN 75

                                  47 ***<STEP 1>    OBSERVE NORMAL OS LINKAGE CONVENTIONS.
000000 90EC D00C          0000C   48          STM   R14,R12,12(R13)     SAVE CALLER'S REGISTERS
000004 45EF 0050          00050   49          BAL   R14,80(R15)         BRANCH AROUND SAVE AREA
000008                            50          DS    18F                 REGISTER SAVE AREA
00005C 50ED 0008          00008   51          ST    R14,8(R13)          SET FORWARD LINK
000054 50DE 0004          00004   52          ST    R13,4(R14)          SET BACK LINK
000058 18DE                       53          LR    R13,R14             R13 IS THE BASE REGISTER
                          00008   54          USING VARBUILD+8,R13

                                  55 *
                                  56 ***<STEP 2>    OPEN THE DCBS.
00005A                            57          OPEN  (CARDFL,(INPUT),VARFL,(OUTPUT))
                                  65 *
                                  66 ***<STEP 3>    READ THE 1ST RECORD.
000060A                           67          GET   CARDFL              GET THE FIRST RECORD
000074 1831                       71          LR    R3,R1               R3 <- ADDRESS OF FIRST RECORD
                                  72 *
                                  73 ***<STEP 4>    PUT IN THE SOC. SEC. # AND 1ST SCORE.
000076 D208 D0F4 3000 000FC 00000 74 MAINLOOP MVC   SOCSEC#(9),0(R3)    MOVE IN SOC. SEC. # FOR NEW RECORD
00007C F212 00FD 300A 00105 0000A 75          PACK  SCORES(2),10(3,R3) PACK IN FIRST TEST SCORE
000082 4120 0UFF          00107   76          LA    R2,SCORES+2         R2 <- ADDRESS TO PACK NEXT SCORE
                                  77 *
                                  78 ***<STEP 5>    PUT IN SCORES FOR CONSECUTIVE CARDS WITH THE SAME #.
000086                            79 BUILDLP  GET   CARDFL              GET THE NEXT CARD
                                  83 *
000090 D508 D0F4 1000 000FC 00000 84          CLC   SOCSEC#(9),0(R1)    SAME STUDENT?
000096 4770 00A0          000A8   85          BNE   NEXTGUYS            NO -> BRANCH
00009A F212 2000 100A 00000 0000A 86          PACK  0(2,R2),10(3,R1)    PACK IN THE TEST SCORE
0000A0 4122 0002          00002   87          LA    R2,2(R2)            INCREMENT THE POINTER TO NEXT SCORE
0000A4 47F0 007E          00086   88          B     BUILDLP
                                  89 *
                                  90 ***<STEP 6>    CALL 'PUTREC' TO WRITE OUT THE RECORD.
0000A8 1831                       91 NEXTGUYS LR    R3,R1               SAVE ADDRESS OF LAST INPUT RECORD
0000AA 45A0 00C8          000D0   92          BAL   R10,PUTREC          CALL A ROUTINE TO WRITE THE RECORD
0000AE 47F0 006E          00076   93          B     MAINLOOP            GO BACK TO PROCESS NEXT SET
                                  94 *
                                  95 ***<STEP 7>    EOF OCCURRED.  NOW WRITE THE LAST RECORD.
000082 45A0 00C8          00000   96 EODRTN   BAL   R10,PUTREC          WRITE THE LAST RECORD
                                  97 *
```

**Program 7-3 (continued)**

```
          VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE    3

   LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                    16 JUN 75

                                     98 ***<STEP 8>    CLOSE THE FILES AND EXIT.
000086                               99            CLOSE (CARDFL,,VARFL)
0000C6 58DD 0004            00004   107            L     R13,4(R13)
0000CA 98EC D00C            0000C   108            LM    R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
0000CE 07FE                         109            BR    R14                 EXIT
                                    110 *
                                    111 * PUTREC SIMPLY FILLS IN THE RDW AND ISSUES A PUT TO CAUSE THE
                                    112 * RECORD TO BE WRITTEN TO THE DISK FILE (ACTUALLY, THE PUT
                                    113 * CAUSES THE RECORD TO BE TRANSFERRED TO THE OUTPUT BUFFER).
                                    114 *
000000 5820 00E8            00000   115 PUTREC    S     R2,=A(RDW)          R2 <- LENGTH OF RECORD
000004 4020 00F0            00008   116            STH   R2,RDW              STORE INTO LEFT HALF OF RDW
000008 D201 00F2 00EC 00000 00004   117            MVC   RDW+2(2),=H'0'      ZERO RIGHT HALF
00000E                              118            PUT   VARFL,RDW           WRITE 1 VARIABLE-LENGTH RECORD
0000EC 07FA                         123            BR    R10                 RETURN
                                    124 *
0000F0                              125            LTORG
000000F0 00000008                   126                  =A(RDW)
0000F4 0000                         127                  =H'0'
                                    128 *
                                    129 * THE VARIABLE-LENGTH RECORD IS CONSTRUCTED HERE.  THE
                                    130 * THREE FIELDS — RDW, SOCSEC#, AND SCORES — ARE ALL PART
                                    131 * OF THE RECORD.
                                    132 *
0000F8                              133 RDW       DS    F                   RECORD DESCIPTOR WORD
0000FC                              134 SOCSEC#   DS    CL9                 SOCIAL SECURITY NUMBER
000105                              135 SCORES    DS    20PL2               MAXIMUM OF 20 SCORES IN THE RECORD
                                    136 *
                                    137 CARDFL    DCB   DSORG=PS,DDNAME=INPUT,MACRF=GL,EODAD=EODRTN,                X
000120                                                  RECFM=F,BLKSIZE=80,LRECL=80
                                    191 *
                                    192 * THE FOLLOWING DCB DEFINES THE PARAMETERS TO WRITE A FILE
                                    193 * OF VARIABLE-LENGTH BLOCKED RECORDS USING MOVE-MODE.
                                    194 *
                                    195 VARFL     DCB   DSORG=PS,DDNAME=VARFILE,MACRF=PM,RECFM=VB,                 X
000190                                                  LRECL=53,BLKSIZE=3520
                                    249 *
                                    250            EQUREGS
000000                              267            END   VARBUILD
```

## Program 7-4

```
          VARLIST - HOW TO ACCESS VARIABLE-LENGTH RECORDS                                                    PAGE    1

LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                    16 JUN 75

                                   2 * IN THIS EXAMPLE THE RECORDS PRODUCED BY 'VARBUILD' ARE
                                   3 * ACCESSED AND USED TO PRINT OUT THE TEST SCORES FOR ALL
                                   4 * THE STUDENTS.  THE READER SHOULD STUDY VARBUILD CAREFULLY
                                   5 * BEFORE EXAMINING THIS EXAMPLE, SINCE THE FORMAT AND CONTENTS
                                   6 * OF THE RECORDS ARE DISCUSSED THERE.
                                   7 *
                                   8 * THE LOGIC OF VARLIST IS AS FOLLOWS:
                                   9 *
                                  10 *          STEP 1.  OBSERVE NORMAL OS LINKAGE CONVENTIONS.
                                  11 *
                                  12 *          STEP 2.  OPEN THE DCBS.
                                  13 *
                                  14 *          STEP 3.  READ A VARIABLE-LENGTH RECORD.  ON EOF GO TO STEP 6.
                                  15 *
                                  16 *          STEP 4.  CONSTRUCT A PRINT LINE FROM THE DATA IN THE RECORD.
                                  17 *
                                  18 *          STEP 5.  PUT OUT THE PRINT LINE.  GO TO STEP 3.
                                  19 *
                                  20 *          STEP 6.  CLOSE THE FILES AND EXIT.
                                  21 *
000000                            22 VARLIST CSECT
                                  23          PRINT NOGEN
                                  24 *
                                  25 ***<STEP 1>    FOLLOW NORMAL LINKAGE CONVENTIONS
000000 90EC 000C        00000     26          STM   R14,R12,12(R13)      STORE CALLER'S REGISTERS
000004 45EF 0050        00050     27          BAL   R14,80(R15)          BRANCH AROUND THE SAVE AREA
000008                            28          DS    18F                  REGISTER SAVE AREA
00005D 50E0 0008        00008     29          ST    R14,8(R13)           NOW LINK THE SAVE AREAS
000054 50DE 0004        00004     30          ST    R13,4(R14)
000058 18DE                       31          LR    R13,R14              R13 WILL BE THE BASE REGISTER
                        00008     32          USING VARLIST+8,R13
                                  33 *
                                  34 *
                                  35 ***<STEP 2>    OPEN THE DCBS.
00005A                            36          OPEN  (VARIN,(INPUT),OUTFL,(OUTPUT))
                                  44 *
                                  45 ***<STEP 3>    READ A RECORD.  ON EOF GO TO STEP 6.
00006A                            46 GETLOOP  GET   VARIN,RECORD         GET A VARIABLE-LENGTH RECORD
                                  51 *
```

**Program 7-4 (continued)**

```
          VARLIST - HOW TO ACCESS VARIABLE-LENGTH RECORDS                                                    PAGE    2

   LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                  16 JUN 75

                                      52 ***<STEP 4>    CONSTRUCT THE PRINT LINE.
000078 9240 D008        000E0         53          MVI   PRNTLINE,C' '        CLEAR THE PRINT LINE
00007C D283 D009 D008 000E1 000E0     54          MVC   PRNTLINE+1(132),PRNTLINE
                                      55 *
                                      56 * PUT SOC SEC # INTO PRINT LINE
000082 D208 D009 D162 000E1 0016A     57          MVC   PRNTLINE+1(9),RECORD+4
000088 4120 00E6        000EE         58          LA    R2,PRNTLINE+14       R2 <- ADDRESS TO PUT NEXT SCORE
00008C 4130 0168        00173         59          LA    R3,RECORD+13         R3 <- ADDRESS OF NEXT SCORE TO EDIT
000090 4840 015E        00166         60          LH    R4,RECORD            R4 <- LENGTH OF RECORD
000094 5840 0258        00260         61          S     R4,=F'13'            R4 <- LENGTH OF SCORES IN RECORD
000098 8A40 0001        00001         62          SRA   R4,1                 R4 <- # OF SCORES IN THE RECORD
                                      63 *
00009C D203 2000 025C 00000 00264     64 DUMP#S   MVC   0(4,R2),=X'40202120'
0000A2 DE03 2000 3000 00000 00000     65          ED    0(4,R2),0(R3)        EDIT IN 1 SCORE

0000A8 4122 0005        00005         66          LA    R2,5(R2)             POINT TO NEXT SCORE IN PRINT LINE
0000AC 4133 0002        00002         67          LA    R3,2(R3)             POINT TO NEXT SCORE
0000B0 4640 0094        0009C         68          BCT   R4,DUMP#S            GO BACK IF MORE TO PUT IN LINE
                                      69 *
                                      70 ***<STEP 5>    PRINT THE LINE AND GO BACK TO STEP 3.
0000B4                                71          PUT   OUTFL,PRNTLINE       PRINT A LINE
0000C2 47F0 0062        0006A         76          B     GETLOOP
                                      77 *
                                      78 ***<STEP 6>    CLOSE THE FILES AND EXIT.
0000C6                                79 EOD      CLOSE (VARIN,,OUTFL)       CLOSE THE FILES
0000D6 58DD 0004        00004         87          L     R13,4(R13)           NOW EXIT
0000DA 98EC D00C        0000C         88          LM    R14,R12,12(R13)
0000DE 07FE                           89          BR    R14
                                      90 *
0000E0                                91 PRNTLINE DS    CL133                PRINT LINE
                                      92 *
000166                                93          DS    0H                   ALIGN RECORD ON A HALFWORD
                                      94 *                                   THIS ALLOWS LH OF THE RECORD LENGTH
000166                                95 RECORD   DS    CL53
                                      96 *
                                      97 OUTFL    DCB   DSORG=PS,DDNAME=PRINTOUT,MACRF=PM,RECFM=FA,              X
000198                                            LRECL=133,BLKSIZE=133
                                     151 *
                                     152 VARIN    DCB   DSORG=PS,DDNAME=VARIN,MACRF=GM,RECFM=VB,EODAD=EOD,       X
0001FC                                            LRECL=53,BLKSIZE=3520
                                     206 *
                                     207          EQUREGS
000260                               224          LTORG
000260 00000000                      225                =F'13'
000264 40202120                      226                =X'40202120'
000000                               227          END   VARLIST
```

This uses a feature that is not presented in the examples: at end-of-file, R14 contains the address of the instruction immediately following the GET. Thus

```
        GET   INFILE,CARD
LOOP    CLI   EOFFLAG,C'Y'          TEST FOR END-OF-FILE
        BE    EXITLOOP
        .
        .
        .
        GET   INFILE,CARD
        B     LOOP
```

illustrates the construction of structured loops, using an EODRTN that simply sets a flag when end-of-file occurs.

The preceding examples, although they are complete assembler-language programs, do not consider the required Job Control Language statements necessary to connect the programs logically with the files that they are to process. As we noted before, it is not our intent to present a detailed discussion of Job Control Language. The following short discussion of DD statements is included just to give the reader a brief introduction to their use.

For each file that you wish to process, you must specify a Job Control Language statement called a *DD statement*. The DD statement has the form

```
//ddname      DD      operands
```

where the ddname is the same as that coded in the DDNAME operand of the DCB being used to process the file. The operands vary in accordance with the type of device on which the file is recorded and the services that you require of the operating system. Some simple examples of DD statements and brief explanations of their meanings follow:

- *Example 1.* //INPUT DD *

  This indicates that the data to be processed is coming from the same input medium (probably cards) as the DD statement. The DCB used to read this data will have as an operand DDNAME = INPUT.

- *Example 2.* //OUTPUT DD SYSOUT = A

  This indicates that data will be written to a printer. The DCB used to write this data will have as an operand DDNAME = OUTPUT.

- *Example 3.* //FILE DD UNIT = 2400,VOL = SER = MYTAPE,
  // LABEL = (2,SL),DSN = MYFILE,DISP = OLD

  This indicates that data will be read from a nine-track tape that has been named MYTAPE. The data area used is the second file on the tape and has been named MYFILE. The DCB used to read this data will have as an operand DDNAME = FILE.

- *Example 4.*

```
//DISK DD UNIT=2314,VOL=SER=PACK01,
        DSN=DATASET,DISP=(NEW,KEEP),
//      SPACE=(TRK,(2))
```

This indicates that data will be written onto a 2314 disk storage pack. This new file will be named DATASET and the system will reserve space for two tracks of data. The DCB used to write this data will have as an operand DDNAME=DISK.

The essential ideas necessary for utilization of the basic services offered by QSAM have been covered. The reader should be aware, however, that there are many available options, some of which are of considerable importance, to be considered if extensive use of QSAM is anticipated. For more details on the facilities offered by QSAM, refer to the appropriate IBM manual on data management services.

## 7.7 INVOKING QSAM SERVICES IN A DOS ENVIRONMENT

DOS is the operating system that IBM supports for many of its smaller machines. The services offered by DOS are more limited than those offered by OS. However, the basic I/O services, such as processing of sequential files, are almost identical under the two systems. In this section, we present the use of QSAM services under DOS.

Under OS, the DCB macro is used to generate a storage area for retaining information about the organization and status of a file. Under DOS, each file must also have such a storage area. However, in this case, the programmer must choose the macro based on the general type of device on which the file resides. For example,

- DTFCD is used for card files.
- DTFPR is used for printer files.
- DTFSD is used for sequential files on disk.

These are the only types of files that will be discussed in this section. The interested reader should consult the appropriate IBM reference manual for the full range of alternatives.

The DTFs, each of which represents a single file to be processed, are normally generated at the end of a program, along with the DS and DC statements. The label on a DTF must not be more than seven characters long. Following are the most commonly used formats:

1. *Processing a card file* (DTFCD).

```
label        DTFCD   DEVADDR=SYSIPT
                     RECFORM=FIXUNB
                     BLKSIZE=80
                     TYPEFLE=INPUT
                     EOFADDR=eodad
                     IOAREA1=io1
                     IOAREA2=io2
                     WORKA=YES
                     DEVICE=device
```

a. DEVADDR=SYSIPT specifies that the file is a standard input file. SYSIPT is a symbolic reference that normally indicates a card input file.

b. RECFORM=FIXUNB specifies a file that has fixed-length, unblocked records.

c. BLKSIZE=80 gives the length of each physical block. (For unblocked files, each physical block contains a single record.)

d. TYPEFLE=INPUT specifies that the records will be read. If OUTPUT were specified, the file could be used to punch cards.

e. EOFADDR=eodad specifies the address that control should pass to on end-of-file.

f. IOAREA1=io1 specifies the name of an area that the system can use as an I/O buffer. One such area is required, but two should normally be used. (Two allow the system to read into one buffer while data is accessed in the other buffer.) The area io1 must be defined with a DS statement somewhere in the program, and the area must be long enough to hold a physical block. Normally, the I/O buffers are defined just before the END statement (since they do not have to be addressable).

g. IOAREA2=io2 is optional but highly recommended.

h. WORKA=YES specifies move mode.

i. DEVICE=device must be used to specify the type of device used. In our examples, we specify 2540, which is one model of card reader. However, this parameter depends on the configuration being used.

2. *Processing a printed file* (DTFPR).

```
label        DTFPR   DEVADDR=SYSLST
                     RECFORM=FIXUNB
                     BLKSIZE=blksize
                     CTLCHR=ASA
                     IOAREA1=io1
                     IOAREA2=io2
                     WORKA=YES
                     DEVICE=device
```

The blksize is normally a value up to 133 (for most printers). CTLCHR = ASA is used to indicate that the first character of each line should be interpreted as a carriage control character. The other parameters are similar to those specified on the DTFCD.

3. *Processing a sequential disk file* (DTFSD).

```
label        DTFSD   DEVADDR = SYSddd
                     RECFORM = format
                     BLKSIZE = blksize
                     RECSIZE = recsize
                     TYPEFLE = access-type
                     EOFADDR = eodad
                     IOAREA1 = io1
                     IOAREA2 = io2
                     WORKA = YES
                     IOREG = (r)
                     DEVICE = device
```

a. The DEVADDR operand specifies a "logical address' for the device. Normally, the names are SYS001, SYS002, etc.—using a distinct value for each file in the program.

b. RECFORM gives the record format. The most common values are

| *Format* | *Meaning* |
|---|---|
| FIXUNB | Fixed-length, unblocked records |
| FIXBLK | Fixed-length, blocked records |
| VARUNB | Variable-length, unblocked records |
| VARBLK | Variable-length, blocked records |

c. BLKSIZE = blksize gives the size of a physical block. One peculiarity of this parameter is that output files require an extra eight bytes. Therefore, a RECFORM = FIXBLK, with TYPEFLE = OUTPUT, RECSIZE = 100, and 16 records per block requires BLKSIZE = 1608.

d. RECSIZE = recsize gives the length of a logical record. This parameter should not be used for variable-length records. (The RDW will be used to determine the length.)

e. TYPEFLE = access-type. Use INPUT or OUTPUT in most cases.

f. EOFADDR = eodad gives the end-of-file address. Use only on input files.

g. IOAREA1 = io1. Again, io1 must be defined in the program (normally at the end), and it must be large enough to hold a physical block.

h. IOAREA2 = io2. Again, this is optional but should normally be used. It can significantly reduce run time.

i. WORKA = YES specifies move mode. If locate model is desired, leave this parameter off and use the IOREG operand.

j. IOREG = (r) specifies locate mode. Under OS, the record address is always returned in R1; but under DOS, you specify the register number (2-12) to be used to locate the record. Thus, IOREG = (3) specifies R3 as the register used to reference a position in one of the buffers.

k. DEVICE = device specifies the type of disk on which the file resides.

The following examples should help to clarify use of the DTFs:

- *Example 1.* A card file.

```
CARDDTF   DTFCD   DVADDR = SYSIPT,BLKSIZE = 80,                          X
                  RECFORM = FIXUNB,TYPEFLE = INPUT,                      X
                  EOFADDR = EOFRT,WORKA = YES,IOAREA1 = CARDIO1,         X
                  IOAREA2 = CARDIO2,DEVICE = 2540
```

This could be used to read cards in move mode from a 2540 card reader. At end-of-file, a branch would automatically occur to EOFRT. CARDIO1 and CARDIO2 would be 80-byte areas defined toward the end of the program.

- *Example 2.* A printed file.

```
PRINTDTF  DTFPR   DEVADDR = SYSLST,BLKSIZE = 133,RECFORM = FIXUNB,  X
                  WORK A = YES,CTLCHR = ASA,DEVICE = 3202,           X
                  IOAREA1 = PRINTIO1,IOAREA2 = PRINTIO2
```

This could be used to print records in move mode (with carriage control characters) on a 3202 printer.

- *Example 3.* A sequential disk file.

```
FILEIN    DTFSD   DEVADDR = SYS001,RECFORM = FIXBLK,BLKSIZE = 1600, X
                  RECSIZE = 100,EOFADDR = EOFRT,TYPEFLE = INPUT,     X
                  IOREG = (3),DEVICE = 3340,IOAREA1 = INIO1,         X
                  IOAREA2 = INIO2
```

This specifies an input file, processed in locate mode (with R3 as the locate register), from a 3340 disk drive.

The OPEN and CLOSE macros have a slightly different format under DOS. Use

```
OPEN    file1,file2,...
```

to open several files and

```
CLOSE    file1,file2,...
```

to close the files. Thus,

```
OPEN     CARDDTF,PRNTDTF
```

would open two files.

The GET and PUT macros are essentially identical to those used under OS. Use

```
GET      dtfname,area
```

for move mode access and

```
GET      dtfname
```

for locate mode access. (In this case, the IOREG is pointed at the record to be processed.) Use

```
PUT      dtfname,area
```

for move mode access. We do not recommend locate mode PUTs.

Before we end this discussion, two more points must be covered:

- The use of almost any IBM macro can cause the destruction of the contents of R0, R1, R14, and R15 (just as under OS).
- DOS does not invoke a user program in the same way as OS does. In particular, R13, R14, and R15 are no longer set up according to OS conventions. When you enter the main program, use

  ```
  program  CSECT
           BALR  R12,0
           USING  *,R12
  ```

  to set up a base register. If you intend to call external subroutines, point R13 at an 18-word register save area. To leave the main program, use

  ```
  EOJ
  ```

  which causes an exit back to the operating system.

With these comments in mind, you should be able to understand Programs 7-5 through 7-8. They illustrate the use of cards, printers, and sequential disk files (for both fixed-length and variable-length records). These programs are rewritten versions of the programs presented in Section 7.6—Programs 7-1 through 7-4.

## Program 7-5



```
LOC   OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                          DOS/VSE ASSEMBLER 15.41 82-05-03

                                   2 * THIS SHORT PROGRAM IS DESIGNED TO ILLUSTRATE THE STEPS REQUIRED
                                   3 * TO READ CARDS AND/OR PRINT LINES USING QSAM UNDER DOS.
                                   4 *
                                   5 * THE PROGRAM SIMPLY 80-80 LISTS A DECK OF CARDS, SKIPPING TO THE TOP
                                   6 * OF A PAGE AFTER EVERY 50 LINES.
                                   7 *
                                   8 * THE LOGIC IS AS FOLLOWS:
                                   9 *
                                  10 *         STEP 1.  NORMAL DOS LINKAGE CONVENTIONS ARE NOT THE SAME AS
                                  11 *                  UNDER OS.  ALL THAT IS ACTUALLY REQUIRED IS TO SET
                                  12 *                  UP A BASE REGISTER (DO NOT ASSUME THAT R13, R14, AND
                                  13 *                  R15 ARE ESTABLISHED FOR YOU, AS UNDER OS).
                                  14 *
                                  15 *         STEP 2.  OPEN THE FILES.
                                  16 *
                                  17 *         STEP 3.  SET THE COUNTER OF THE LINES TO PRINT ON THE CURRENT
                                  18 *                  PAGE TO 50.
                                  19 *
                                  20 *         STEP 4.  GET A CARD.  IF END-OF-FILE OCCURS, AN AUTOMATIC
                                  21 *                  BRANCH TO STEP 8 WILL OCCUR.
                                  22 *
                                  23 *         STEP 5.  PRINT OUT THE CARD JUST READ.
                                  24 *
                                  25 *         STEP 6.  SET THE CARRIAGE CONTROL TO SINGLE SPACE, AND
                                  26 *                  DECREMENT THE COUNT OF THE LINES LEFT FOR THIS PAGE.
                                  27 *
                                  28 *         STEP 7.  SET THE CARRIAGE CONTROL FOR SKIP TO TOP OF PAGE
                                  29 *                  BEFORE PRINTING, AND GO BACK TO STEP 3.
                                  30 *
                                  31 *         STEP 8.  CLOSE THE FILES AND EXIT.  NOTE THAT TO EXIT A DOS
                                  32 *                  PROGRAM THE "EOJ" MACRO IS USED.
                                  33 *
000000                            34 LISTPROG CSECT
                                  35          PRINT NOGEN
                                  36 *
                                  37 ***<STEP 1>    SET UP A BASE REGISTER
                                  38 *
000000 05C0                       39          BALR  R12,0
                        00002     40          USING *,R12
                                  41 *
                                  42 ***<STEP 2>    OPEN THE FILES
                                  43 *
                                  44          OPEN  CARDDTF,PRNTDTF
                                  53 *
                                  54 ***<STEP 3>    SET THE COUNT OF LINES LEFT ON THE PAGE TO 50
                                  55 *
000016 4120 0032        00032     56 STARTPG  LA    R2,50            R2 <- # LINES LEFT ON THE PAGE
                                  57 *
                                  58 ***<STEP 4>    READ A CARD
                                  59 *
                                  60 READLOOP GET   CARDDTF,CARD     READ A CARD
```

**Program 7-5 (continued)**

```
HOW TO READ CARDS AND PRINT LINES UNDER DOS                                                    PAGE    3

 LOC   OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                          DOS/VSE ASSEMBLER 15.41 82-05-03

                                    66 *
                                    67 ***<STEP 5>    PRINT IT.
                                    68 *
                                    69          PUT   PRNTDTF,CARD-1  PRINT IT
                                    75 *
                                    76 ***<STEP 6>    SET THE CARRIAGE CONTROL TO SINGLE SPACE.  IF MORE LINES
                                    77 *              LEFT ON THE PAGE, GO TO STEP 4.
00003A 9240 C05E      00060         78          MVI   CARD-1,C' '      SET CC TO BLANK
00003E 4620 C018            0001A   79          BCT   R2,READLOOP
                                    80 *
                                    81 ***<STEP 7>    SET CC FOR TOP OF PAGE
                                    82 *
000042 92F1 C05E      00060         83          MVI   CARD-1,C'1'
000046 47F0 C014      00016         84          B     STARTPG          GO START A NEW PAGE
                                    85 *
                                    86 ***<STEP 8>    CLOSE FILES AND EXIT
                                    87 *
                                    88 EOFRT    CLOSE CARDDTF,PRNTDTF
                                    97          EOJ
                                   100 *
000060 F1                          101          DC    C'1'             CARRIAGE CONTROL BYTE
000061                             102 CARD     DS    CL80
                                   103 *
                                   104 CARDDTF  DTFCD DEVADDR=SYSIPT,BLKSIZE=80,RECFORM=FIXUNB,TYPEFLE=INPUT, X
                                                      EOFADDR=EOFRT,WORKA=YES,IOAREA1=CARDIO1,IOAREA2=CARDIO2,X
                                                      DEVICE=2540
                                   125 *
                                   126 PRNTDTF  DTFPR DEVADDR=SYSLST,BLKSIZE=81,RECFORM=FIXUNB,WORKA=YES,     X
                                                      CTLCHR=ASA,IOAREA1=PRINTIO1,IOAREA2=PRINTIO2,           X
                                                      DEVICE=3203
                                   147 *
000120                             148 CARDIO1  DS    CL80             THE I/O BUFFER AREAS
000170                             149 CARDIO2  DS    CL80
0001C0                             150 PRINTIO1 DS    CL81
000211                             151 PRINTIO2 DS    CL81
                            0000C  152 R12      EQU   12
                            00002  153 R2       EQU   2
                                   154          END
000268 5B5BC2D6D7C5D540            155                =C'$$BOPEN '
000270 5B5BC2C3D3D6E2C5            156                =C'$$BCLOSE'
000278 000000B8                    157                =A(CARDDTF)
00027C 00000061                    158                =A(CARD)
000280 000000F0                    159                =A(PRNTDTF)
000284 00000060                    160                =A(CARD-1)
```

**Program 7-6**

```
COPYFILE - COPY AND DISPLAY A SEQUENTIAL FILE                                                    PAGE     2

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                          DOS/VSE ASSEMBLER 15.41 82-05-03

                                  2 * THIS PROGRAM ILLUSTRATES THE USE OF QSAM (UNDER DOS) TO READ
                                  3 * AND WRITE SEQUENTIAL DISK FILES.  IN THIS PARTICULAR CASE
                                  4 * A FILE OF 100-BYTE RECORDS IS COPIED.  THE RECORDS ARE
                                  5 * GROUPED INTO PHYSICAL BLOCKS OF 1600 BYTES.  THE PROGRAM ALSO
                                  6 * DISPLAYS THE CONTENT OF EACH RECORD (IT IS ASSUMED THAT THE
                                  7 * RECORDS CONTAIN DATA WHICH IS ALL IN CHARACTER FORMAT).  THE
                                  8 * INPUT FILE IS PROCESSED IN LOCATE MODE (USING R3 AS THE IO
                                  9 * REGISTER SET TO POINT AT THE READ RECORD), WHILE BOTH OUTPUT
                                 10 * FILES ARE PROCESSED IN MOVE MODE.  THE LOGIC IS AS FOLLOWS:
                                 11 *
                                 12 *         STEP 1.  SET UP A BASE REGISTER.
                                 13 *
                                 14 *         STEP 2.  OPEN THE FILES.
                                 15 *
                                 16 *         STEP 3.  SET THE COUNT OF LINES LEFT TO PRINT ON THE
                                 17 *                  CURRENT PAGE TO 50.
                                 18 *
                                 19 *         STEP 4.  READ A RECORD FROM THE INPUT FILE.  SINCE
                                 20 *                  PROCESSING IS BEING DONE USING LOCATE MODE,
                                 21 *                  THE ADDRESS OF THE RECORD IS RETURNED IN THE
                                 22 *                  IO REGISTER (R3 FOR THIS FILE).
                                 23 *
                                 24 *         STEP 5.  WRITE THE RECORD OUT TO THE NEW FILE USING
                                 25 *                  MOVE MODE.  NOTE THAT THE ADDRESS OF THE
                                 26 *                  RECORD CAN BE A VALUE IN A REGISTER.
                                 27 *
                                 28 *         STEP 6.  PRINT THE RECORD.  THIS REQUIRES FIRST MOVING
                                 29 *                  IT TO A WORK AREA SO THAT CARRIAGE CONTROL
                                 30 *                  CAN BE INSERTED.
                                 31 *
                                 32 *         STEP 7.  SET THE CARRIAGE CONTROL TO SINGLE SPACE.  IF
                                 33 *                  THERE ARE MORE LINES LEFT TO PRINT ON THE
                                 34 *                  CURRENT PAGE, GO BACK TO STEP 4.
                                 35 *
                                 36 *         STEP 8.  SET THE CARRIAGE CONTROL FOR SKIP TO 1 BEFORE
                                 37 *                  PRINTING, AND RETURN TO STEP 3.
                                 38 *
                                 39 *         STEP 9.  PRINT THE END OF LIST MESSAGE, CLOSE THE FILES,
                                 40 *                  AND EXIT.
                                 41 *
000000                           42 COPYFILE CSECT
                                 43         PRINT NOGEN
                                 44 *
                                 45 ***<STEP 1>    SET UP A BASE REGISTER
                                 46 *
000000 05C0                      47         BALR  R12,0
                        00002    48         USING *,R12
                                 49 *
                                 50 ***<STEP 2>    OPEN THE FILES
                                 51 *
                                 52         OPEN  FILEIN,FILEOUT,LIST
```

**Program 7-6 (continued)**

```
        COPYFILE - COPY AND DISPLAY A SEQUENTIAL FILE                                                    PAGE     3

  LOC   OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                                DOS/VSE ASSEMBLER 15.41 82-05-03

                                      62 *
                                      63 ***<STEP 3>    SET THE COUNT OF LINES LEFT ON THE PAGE TO 50
                                      64 *
00001A 4120 0032            00032     65 STARTPG  LA    R2,50             R2 <- # LINES LEFT ON THE PAGE
                                      66 *
                                      67 ***<STEP 4>    READ A RECORD FROM THE INPUT FILE
                                      68 *
                                      69 READLOOP GET   FILEIN
                                      74 *
                                      75 ***<STEP 5>    WRITE THE RECORD OUT TO THE NEW FILE
                                      76 *
                                      77          PUT   FILEOUT,(3)       *** NOTE THAT THE SECOND OPERAND CAN
                                      83 *                                *** BE AN ADDRESS IN A REGISTER
                                      84 *
                                      85 ***<STEP 6>    PRINT THE RECORD
                                      86 *
000038 D263 C0AB 3000 000AD 00000     87          MVC   RECORD+1(100),0(R3) MOVE RECORD TO WORK AREA
                                      88          PUT   LIST,RECORD
                                      94 *
                                      95 ***<STEP 7>    SET CARRIAGE CONTROL FOR SINGLE SPACE, AND TEST
                                      96 *              FOR MORE LINES LEFT ON THE PAGE
00004E 9240 C0AA      000AC           97          MVI   RECORD,C' '       SET CC TO BLANK
000052 4620 C01C            0001E     98          BCT   R2,READLOOP
                                      99 *
                                     100 ***<STEP 8>    SET CC FOR TOP OF PAGE
                                     101 *
000056 92F1 C0AA      000AC          102          MVI   RECORD,C'1'
00005A 47F0 C018      0001A          103          B     STARTPG           GO START A NEW PAGE
                                     104 *
                                     105 ***<STEP 9>    PRINT END-OF-LIST MESSAGE, CLOSE FILES, & EXIT
                                     106 EOFRT   PUT   LIST,ENDMESS
                                     112          CLOSE LIST,FILEIN,FILEOUT
                                     122          EOJ
                                     125 *
000088                               126          LTORG
000088 5B5BC2D6D7C5D540              127                =C'$$BOPEN '
000090 5B5BC2C3D3D6E2C5              128                =C'$$BCLOSE'
000098 000001B0                      129                =A(FILEIN)
00009C 00000258                      130                =A(FILEOUT)
0000A0 00000178                      131                =A(LIST)
0000A4 000000AC                      132                =A(RECORD)
0000A8 00000111                      133                =A(ENDMESS)
                                     134 *
0000AC F140404040404040              135 RECORD  DC    CL101'1'          ROOM FOR 1 RECORD WITH CC
000111 F05C5C5C40C5D5C4              136 ENDMESS DC    CL101'0*** END OF LISTING ****'
                                     137 *
                                     138 LIST    DTFPR DEVADDR=SYSLST,BLKSIZE=101,RECFORM=FIXUNB,WORKA=YES,     X
                                                       CTLCHR=ASA,IOAREA1=PRINTIO1,IOAREA2=PRINTIO2,            X
                                                       DEVICE=3203
                                     159 *
                                     160 FILEIN  DTFSD DEVADDR=SYS001,BLKSIZE=1600,EOFADDR=EOFRT,               X
```

**Program 7-6 (continued)**

```
      COPYFILE - COPY AND DISPLAY A SEQUENTIAL FILE                                                    PAGE     4

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                              DOS/VSE ASSEMBLER 15.41 82-05-03

                                                        IOAREA1=INIO1,IOAREA2=INIO2,                                X
                                                        DEVICE=3340,IOREG=(3),RECFORM=FIXBLK,RECSIZE=100,           X
                                                        TYPEFLE=INPUT
                                  220 *
                                  221 FILEOUT  DTFSD    DEVADDR=SYS002,BLKSIZE=1608,DEVICE=3340,                    X
                                                        IOAREA1=OUTIO1,IOAREA2=OUTIO2,WORKA=YES,                    X
                                                        RECFORM=FIXBLK,RECSIZE=100,TYPEFLE=OUTPUT
                                  286 *
00030C                            287 PRINTIO1 DS       CL101
000371                            288 PRINTIO2 DS       CL101
0003D6                            289 INIO1    DS       CL1600
000A16                            290 INIO2    DS       CL1600
001056                            291 OUTIO1   DS       CL1608
00169E                            292 OUTIO2   DS       CL1608
                                  293 *
                          00003   294 R3       EQU      3
                          0000C   295 R12      EQU      12
                          00002   296 R2       EQU      2
                                  297          END
```

**Program 7-7**

```
VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE    2

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                  DOS/VSE ASSEMBLER 15.52 82-05-03

                                  2 * THIS PROGRAM ILLUSTRATES THE USE OF VARIABLE LENGTH RECORDS
                                  3 * UNDER DOS.  THE PROGRAM READS CARDS, EACH OF WHICH CONTAINS
                                  4 *
                                  5 *       A STUDENT'S SOCIAL SECURITY NUMBER IN COL.S 1-9 AND
                                  6 *       A TEST SCORE (0-100) IN COLUMNS 11-13.
                                  7 *
                                  8 * ALL OF THE CARDS FOR A GIVEN STUDENT OCCUR TOGETHER IN THE CARD INPUT
                                  9 * FILE.  THE PROGRAM CREATES 1 VARIABLE-LENGTH RECORD FOR EACH STUDENT;
                                 10 * THE RECORD CONTAINS ALL OF THE STUDENT'S TEST SCORES IN PACKED
                                 11 * DECIMAL FORMAT.  THE PRECISE FORMAT OF THE GENERATED RECORDS IS
                                 12 *
                                 13 *       +0(4)      RDW (2 BYTES OF LENGTH, 2 BYTES OF 0000)
                                 14 *       +4(9)      SOCIAL SECURITY NUMBER
                                 15 *       +13(UP TO 40) THE STUDENT'S SCORES
                                 16 *                     EACH SCORE WILL BE IN A 2-BYTE PACKED FIELD
                                 17 *
                                 18 * THUS, THE MAXIMUM LENGTH OF ONE OF THE GENERATED RECORDS IS 53,
                                 19 * AND THIS WOULD REQUIRE 20 CONSECUTIVE TEST SCORES FOR THE SAME
                                 20 * STUDENT.  THE LOGIC OF THE PROGRAM IS
                                 21 *
                                 22 *         STEP 1.  SET UP A BASE REGISTER.
                                 23 *
                                 24 *         STEP 2.  OPEN THE FILES.
                                 25 *
                                 26 *         STEP 3.  READ THE FIRST RECORD AND SAVE ITS ADDRESS
                                 27 *
                                 28 *         STEP 4.  PUT THE SOC. SEC. # INTO THE NEW RECORD.  ALSO,
                                 29 *                  PACK IN THE SCORE OFF THE FIRST CARD.
                                 30 *
                                 31 *         STEP 5.  READ CARDS, PACKING THE SCORES INTO THE DISK
                                 32 *                  RECORD, UNTIL A CARD WITH A NEW SOC. SEC. #
                                 33 *                  IS READ OR END-OF-FILE OCCURS.  IF END-OF-FILE
                                 34 *                  OCCURS, A BRANCH TO STEP 7 WILL TAKE PLACE
                                 35 *                  AUTOMATICALLY.
                                 36 *
                                 37 *         STEP 6.  CALL 'PUTREC' TO PUT IN THE RDW AND WRITE OUT
                                 38 *                  THE CONSTRUCTED RECORD.  GO TO STEP 4 (SINCE
                                 39 *                  THE FIRST RECORD FOR THE NEXT STUDENT HAS
                                 40 *                  BEEN READ ALREADY).
                                 41 *
                                 42 *         STEP 7.  CALL 'PUTREC' TO WRITE OUT THE LAST RECORD.
                                 43 *
                                 44 *         STEP 8.  CLOSE THE FILES AND EXIT.
                                 45 *
000000                           46 VARBUILD CSECT
                                 47          PRINT NOGEN
                                 48 *
                                 49 ***<STEP 1>    SET UP A BASE REGISTER
                                 50 *
000000 05C0                      51          BALR  R12,0
                        00002    52          USING *,R12
```

**Program 7-7 (continued)**

```
VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE     3

 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                  DOS/VSE ASSEMBLER 15.52 82-05-03

                                   53 *
                                   54 ***<STEP 2>    OPEN THE FILES
                                   55 *
                                   56          OPEN  CARDFL,VARFL
                                   65 *
                                   66 ***<STEP 3>    READ THE FIRST RECORD
                                   67 *
                                   68          GET   CARDFL,CARD
                                   74 *
                                   75 ***<STEP 4>    PUT IN THE SOC. SEC. # AND THE FIRST SCORE
                                   76 *
000026 D208 C116 C0C0 00118 000C2  77 MAINLOOP MVC   SOCSEC#(9),CARD
00002C F212 C11F C0CA 00121 000CC  78          PACK  SCORES(2),CARD+10(3) PACK IN FIRST TEST SCORE
000032 4120 C121            00123  79          LA    R2,SCORES+2      R2 <- ADDRESS TO PACK NEXT SCORE
                                   80 *
                                   81 ***<STEP 5>    PUT IN SCORES FOR CONSECUTIVE #S WITH THE SAME SSN
                                   82 *
                                   83 BUILDLP GET   CARDFL,CARD      GET THE NEXT CARD
                                   89 *
000046 D508 C116 C0C0 00118 000C2  90          CLC   SOCSEC#(9),CARD  SAME STUDENT?
00004C 4770 C05C      0005E        91          BNE   NEXTGUYS         NO -> BRANCH
000050 F212 2000 C0CA 00000 000CC  92          PACK  0(2,R2),CARD+10(3) PACK IN THE TEST SCORE
000056 4122 0002            00002  93          LA    R2,2(R2)
00005A 47F0 C034      00036        94          B     BUILDLP
                                   95 *
                                   96 ***<STEP 6>    CALL 'PUTREC' TO WRITE OUT THE RECORD
                                   97 *
00005E 45A0 C07E            00080  98 NEXTGUYS BAL   R10,PUTREC       WRITE THE RECORD
000062 47F0 C024      00026        99          B     MAINLOOP
                                  100 *
                                  101 ***<STEP 7>    EOF OCCURRED, SO WRITE THE LAST RECORD
                                  102 *
000066 45A0 C07E            00080 103 EOFRTN   BAL   R10,PUTREC        WRITE THE LAST RECORD
                                  104 *
                                  105 ***<STEP 8>    CLOSE THE FILES AND EXIT
                                  106 *
                                  107          CLOSE CARDFL,VARFL
                                  116          EOJ
                                  119 *
                                  120 * PUTREC SIMPLY FILLS IN THE RDW AND ISSUES A PUT TO CAUSE THE
                                  121 * RECORD TO BE WRITTEN TO THE DISK (ACTUALLY, THE PUT CAUSES
                                  122 * THE RECORD TO BE TRANSFERRED TO THE OUTPUT BUFFER).
                                  123 *
000080 5B20 C0B6            000B8 124 PUTREC   S     R2,=A(RDW)       R2 <- LENGTH OF THE RECORD
000084 4020 C112            00114 125          STH   R2,RDW           STORE INTO LEFT HALF OF THE RDW
000088 D201 C114 C0BE 00116 000C0 126          MVC   RDW+2(2),=H'0'
                                  127          PUT   VARFL,RDW
00009E 07FA                       133          BR    R10              RETURN
                                  134 *
0000A0                            135          LTORG
0000A0 5B5BC2D6D7C5D540           136                =C'$$BOPEN '
```

**Program 7-7 (continued)**

```
VARBUILD - BUILD A FILE OF VARIABLE-LENGTH RECORDS                                                    PAGE    4

  LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                          DOS/VSE ASSEMBLER 15.52 82-05-03

0000A8 5B5BC2C3D3D6E2C5             137                =C'$$BCLOSE'
0000B0 00000150                     138                =A(CARDFL)
0000B4 000000C2                     139                =A(CARD)
0000B8 00000114                     140                =A(RDW)
0000BC 00000190                     141                =A(VARFL)
0000C0 0000                         142                =H'0'
0000C2                              143 CARD      DS    CL80
                                    144 *
                                    145 * THE VARIABLE-LENGTH RECORD IS BUILT HERE.  THE THREE FIELDS
                                    146 * ARE ALL PART OF THE RECORD.
                                    147 *
000114                              148 RDW       DS    F                RECORD DESCRIPTOR WORD
000118                              149 SOCSECN   DS    CL9              SOCIAL SECURITY NUMBER
000121                              150 SCORES    DS    20PL2            MAX POF 20 SCORES IN THE RECORD
                                    151 *
                                    152 CARDFL    DTFCD DEVADDR=SYSIPT,BLKSIZE=80,RECFORM=FIXUNB,TYPEFLE=INPUT, X
                                                        EOFADDR=EOFRTN,WORKA=YES,IOAREA1=CARDIO1,                X
                                                        IOAREA2=CARDIO2,DEVICE=2540
                                    173 *
                                    174 VARFL     DTFSD DEVADDR=SYS001,BLKSIZE=3520,DEVICE=3340,                 X
                                                        IOAREA1=OUTIO1,IOAREA2=OUTIO2,WORKA=YES,                 X
                                                        RECFORM=VARBLK,TYPEFLE=OUTPUT
                                    242 *
000250                              243 OUTIO1    DS    CL3520
001010                              244 OUTIO2    DS    CL3520
001DD0                              245 CARDIO1   DS    CL80
001E20                              246 CARDIO2   DS    CL80
                                    247 *
                          0000A     248 R10       EQU   10
                          0000C     249 R12       EQU   12
                          00002     250 R2        EQU   2
                          00000     251           END   VARBUILD
```

**Program 7-8**

```
VARLIST - HOW TO ACCESS VARIABLE-LENGTH RECORDS                                                    PAGE    2

 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                DOS/VSE ASSEMBLER 15.57 82-05-03

                                   2 * IN THIS EXAMPLE THE RECORDS PRODUCED BY 'VARBUILD' ARE
                                   3 * ACCESSED AND USED TO PRINT OUT THE TEST SCORES FOR ALL THE
                                   4 * STUDENTS.  THE READER SHOULD STUDY VARBUILD CAREFULLY BEFORE
                                   5 * EXAMINING THIS EXAMPLE, SINCE THE FORMAT AND CONTENTS OF THE
                                   6 * RECORDS ARE DISCUSSED THERE.
                                   7 *
                                   8 * THE LOGIC OF VARLIST IS AS FOLLOWS:
                                   9 *
                                  10 *         STEP 1.  SET UP A BASE REGISTER.
                                  11 *
                                  12 *         STEP 2.  OPEN THE FILES.
                                  13 *
                                  14 *         STEP 3.  READ THE FIRST RECORD ON EOF GO TO STEP 6.
                                  15 *
                                  16 *         STEP 4.  CONSTRUCT A PRINT LINE FROM THE RECORD
                                  17 *
                                  18 *         STEP 5.  PUT OUT THE PRINT LINE AND GO TO STEP 3.
                                  19 *
                                  20 *         STEP 6.  CLOSE THE FILES AND EXIT.
                                  21 *
000000                            22 VARLIST  CSECT
                                  23          PRINT NOGEN
                                  24 *
                                  25 ***<STEP 1>    SET UP A BASE REGISTER
                                  26 *
000000 05C0                       27          BALR  R12,0
                          00002   28          USING *,R12
                                  29 *
                                  30 ***<STEP 2>    OPEN THE FILES
                                  31 *
                                  32          OPEN  VARIN,OUTFL
                                  41 *
                                  42 ***<STEP 3>    READ THE FIRST RECORD
                                  43 *
                                  44 GETLOOP  GET   VARIN,RECORD
                                  50 *
                                  51 ***<STEP 4>    CONSTRUCT THE PRINT LINE
                                  52 *
000026 9240 C0B6      000B8       53          MVI   PRNTLINE,C' '    CLEAR THE PRINT LINE
00002A D283 C0B7 C0B6 000B9 000B8 54          MVC   PRNTLINE+1(132),PRNTLINE
                                  55 *
                                  56 * PUT THE SOC SEC # INTO THE PRINT LINE
                                  57 *
000030 D208 C0B7 C140 000B9 00142 58          MVC   PRNTLINE+1(9),RECORD+4
000036 4120 C0C4             000C6 59          LA    R2,PRNTLINE+14    R2 <- ADDRESS TO PUT NEXT SCORE
00003A 4130 C149             0014B 60          LA    R3,RECORD+13      R3 <- ADDRESS OF NEXT SCORE TO EDIT
00003E 4840 C13C             0013E 61          LH    R4,RECORD         R4 <- LENGTH OF THE RECORD
000042 5B40 C0A6             000A8 62          S     R4,=F'13'         R4 <- LENGTH OF SCORES IN THE RECORD
000046 8A40 0001             00001 63          SRA   R4,1              R4 <- # OF SCORES IN THE RECORD
                                  64 *
00004A D203 2000 C0AA 00000 000AC 65 DUMPWS   MVC   0(4,R2),=X'40202120'
```

**Program 7-8 (continued)**

```
VARLIST - HOW TO ACCESS VARIABLE-LENGTH RECORDS                                                    PAGE     3

  LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT                                DOS/VSE ASSEMBLER 15.57 82-05-03

000050 DE03 2000 3000 00000 00000    66          ED    0(4,R2),0(R3)     EDIT IN 1 SCORE
000056 4122 0005            00005    67          LA    R2,5(R2)
00005A 4133 0002            00002    68          LA    R3,2(R3)          POINT TO NEXT SCORE
00005E 4640 C048            0004A    69          BCT   R4,DUMPWS
                                     70 *
                                     71 ***<STEP 5>    PRINT THE LINE AND GO BACK TO STEP 3.
                                     72 *
                                     73          PUT   OUTFL,PRNTLINE    PRINT A LINE
000072 47F0 C014      00016          79          B     GETLOOP
                                     80 *
                                     81 ***<STEP 6>    CLOSE THE FILES AND EXIT
                                     82 *
                                     83 EOD      CLOSE VARIN,OUTFL
                                     92          EOJ
                                     95 *
000090                               96          LTORG
000090 5B5BC2D6D7C5D540              97                =C'$$BOPEN '
000098 5B5BC2C3D3D6E2C5              98                =C'$$BCLOSE'
0000A0 00000180                      99                =A(VARIN)
0000A4 0000013E                     100                =A(RECORD)
0000A8 0000000D                     101                =F'13'
0000AC 40202120                     102                =X'40202120'
0000B0 00000230                     103                =A(OUTFL)
0000B4 000000B8                     104                =A(PRNTLINE)
0000B8                              105 PRNTLINE DS    CL133             THE PRINT LINE
                                    106 *
00013E                              107         DS    0H                ALIGN RECORD ON A HALFWORD BOUNDARY -
                                    108 *                               THIS ALLOWS A LH OF THE RECORD LENGTH
00013E                              109 RECORD  DS    CL53
                                    110 *
                                    111 VARIN   DTFSD DEVADDR=SYS001,BLKSIZE=3520,DEVICE=3340,                X
                                                      IOAREA1=INIO1,IOAREA2=INIO2,WORKA=YES,                  X
                                                      RECFORM=VARBLK,EOFADDR=EOD,TYPEFLE=INPUT
                                    173 *
                                    174 OUTFL   DTFPR DEVADDR=SYSLST,BLKSIZE=133,RECFORM=FIXUNB,WORKA=YES,    X
                                                      CTLCHR=ASA,IOAREA1=PRINTIO1,IOAREA2=PRINTIO2,           X
                                                      DEVICE=3203
                                    195 *
000260                              196 INIO1   DS    CL3520
001020                              197 INIO2   DS    CL3520
001DE0                              198 PRINTIO1 DS   CL80
001E30                              199 PRINTIO2 DS   CL80
                                    200 *
                             00002  201 R2      EQU   2
                             00003  202 R3      EQU   3
                             00004  203 R4      EQU   4
                             0000C  204 R12     EQU   12
                             00000  205         END   VARLIST
```

# 8

# Advanced Techniques

## 8.1 CONSTANTS, LITERALS, AND THE DC AND DS STATEMENTS

The DC and DS statements and literals have been touched upon in earlier sections. These areas will be covered here in considerably more depth. The reader is cautioned, however, that this presentation is not intended to be exhaustive. The intent here, as in all other sections of this text is to offer a clear working introduction to the subject. Detailed presentations of all the subjects covered are available in the manuals published by IBM.

To understand the general format of the DC statement, one must have a knowledge of the expressions and terms that may be used in defining constants. Terms are of two types, self-defining and relocatable.

A *self-defining term* is a term that has an inherent value, in contrast to a term that is assigned a value by the assembler. There are four types of self-defining terms:

- A *decimal self-defining term* is simply a string of decimal digits. For example, 0, 983, 08, and 48932 are decimal self-defining terms.
- A *character self-defining term* consists of from one to three characters enclosed within apostrophes and preceded by a C. The following are examples of character self-defining terms:

  C' '  C'123'  C'&&&&'
  C'ABC'  C'1*'

  Remember that two adjacent occurrences of the apostrophe or ampersand are used to represent a single occurrence of these symbols in a character string.

  The value represented by a character self-defining term is found by

replacing the characters with their two-digit hexadecimal equivalents and evaluating the result. Thus,

C' ' = X'40' = 64

- A *hexadecimal self-defining term* consists of from one to six hexadecimal digits enclosed within apostrophes and preceded by an X. Examples of hexadecimal self-defining terms include

X'1'  X'C1F'  X'01ABC'

- A *binary self-defining term* consists of from one to 24 binary digits enclosed within apostrophes and preceded by a B. The following are examples of binary self-defining terms:

B'1'  B'0010'  B'1010111'

Binary self-defining terms have been used earlier in this text to represent the masks in the BC and BCR instructions. Actually, any self-defining term with a correct value (0 to 15) may be used to represent such a mask. For example,

```
        BCR     B'1010',14
        BCR     10,14
and     BCR     X'A',14
```

are equivalent. The binary representation was chosen because of the natural correspondence between the bits and the setting of the condition code. In practice, however, decimal terms are more commonly used to specify masks.

A *relocatable term* is a term whose value depends upon where the program of which it is a part is located in main storage. The labels of storage areas, instructions, and constants are relocatable terms. The value of a relocatable term is assigned before each execution of the program in which the term appears. This value is offset from the start of the program by some fixed amount. For example, for one execution of a program, the relocatable term

LOOP

may be assigned a value of 2110. However, for another execution of the same program, the start of the program could be offset by 100 bytes from its previous location; in this case, the value assigned would be 2210.

*Expressions* may be formed from self-defining and relocatable terms using arithmetic operators and parentheses. The expressions thus formed are termed either absolute or relocatable. An *absolute expression* is an expression whose value is not dependent upon the location of the program in storage. A *relocatable expression* is an expression whose value changes by *n* if the program of which it is a part is relocated by *n* bytes.

The following arithmetic symbols may be used in forming expressions from terms:

| *Symbol* | *Meaning* |
|---|---|
| + | Addition |
| – | Subtraction |
| * | Multiplication |
| / | Division |

The following rules apply to the formation of absolute expressions:

1. Each self-defining term is an absolute expression.
2. If L1 and L2 are relocatable terms, then (L1–L2) is an absolute expression.
3. If A1 and A2 are absolute expressions, then

(A1 + A2)
(A1*A2)
(A1 – A2)
and (A1/A2)

are absolute expressions.

The second rule may seem strange at first. However, consideration of the example

(EXIT – LOOP)

should lead to the conclusion that this difference remains constant regardless of the relocation factor of the program. That is, if the program is relocated, the values of EXIT and LOOP will be offset by the same amount. The following are examples of absolute expressions:

(((EXIT – ENTRY) + 1) + 20)
(((ADDR1 – ADDR2)/4)*X'10')
(((X'A'*B'101')/20) + 5)

The following rules apply to the formation of relocatable expressions:

1. Any relocatable term is a relocatable expression.
2. If A is an absolute expression and L is a relocatable expression, then

(A + L)
(L + A)
and (L – A)

are relocatable expressions.

The following are examples of relocatable expressions:

((START + 20) – X'13')
(LOOP – (X'ABC'/X'4'))
(EXIT – (((ADDR1 – ADDR2)/C'ABC')/X'AB'))

Parentheses may be omitted from expressions, and minor permutations of terms are allowed in some circumstances. The evaluation of an expression, whether fully parenthesized or not, proceeds as follows:

1. Each term is evaluated.
2. The subexpressions within parentheses are evaluated, proceeding from the innermost parentheses outward.
3. All multiplications and divisions are performed in left-to-right order; then all additions and subtractions are carried out in left-to-right order.
4. All arithmetic operations are performed on 32-bit binary numbers, and the final result is truncated to 24 bits.

A generous limit of 16 terms and five levels of parentheses is allowed in the formation of an expression.

The *DC statement*, which is used to provide constant data in storage, has the following general format:

```
label      DC      one or more operands
```

Each operand is of the form

dTmv

where d is the duplication factor
T is the type
m is the modifier (only length modifiers will be considered)
v is the value or values

For example, in the statement

```
DC      5CL4'3'
```

5 is the duplication factor
C is the type
L4 is the length modifier
'3' is the value

The *duplication factor* can be specified in any one of the following ways:

- It may be omitted. In this case, a duplication factor of 1 is assumed.
- It may be a decimal self-defining term.
- It may be a positive absolute expression from which the outside parentheses have not been omitted. All labels used in this expression must be previously defined (i.e., specified earlier in the program).

The following examples illustrate the use of each form that the duplication factor can take:

```
DC      C' '
DC      3C' '
DC      (20/4+X'A')C' '
```

If a duplication factor of 0 is used in a DC statement, execution of the statement generates nothing. The sole effect is to force a boundary alignment. For example, the statement

```
DC      0F'0'
```

does not cause a fullword to be generated, but merely moves the location counter ahead to the next fullword boundary.

The valid *types* that we will consider at this time are

C, X, B, F, H, A, and D

The use of each of these constant types in DC statements is discussed next, along with the value that can be associated with a DC operand.

The *length modifier* is of the form

Ln

where n is either a decimal self-defining term or a positive absolute expression from which the outside parentheses may not be omitted. (Any label used in this expression must be previously defined.)

If the length modifier is omitted, an implied length is assumed. The constant types are listed below with their respective maximum-length modifiers and implied lengths.

| *Constant* | *Maximum Length* | *Implied Length* | *Normally Aligned* |
|---|---|---|---|
| C | 256 | As needed | On a byte |
| X | 256 | As needed | On a byte |
| B | 256 | As needed | On a byte |
| F | 8 | 4 | On a fullword |
| H | 8 | 2 | On a halfword |
| A | 4 | 4 | On a fullword |
| D | 8 | 8 | On a doubleword |

The address of the label naming a DC constant is the address of the leftmost byte of the first constant specified by that instruction. If no length modifier is specified in the operand, boundary alignment may occur. For example, in this instance, an F-type constant always begins on a fullword boundary. If a length modifier is specified, no boundary alignment will occur.

The value or values that can be specified with each of these constant types in an operand are as follows:

A *C-type constant* has the form

'string of characters'

Only one value may be specified in an operand. The implied length of the constant is the number of characters in the constant, and no boundary alignment is performed.

An *X-type constant* has the form

'string of hexadecimal digits'

Only one X-type constant may be specified in an operand. If an X-type constant contains an even number, $n$, of digits, the implied length of the constant is $n/2$. If the constant contains an odd number, $m$, of digits, a zero is affixed on the left and the implied length in this case is $(m+1)/2$. No boundary alignment occurs.

A *B-type constant* has the form

'string of binary digits'

Only one B-type constant may be specified in an operand. If the number of digits in a B-type constant is not an even multiple of 8, zeros are padded on the left to round the total number of digits up to an even multiple of 8. For example, the statement

```
DC      B'1'
```

is equivalent to

```
DC      B'00000001'
```

The implied length of a B-type constant is the number of bytes necessary to store the constant, and no boundary alignment is performed.

The *F-* and *H-type constants* can be used to generate constants that occupy fullwords and halfwords, respectively. With either type, more than one value can be specified in an operand. For example, the statement

```
DC      F'1,-2,3604'
```

is valid.

An *A-type constant* can be specified by any valid absolute or relocatable expression. The value is calculated to 32 bits and then truncated to 24 bits. The implied length is 4 and the value is stored in the rightmost 24 bits of a fullword. Boundary alignment is to the next fullword boundary.

The *D-type constant* can be used to generate a constant of zero on a doubleword boundary as follows:

```
DC      D'0'
```

Many uses of the D-type constant involve features of assembly language that are not covered until Chapter 10. However, the most common use is simply to reserve a doubleword of storage.

To conclude this discussion of the DC statement, we direct your attention to the fact that more than one operand can appear in a DC statement. If more than one value is specified in an operand, each value must have the same characteristics; however, different types of operands can be specified in the same DC statement. For example, the statement

```
DC        X'01',C'CHAR',F'4'
```

is valid.

The *DS statement* is of the form

```
label     DS     one or more operands
```

With the following exceptions, the operands are of the same form as those specified for the DC statement:

1. No values need be specified for the operands.
2. The length modifier for a C- or X-type field may specify up to 65,535 bytes, rather than 256.

The DS statement generates nothing, whether or not values are specified. Its sole function is to set aside storage areas. If values are specified, they are used merely to assign implied lengths in the absence of a length modifier.

A *literal* is of the form

```
=operand
```

where the operand differs from the operand defined for the DC statement only in the following respects:

1. Unsigned decimal self-defining terms must be used to specify the duplication factor and length modifier.
2. The duplication factor must be nonzero.

Some examples of literals are

```
=BL4'1'
=F'4,-3'
=CL3'1'
```

Each label used in a program has a length attribute. This fact is usually important only in the case of labels used with DC and DS statements. The length attribute of a label used for a DC or DS statement is the value of the length modifier of the first operand or, in the absence of a length modifier, the implied length of the first operand. This is a critical fact that should be carefully noted. Following are several sample statements with their length attributes:

| *Statement* | | | *Length Attribute* |
|---|---|---|---|
| FIELD1 | DC | CL12'1' | 12 |
| FIELD2 | DC | 2CL12'1' | 12 |
| FIELD3 | DC | F'0' | 4 |
| FIELD4 | DS | XL3'1' | 3 |
| FIELD5 | DS | (4/X'2')BL(X'A'*B'10') | 20 |

## Exercises

**1.** Give the DC statement to generate a 256-byte storage area containing 16 consecutive copies of

0F0E0D0C0B0A09080706050403020100.

**2.** Suppose that you number the bits in a byte from the left, from 1 (this is unusual; normally they are numbered from the right from 0). We are interested in generating a 256-byte area in which the leftmost byte corresponds to 00, the next to 01, and so forth (i.e., the last byte corresponds to FF). In each byte of the table, we wish to have the number of the leftmost 1-bit of the "corresponding value." Thus, the table would begin with

| | |
|---|---|
| 00 | 00 has no 1-bits |
| 08 | 01 has only bit 8 on |
| 07 | 02 has only the 7 bit on |
| 07 | 03 has both the 7 and 8 bit on |
| . | . |
| . | . |
| 01 | FD has bits 1,2,3,4,5,7, and 8 on |
| 01 | FE has bits 1,2,3,4,5,6, and 7 on |
| 01 | FF has all bits on |

Give a set of DC statements that generate the desired 256-byte area. Note that this table is exactly what is needed for one of the assignments that occurs later in this chapter.

**3.** How much memory is set aside by the following DS statement?

```
DS    2D'3',B'1101',CL4'1',H'2'
```

Show the contents of the storage set aside by the statement.

## 8.2 THE AND, OR, AND EXCLUSIVE OR INSTRUCTIONS

In this section, instruction sets are introduced that can be used to perform logical operations between two fullword operands, between an immediate byte and a byte in storage, or between two fields in storage.

Some basic familiarity with the logical operators AND, OR, and EXCLUSIVE OR is required to make a discussion of these instructions meaningful. The results of performing these three logical operations on bits are summarized in Table 8-1.

**Table 8-1**

*AND*

| Bit 1 | Bit 2 | Result |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

*OR*

| Bit 1 | Bit 2 | Result |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

*EXCLUSIVE OR*

| Bit 1 | Bit 2 | Result |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

The following rules should be useful:

1. When an AND operation is performed on two bits, the result is 1 only if both bits have a value of 1; otherwise, the result is 0.
2. When an OR operation is performed on two bits, the result is 0 only if both bits have a value of 0; otherwise, the result is 1.
3. When an EXCLUSIVE OR operation is performed on two bits, the result is 1 if the bits have different values; the result is 0 if both bits have the same value.

These logical operations can be extended to bit strings of any length. The result of performing a logical operation on bit strings of equal length is determined by calculating the result of performing that logical operation on each corresponding pair of bits from the two strings. This process is illustrated in the following examples:

- *Example 1.* The AND operation.

| | | | |
|---|---|---|---|
| First string | 0000 | 0101 | 110101 |
| Second string | 1111 | 1001 | 011100 |
| Result | 0000 | 0001 | 010100 |

- *Example 2.* The OR operation.

| | | | |
|---|---|---|---|
| First string | 0000 | 0101 | 110101 |
| Second string | 1111 | 1001 | 011100 |
| Result | 1111 | 1101 | 111101 |

- *Example 3.* The EXCLUSIVE OR operation.

| | | | |
|---|---|---|---|
| First string | 0000 | 0101 | 110101 |
| Second string | 1111 | 1001 | 011100 |
| Result | 1111 | 1100 | 101001 |

The instructions that implement these logical operations between fullword operands are N, NR, O, OR, X, and XR. A discussion of these instructions follows.

Execution of the RX instruction

N r,D(X,B) (*AND*)

causes an AND operation to be performed on the fullword in the register r and the fullword in memory at the address D(X,B). The result replaces the first operand; the second operand is unaltered. If every bit in the result has a value of 0, the condition code is set to 0; otherwise, the condition code is set to 1.

The instruction

NR $r_1,r_2$ (*AND Register*)

is the RR counterpart of the N instruction. Execution of the NR instruction is analogous to the execution of the N instruction except that in the NR instruction the second operand is the fullword in the register $r_2$.

The key to most uses of the N instruction is as follows: *Any bit in the result corresponding to a bit in the second operand with a value of 0 will have a value of 0; any bit in the result corresponding to a bit in the second operand with a value of 1 will have the same value as the corresponding bit in the first operand.*

A possibly clearer, though less precise, way of stating this is as follows: *Performing an AND operation between an arbitrary bit and 0 results in a 0; performing an AND operation between an arbitrary bit and 1 leaves the value of the bit unaltered.*

Thus, execution of the instruction

N R1,=X'00000000'

will zero R1, while execution of the instruction

N R1,=X'FFFFFFFF'

will not alter the contents of R1.

The following examples illustrate uses of the AND instructions.

- *Example 1.* Assume that R1 contains an address that may or may not be on a fullword boundary. To ensure that this address is adjusted to a fullword boundary (by rounding down to the next lower fullword boundary, if necessary), it is sufficient to turn the values of the rightmost two bits of R1 to 0. (If this is not obvious, consider that the numerical value represented by any other bit in R1 is a multiple of 4.) Execution of the instruction

```
N       R1,=X'FFFFFFFC'
```

will accomplish this purpose. Note that only the values of the rightmost two bits of R1 can be affected. Had it been desirable to round the address up rather than down, the following pair of instructions could have been used:

```
LA      R1,3(R1)
N       R1,=X'FFFFFFFC'
```

Analogous instructions should be used to round a binary number up or down to the nearest multiple of any other power of 2.

- *Example 2.* Occasionally it is necessary to calculate the remainder resulting from the division of a given number by a divisor that is a power of 2. In particular, suppose that the remainder resulting from the division of the number in R1 by 16 must be inserted in R0. Careful consideration of this problem should convince the reader that this remainder is the number represented by the rightmost four bits of R1. Therefore, execution of the instructions

```
L       R0,=X'0000000F'
NR      R0,R1
```

will produce the desired result.

Execution of the instruction

```
O       r,D(X,B)                    (OR)
```

causes an OR operation to be performed on the fullwords in the register r and at the address D(X,B). The result replaces the contents of the register r; the second operand is unaltered. If the value of every bit in the result is 0, the condition code is set to 0; otherwise, the condition code is set to 1.

Execution of the instruction

```
OR      r1,r2                       (OR Register)
```

has an effect analogous to that produced by the execution of an O instruction except that in this case the second operand is in the register $r_2$.

The key to using the O instruction is as follows: *Performing an OR operation between an arbitrary bit and 0 leaves the value of the bit unaltered; performing an OR operation between an arbitrary bit and 1 results in a value of 1.*

The following simple examples illustrate uses of the OR instructions:

- *Example 1.* In the interest of conserving registers for other uses, it is sometimes desirable to use a register that otherwise may serve as a base or index register as a "flag." If such a register is used for this purpose, the right 24 bits must not be altered (these are the bits used in the computation of addresses) so as not to affect the execution of statements that use the register as a base or index register. Suppose that R12 is to be used for this purpose. The instruction

```
O       R12,=X'80000000'
```

may be used to turn the leftmost bit to 1, and the instruction

```
N       R12,=X'7FFFFFFF'
```

may be used to turn the leftmost bit to 0. The instruction

```
LTR     R12,R12
```

may then be used to test the condition of the flag.

- *Example 2.* Suppose that R2 contains a number in the range 0 to 9. In order to contain the character representation of this integer, the rightmost byte of R2 can be changed by the instruction

```
O       R2,=X'000000F0'
```

Execution of the instruction

```
X       r,D(X,B)        (EXCLUSIVE OR)
```

causes an EXCLUSIVE OR operation to be performed on the contents of the register r and the fullword at D(X,B). The result replaces the contents of the register r; the word at D(X,B) is unaltered. As with the other logical instructions, the condition code is set to 0 if all the bits in the result have a value of 0; otherwise, the condition code is set to 1.

Execution of the instruction

```
XR      r1,r2           (EXCLUSIVE OR Register)
```

differs from that of the EXCLUSIVE OR instruction only in that the second operand is in the register $r_2$.

The effect of executing an EXCLUSIVE OR instruction may be summarized as follows: *Performing an EXCLUSIVE OR operation between an arbitrary bit and 0 leaves the value of the bit unchanged; performing an*

*EXCLUSIVE OR operation between an arbitrary bit and 1 reverses the value of the bit.*

A common use of the EXCLUSIVE OR instruction is to exchange the contents of two registers. In particular, execution of the instructions

```
XR      R2,R3
XR      R3,R2
XR      R2,R3
```

causes the contents of R2 and R3 to be exchanged. The execution time required by these three instructions is greater than the time required by the instructions

```
LR      R4,R2
LR      R2,R3
LR      R3,R4
```

The XR sequence does not, however, require an additional register. The reader should convince himself that the three XR instructions do, in fact, exchange the contents of the two registers.

The three SI instructions—NI, OI, and XI—can be used to perform logical operations on bytes. The execution of any of these instructions will cause the appropriate logical operation to be performed on a byte in storage, and the immediate byte will be encoded in the instruction itself. The result replaces the byte in storage. A description of these instructions and examples of their uses follow.

Execution of the instruction

```
NI      D(B),byte          (AND Immediate)
```

will cause an AND operation to be performed on the byte in storage specified by the first operand and the byte designated as the second operand. The result replaces the first operand, and the second operand is unaltered. A protection error or an addressability exception can occur. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Resulting byte is 00. |
| 1 | Resulting byte is not 00. |
| 2 | — |
| 3 | — |

Execution of the following two instructions is analogous to the NI except for the logical operations involved:

```
OI      D(B),byte          (OR Immediate)
XI      D(B),byte          (EXCLUSIVE OR
                            Immediate)
```

The keys to the use of these three instructions are:

1. An NI instruction is used to turn the values of bits to 0.
2. An OI instruction is used to turn the values of bits to 1.
3. An XI instruction is used to reverse the values of bits.

As an illustration, suppose that the one-byte field FIELD contains the value X'27'. Then, execution of the instruction

```
OI      FIELD,B'01001000'
```

would alter the contents of FIELD to X'6F'; execution of the instruction

```
NI      FIELD,X'0F'
```

would alter the contents of FIELD to X'07'; and execution of the instruction

```
XI      FIELD,X'F0'
```

would alter the contents of FIELD to X'D7'. If these examples are not clear, the discussion of AND, OR, and EXCLUSIVE OR in this section should be carefully reviewed.

One particularly common use of NI and OI instructions is to alter the masks in branch instructions. To appreciate exactly how this is done, note that the instructions

```
BC      B'0000',addr
```

and

```
NOP     addr
```

are both encoded as

$$470h_I h_B h_D h_D h_D$$

where $h_I h_B h_D h_D h_D$ is the encoding of addr.

The NOP operation is an extended mnemonic that means "no operation." The RR counterpart of this NOP instruction is

```
NOPR    r
```

which is encoded as

$$070h_r$$

The principal use of the NOP instruction is in generating branch instructions that can be "activated" later in the program. The following example illustrates how this is achieved:

```
LOOP    NOP     NOTFIRST
        OI      LOOP+1,X'F0'     SET BRANCH
        .
        .
        .
```

```
        (a routine that is to be executed only once)

                .
                .
                .
NOTFIRST . . .
```

In this case, the sequence of instructions between the OI instruction and NOTFIRST is executed only once. Execution of the OI instruction activates the branch so that, on any successive pass through the loop, the branch to NOTFIRST is taken. Later in the program, the branch could be deactivated by execution of the instruction

```
NI      LOOP+1,X'0F'    DEACTIVATE BRANCH
```

Although the technique of altering branch masks is commonly employed, a growing number of people now regard it as a practice to be avoided. The basic objection is that a program containing such branch statements is frequently hard to debug and alter. A flag is clearer and therefore should normally be used.

Before we end this discussion of logical immediate instructions, one common use should be mentioned. When a packed decimal field is unpacked, the rightmost byte may contain an undesirable value due to the value for the sign. In such cases it is necessary to use an OI to make sure that the rightmost character is a printable decimal digit. Thus,

```
UNPK    SOCSEC(9),SSN(5)
OI      SOCSEC+8,X'F0'
```

would unpack a Social Security number into a 9-character printable format.

The instructions XC, OC, and NC, which cause OR, AND, and EXCLUSIVE OR operations to be performed between two fields in storage, are used far less often than their RX, RR, and SI counterparts. In a few instances, however, they prove to be extremely useful.

Execution of the instruction

```
XC      D1(L,B1),D2(B2)    (EXCLUSIVE OR)
```

causes an EXCLUSIVE OR operation to be performed between the two L-byte fields at the addresses D1(B1) and D2(B2). The result replaces the first operand. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Resulting bytes are all 0. |
| 1 | Resulting bytes are *not* all 0. |
| 2 | — |
| 3 | — |

There are two common uses of the XC instruction:

- Every byte in a field can be set to a value of 00 by performing an EXCLUSIVE OR operation between the field and itself. For example, execution of the instruction

```
XC      TABLE,TABLE
```

  sets every byte of TABLE to a value of 00.

- The contents of two fields in storage can be exchanged through the use of three EXCLUSIVE OR operations. For example, execution of the sequence of instructions

```
XC      F1,F2
XC      F2,F1
XC      F1,F2
```

  will cause the contents of F1 and F2 to be exchanged.

Execution of the instruction

```
OC      D1(L,B1),D2(B2)                    (OR)
```

causes an OR operation to be performed between the two operands. The result replaces the first operand. The settings of the condition code have the same meanings as for the XC instruction.

An OC instruction can be used to change the leading blanks to zeros, in a field containing numeric characters and blanks. For example, execution of the instruction

```
OC      ACCT#,=8X'F0'
```

will replace any blank in the eight-byte field ACCT# with a zero.

Execution of the instruction

```
NC      D1(L,B1),D2(B2)                    (AND)
```

causes an AND operation to be performed between the two operands. The result replaces the first operand. The settings of the condition code are the same as for XC and OC instructions.

NC instructions are used less frequently than OC and XC instructions. An example of the use of an NC instruction will be presented in Section 8.11.

**Exercises**

1. Give an instruction that zeroes out all of the "odd numbered" bits in a R3 (assuming that the rightmost bit is bit 0, and the leftmost bit is bit 31).

2. Give a sequence of instructions that will cause a branch to INTERRUPT if any of bits 23-28 are set to 1 in R6.

3. Give an instruction that sets bit 6 of the byte FLAGS to 1.

4. Give an instruction that "toggles" bit 5 of the byte FLAGS.

## 8.3 THE TM INSTRUCTION

The TM instruction is an SI instruction that can be used to test the values of selected bits in a designated byte of storage. The values of the bits in the immediate byte determine which bits in the byte of storage are to be tested. Bits that correspond to a bit in the immediate byte with a value of 1 are tested, while those that correspond to a bit in the immediate byte with a value of 0 are not tested. For this reason, the immediate byte coded in a TM instruction is called a *mask*. A precise description of the TM instruction follows.

Execution of the instruction

```
TM      D(B),mask
```

(*Test under Mask*)

affects only the condition code, which is set according to the following rules:

- If every bit in the byte at the address D(B) that corresponds to a bit in the mask with a value of 1 has a value of 0, the condition code is set to 0. (The selected bits all have a value of 0.)
- If every bit in the byte at the address D(B) that corresponds to a bit in the mask with a value of 1 has a value of 1, the condition code is set to 3. (The selected bits all have a value of 1.)
- In all other cases, the condition code is set to 1.

Suppose, for example, that FLD contains X'0E'. Then, execution of the instruction

```
TM      FLD,B'10010000'
```

would set the CC to 0, since bits 0 and 3 of FLD both have a value of 0. Similarly, execution of the instruction

```
TM      FLD,B'10001000'
```

would set the CC to 1, and execution of the instruction

```
TM      FLD,B'00001110'
```

would set the CC to 3.

The set of extended mnemonics that can be used following a TM instruction are listed in Appendix B. An examination of that list will indicate that the pair of instructions

```
TM      WORD+3,B'00000011'
BNZ     NOTMULT4
```

will cause a branch to be taken if either or both of the selected bits do not have a value of 0. This condition occurs only when WORD has a value that is not a multiple of 4.

The most common use of TM instructions is for testing flag bits. This is convenient when each of several bits in a designated byte serves as a flag. For example, suppose that FLAGBYTE has been defined as

```
FLAGBYTE DC      X'00'
*  BITS    0-4   ARE UNUSED
*  BIT     5=1   END-OF-FILE HAS OCCURRED
*  BIT     6=1   INVALID ACCOUNT #
*  BIT     7=1   INVALID AMOUNT FIELD
```

Suppose further that some internal subroutine has been called to read an input card and that FLAGBYTE has been set to reflect the result of the attempted read operation. Under these conditions, the following sequence of instructions would cause a transfer of control to the appropriate routine, depending upon the settings of the flag bits:

```
TM      FLAGBYTE,B'00000100'  =1   EOF
BO      EOF
TM      FLAGBYTE,B'00000010'  =1   BAD ACCOUNT #
BO      BADACCT#
TM      FLAGBYTE,B'00000001'  =1   BAD AMOUNT
BO      BADAMNT
```

Note that the OI and NI instructions could be used to turn the flag bits on and off, respectively. For example, the instruction

```
OI      FLAGBYTE,B'00000100'
```

could be used to set the EOF indicator, and the instruction

```
NI      FLAGBYTE,B'11111110'
```

could be used to turn the BADAMNT flag off.

**Exercises**

**1.** Give an instruction sequence that causes a branch to SOMEONE if either bit 4 or bit 6 of FLAGS is a 1 (but the other is 0), to ALL if both bits are 1, and to NEITHER if both bits are 0.

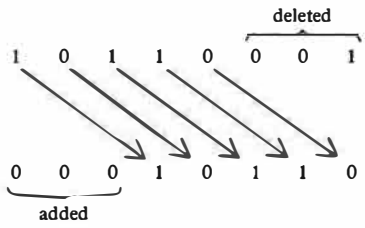
**2.** Give an instruction sequence that branches to HIGH if any (or all) of bits 4-7 of FLAGS are 1, to MID if both bits 2 and 3 are 1, and to LOW, otherwise.

## 8.4 THE SHIFT INSTRUCTIONS

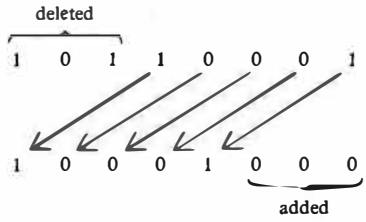
The result of performing an $n$-position right logical shift on a binary number containing $m$ digits may be obtained by doing the following:

1. Remove the rightmost $n$ digits from the original number.
2. Shift each of the remaining digits $n$ positions to the right.
3. Place $n$ zeros to the left of the leftmost digit of the resulting number.

For example, the process of performing a three-position, right logical shift on the number 10110001 can be illustrated as follows:




Left logical shifts are performed in a similar manner. The process of shifting 10110001 left three positions is depicted as follows:




The instructions SLL and SRL perform logical shifts on the contents of a single register, whereas the instructions SLDL and SRDL perform logical shifts on the contents of an even/odd pair of registers. These four instruc-

tions are RS instructions, but the symbolic format for them differs from the format for other RS instructions. The standard symbolic format for an RS instruction is

```
label        mnemonic        r1,r2,D(B)
```

while the symbolic format for the shift instruction is

```
label        mnemonic        r1,D(B)
```

In both cases, the format for the generated machine instruction is

$$h_0h_0h_{r1}h_{r2} \quad h_Bh_Dh_Dh_D$$

However, when the shift instructions are encoded, $h_{r2}$ is automatically set to 0.

Execution of the instruction

```
SLL        r1,D(B)        (Shift Left Single Logical)
```

causes the contents of the register $r_1$ to be shifted left. The digits that are deleted are lost, and the condition code is not altered. The shift is an *n*-position logical shift, and *n* is calculated as follows:

1. The address D(B) is calculated.
2. *n* is set equal to the value indicated by the rightmost six bits of the result.

This calculation is the same for all shift instructions. This means that a shift of up to 63 positions may be specified, but a single-register shift of more than 31 positions should never be used.

Execution of the instruction

```
SRL        r1,D(B)        (Shift Right Single Logical)
```

causes a right logical shift to be performed on the contents of the register $r_1$. In all other respects, it is analogous to the SLL instruction.

To illustrate the use of the SLL and SRL instructions, suppose that

R1 contains 0F0F0F0F
R2 contains 00000005

Execution of the instruction

```
SLL        R1,2
```

would alter the contents of R1 to 3C3C3C3C, and execution of the instruction

```
SLL        R1,0(R2)
```

would alter the contents of R1 to E1E1E1E0. Note that, in the second case, the number of positions shifted depends upon the contents of R2 (i.e., a shift of five positions would be performed). Execution of the instruction

```
SRL     R1,6
```

would alter the contents of R1 to 003C3C3C.

Except that two registers participate in the shifts, execution of either of the double-register logical shift instructions is analogous to the execution of its single-register counterpart. The two registers that participate in the shift are an even-odd pair. This pair of registers is treated during the shift operation as if it were a single 64-bit register.

Execution of the instruction

SLDL $r_1$,D(B) *(Shift Left Double Logical)*

causes the contents of the even-odd pair of registers designated by $r_1$ ($r_1$ must be even) to be shifted left.

Execution of the instruction

SRDL $r_1$D(B) *(Shift Right Double Logical)*

causes the contents of the even-odd pair of registers designated by $r_1$ to be shifted right.

The logical shift instructions are useful for positioning the bits in a register. Suppose, for example, that a payroll program using a very large table is to be written. Suppose further that each entry in the table contains three numbers:

- an employee number (4 digits)
- the number of hours worked (less than 100)
- the hourly pay rate (less than $20.00)

If a separate word were used for each number in an entry, each entry would occupy 12 bytes of storage. On the other hand, it is possible to condense all three numbers of an entry into a single word, using the following format:

bits 0–13 = employee number
bits 14–20 = hours worked
bits 21–31 = pay rate

To reference the data in a single entry in the table, it would then be necessary to have a routine to isolate the numbers in separate registers. The following routine would perform this function:

```
*  ASSUME THAT R1 CONTAINS A TABLE ENTRY
          LR      R2,R1
          N       R2,=X'000007FF'
*  R2 NOW CONTAINS THE RATE
          LR      R3,R1
          SRL     R3,11     SHIFT OFF THE RATE
          N       R3,=X'0000007F'
```

```
*  R3 HAS THE HOURS
                LR      R4,R1
                SRL     R4,18
*  R4 HAS THE EMPLOYEE #
```

The following two instructions offer an alternative way to isolate the employee number:

```
                SR      R0,R0
                SLDL    R0,14
*  NOW R0 HAS THE EMPLOYEE #. NOTE THAT R1 HAS
*  BEEN SHIFTED, AS WELL AS R0.
```

In addition to the four logical shift instructions, there are four arithmetic shift instructions: SLA, SRA, SLDA, and SRDA. Although the operation of the arithmetic shifts is similar to the operation of the logical shifts, the functions for which they are normally used are quite different. The arithmetic shifts are used to achieve the effect of multiplying and dividing by powers of 2.

Execution of the instruction

SLA $r_1$,D(B) (*Shift Left Single Arithmetic*)

differs from the execution of the SLL instruction as follows:

- In an arithmetic left shift, bit 0 does not participate in the shift. If a bit that does not match the sign bit is shifted out of position 1, overflow will occur. Hence, the arithmetic shifts can never alter the sign bit.
- The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Result is 0. |
| 1 | Result < 0. |
| 2 | Result > 0. |
| 3 | Overflow occurred. |

The principal use of the SLA instruction is to achieve the effect of multiplication by powers of 2. Just as adding a 0 to the right of the base 10 representation of a number yields the same result as multiplying that number by 10, adding a 0 to the right of the base 2 representation of a number yields the same result as multiplying that number by 2. Thus, execution of the instruction

```
SLA     R1,4
```

has the same effect on the contents of R1 as does the execution of the instruction

```
M       R0,=F'16'
```

and requires less time. This technique should be applied only to powers of 2 greater than 1, since the contents of a register can be doubled in less time by adding the register to itself.

Execution of the instruction

```
SRA     r1,D(B)          (Shift Right Single
                          Arithmetic)
```

differs from the execution of the SRL instruction in the following respects:

- The bits vacated by the shift are not necessarily filled in with zeros. Instead, these bits take on the value of the sign bit. That is, zeros are filled in if the contents of the register represents a positive number, and ones are filled in if the number represented is negative. For example, the contents of R1 after execution of the instructions

  ```
  L       R1,=X'FFFFFFFF'
  SRA     R1,2
  ```

  would be FFFFFFFF.

- The settings of the condition code are the same as for the SLA instruction except that overflow cannot occur.

The SRA instruction is used to achieve the effect of dividing numbers by powers of 2. For example, the result of dividing R2 by 64 is achieved by use of the instruction

```
SRA     R2,6
```

When this technique is used and the number represented by the contents of the register is not a multiple of the indicated power of 2, rounding occurs. The results are always rounded down. Thus, execution of the instructions

```
LA      R1,22
SRA     R1,2
```

changes the contents of R1 to 00000005, while execution of the instructions

```
L       R1,=F'-22'
SRA     R1,2
```

sets the contents of R1 to FFFFFFFA. This last example (involving a negative number) should be remembered since the result differs from the one that would be obtained using the Divide instruction.

The SLDA and SRDA instructions perform the same operations as the SLA and SRA instructions except that the former operations are applied to even-odd pairs of registers. These instructions are most often used to achieve the effect of multiplying and dividing 64-bit integers by powers of 2. (See Section 4.7 for routines to add, subtract, and compare 64-bit integers.)

Execution of the instruction

SLDA $r_1$,D(B) (*Shift Left Double Arithmetic*)

causes a left arithmetic shift to be performed on the contents of the even-odd pair of registers designated by $r_1$. In all other details, its operation is identical to the operation of the SLA instruction.

Execution of the instruction

SRDA $r_1$,D(B) (*Shift Right Double Arithmetic*)

causes a right arithmetic shift to be performed on the contents of the even-odd pair of registers designated by $r_1$. In all other respects, its operation is identical to that of the SRA instruction.

Program 8-1 concludes this section. The program reads numbers in the range 0 to 3999 and determines how many distinct numbers have been read. A table is maintained that contains 4000 one-bit entries. Initially, all bits in the table have a value of 0. As numbers are read by the program, the values of the corresponding bits in the table are changed to 1. When end-of-file is reached, the number of bits in the table with a value of 1 is determined and the answer is printed.

**Program 8-1**

```
         TITLE 'COUNTUP - COUNT THE NUMBER OF UNIQUE INTEGERS'
*************************************************************************
*
* THIS PROGRAM READS A STREAM OF INTEGERS, AND THEN COUNTS THE NUMBER
* OF UNIQUE VALUES THAT WERE IN THE INPUT.  AS THE VALUES ARE READ,
* BITS ARE MARKED IN A TABLE.  THE TABLE CONTAINS 32*125 BITS,
* EACH BIT CORRESPONDING TO A VALUE IN THE RANGE 0-3,999.  THE
* LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*   STEP 1.  READ THE FIRST CARD.
*
*   STEP 2.  IF EOF HAS OCCURRED, GO TO STEP 5 TO COUNT THE BITS THAT
*            WERE SET.
*
*   STEP 3.  MARK THE BIT IN THE TABLE CORRESPONDING TO THE NUMBER.
*
*   STEP 4.  READ THE NEXT CARD AND GO TO STEP 2.
*
*   STEP 5.  POSITION A POINTER TO THE FIRST WORD IN THE TABLE OF
*            BITS.
*
*   STEP 6.  IF ALL OF THE WORDS HAVE BEEN COUNTED, GO TO STEP 11.
*
*   STEP 7.  LOAD THE WORD TO BE COUNTED.
*
*   STEP 8.  IF ALL OF THE BITS HAVE BEEN COUNTED, GO TO STEP 10.
*
*   STEP 9.  FIND THE NEXT 1 BIT IN THE WORD.  COUNT IT AND RESET
*            THE BIT TO 0.  GO TO STEP 8.
*
```

**Program 8-1 (continued)**

```
*    STEP 10. POSITION TO THE NEXT WORD IN THE TABLE AND GO TO
*             STEP 6.
*
*    STEP 11. PRINT THE FINAL ANSWER.
*
*    STEP 12. EXIT.
*
*********************************************************************
*
COUNTUP  CSECT
         STM    R14,R12,12(R13)     STORE CALLER'S REGISTERS
         BALR   R12,0
         USING  BASEPT,R12
BASEPT   DS     0H
         LA     R14,SAVEAREA
         ST     R14,8(R13)
         ST     R13,4(R14)
         LR     R13,R14
*
***<STEP 1>     READ THE FIRST CARD
*
         XREAD  CARD,80
*
***<STEP 2>    TEST FOR END-OF-FILE
*
EOFTEST  BC     B'0100',GOCOUNT
*
***<STEP 3>    MARK THE BIT FOR THE NUMBER
*
         PACK   DWORD,CARD(6)
         CVB    R3,DWORD
*
         LA     R2,31               PUT 0000001F INTO R2
         NR     R2,R3               R2 <- REMAINDER OF #/32
         SRA    R3,5                R3 <- QUOTIENT OF #/32
         SLA    R3,2                TIMES 4 FOR DISPLACEMENT INTO TABLE
         L      R4,TABLE(R3)        R4 <- WORD WITH BIT TO MARK
         L      R5,=X'80000000'
         SRL    R5,0(R2)            POSITION BIT IN R5
         OR     R4,R5               AND MARK IT IN R4
         ST     R4,TABLE(R3)        PUT IT BACK INTO THE TABLE
*
***<STEP 4>    READ THE NEXT CARD AND GO BACK TO STEP 2.
*
READNXT  XREAD  CARD,80
         B      EOFTEST
*
***<STEP 5>    SET UP TO START WITH THE FIRST WORD IN THE TABLE
*
GOCOUNT  LM     R1,R4,=A(TABLE,0,1,125)
*                                   R1 <- A(NEXT WORD TO COUNT)
*                                   R2 <- COUNT OF BITS SET
*                                   R3 <- THE CONSTANT 1
*                                   R4 <- NUMBER OF WORDS TO COUNT
***<STEP 6>    TEST FOR END OF TABLE
*
TESTEND  S      R4,=F'1'            DECREMENT COUNT OF WORDS LEFT
         BM     GOPRINT
*
***<STEP 7>    LOAD THE NEXT WORD TO COUNT
*
         L      R0,0(R1)
*
```

**Program 8-1 (continued)**

```
***<STEP 8>    MORE BITS IN THE WORD?
*
TESTFORO LTR   R5,R0
         BZ    NEXTWORD
*
***<STEP 9>   FIND THE NEXT BIT, COUNT IT, AND ZERO IT.
*
         AR    R2,R3                INCREMENT COUNT
         SLR   R5,R3                THIS INSTRUCTION AND THE NEXT
*                                   ZERO THE RIGHTMOST 1 BIT IN THE
*                                   REGISTER - TRY SOME EXAMPLES TO
*                                   VERIFY THAT IT WORKS
         NR    R0,R5
         B     TESTFORO
*
***<STEP 10>   POSITION TO THE NEXT WORD AND GO TO STEP 6
*
NEXTWORD LA    R1,4(R1)
         B     TESTEND
*
***<STEP 11>   PRINT THE ANSWER
*
GOPRINT  CVD   R2,DWORD
         MVC   ANSWER(10),=X'40206B2020206B202120'
         ED    ANSWER(10),DWORD+4
         XPRNT CC,24
*
***<STEP 12>   EXIT
*
         L     R13,4(R13)
         LM    R14,R12,12(R13)
         BR    R14
*
         LTORG
CARD     DS    CL80                 CARD INPUT AREA
SAVEAREA DS    18F                  REGISTER SAVE AREA
CC       DC    C'OTHE ANSWER IS'
ANSWER   DS    CL10
DWORD    DS    D                    USED FOR CONVERSIONS
TABLE    DC    125F'0'
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END   COUNTUP
```

**Exercises**

**1.** Give an instruction sequence that positions bits 14-17 of R3 as the rightmost bits of R4 (with all other bits of R4 set to 0). R3 should not be altered.

**2.** Suppose that you wish to load the contents of WORD into R5, setting R4 to FFFFFFFF if WORD represents a negative number (and to 0, if R5 represents a nonnegative number). Give a two-instruction sequence that performs the task.

## 8.5 HALFWORD INSTRUCTIONS

The IBM instruction set includes a set of instructions for manipulating 16-bit signed integers stored in halfwords. (Remember that a halfword is two contiguous bytes beginning on an even address.)

The method of encoding signed integers in 32-bit fullwords was introduced in Section 1.7. This encoding scheme, called two's complement encoding, can easily be generalized to apply to units of memory of varying size. In particular, signed integers can be encoded in halfwords as follows:

- Any number in the range 0 to $7FFF_{16}$ is represented in a halfword in its normal binary representation. Thus, the maximum number that can be represented is 32,767.
- Any number $n$ in the range $-1$ to $-8000_{16}$ is encoded by subtracting the absolute value of $n$ from FFFF and adding 1.

Note that the sign bit (leftmost bit) of an encoded negative integer is always 1, while the sign bit of a positive number is always 0.

Halfword storage areas and constants can be generated using DS and DC statements. The only difference between the rules for halfword areas and those for fullword areas is that H should be used in place of F. Thus, the instruction

```
label      DS      nH
```

is used to set aside a region of $n$ halfwords ($2n$ bytes beginning on an even address), and execution of the instruction

```
label      DC      nH'c'
```

generates $n$ contiguous halfwords containing the constant $c$. In each case, if n is omitted, it is assumed to be 1. As examples of what the DC statement will generate, consider the following table:

| *Instruction* | *Generated* |
|---|---|
| DC H'0' | 0000 |
| DC H'1' | 0001 |
| DC H'-1' | FFFF |
| DC H'-2' | FFFE |
| DC 2H'12' | 000C000C |
| DC H'32767' | 7FFF |
| DC H'-32768' | 8000 |

Halfword literals may be used in the same manner as fullword literals. (An example is given below in the discussion of the Load Halfword instruction.)

Because the storage of halfword integers requires only half as much main storage as does the storage of fullword integers, a considerable savings in the storage requirements of a program can sometimes be achieved through their use. A limiting factor in the use of halfword integers is their range: -32,768 to 32,767. This range is, however, adequate for many applications involving extensive integer tables. The halfword instructions—LH, STH, CH, AH, SH, and MH—are presented next.

Execution of the instruction

LH r,D(X,B) (*Load Halfword*)

causes the contents of r to be replaced by a 32-bit representation of the number stored at the address D(X,B). Thus, after execution of the instruction, the two leftmost bytes of r will contain 0000 if the number loaded was positive or FFFF if that number was negative. The halfword operand in storage is left unchanged, and the condition code is not altered. Thus, after execution of the instruction

LH R1,=H'-2'

the contents of R1 will be FFFFFFFE.

Execution of the instruction

STH r,D(X,B) (*Store Halfword*)

causes the halfword at D(X,B) to be replaced by a copy of the rightmost pair of bytes of r (bits 16-31). The contents of r are unchanged, and the condition code is unaltered.

Execution of the instruction

CH r,D(X,B) (*Compare Halfword*)

causes a comparison to be made between the contents of r and the halfword at D(X,B). Based on the outcome of this comparison, the condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The operands are equal. |
| 1 | The first operand is low. |
| 2 | The first operand is high. |
| 3 | — |

There are halfword instructions—AH, SH, and MH—for performing the arithmetic operations of addition, subtraction, and multiplication. (However, there is no instruction for performing division on halfword operands.)

Execution of the instructions

| | | |
|---|---|---|
| AH | r,D(X,B) | (*Add Halfword*) |
| SH | r,D(X,B) | (*Subtract Halfword*) |

is analogous to the execution of their fullword counterparts, A and S. The sole difference is that, in this case, D(X,B) refers to a halfword representation of an integer rather than a fullword representation.

The multiply halfword instruction involves a single register rather than a pair of registers as its fullword counterpart requires.

Execution of the instruction

| | | |
|---|---|---|
| MH | r,D(X,B) | (*Multiply Halfword*) |

causes the contents of r and the halfword at D(X,B) to be multiplied. The result replaces the contents of r. Overflow does not cause an interrupt; hence, the programmer must assure that the result can be represented in 32 bits.

Program 8-2 illustrates the use of the halfword instructions.

**Program 8-2**

```
         TITLE 'HALFWORD - COUNT OCCURRENCES OF NUMBERS'
*****************************************************************
*
* THIS PROGRAM READS IN A DECK OF CARDS, EACH OF WHICH CONTAINS
* AN INTEGER IN THE RANGE 0-9,999.  A HALFWORD COUNTER EXISTS
* FOR EACH NUMBER IN THE RANGE.  AS EACH INPUT NUMBER IS READ,
* THE CORRESPONDING COUNTER IS INCREMENTED.  AFTER ALL OF THE
* INPUT VALUES HAVE BEEN READ, THE PROGRAM PRINTS EACH COUNTER
* THAT CONTAINS A NONZERO VALUE.  THE LOGIC IS AS FOLLOWS:
*
*   STEP 1.  READ THE FIRST CARD
*
*   STEP 2.  IF EOF HAS OCCURRED, GO TO STEP 5.
*
*   STEP 3.  INCREMENT THE APPROPRIATE HALFWORD COUNTER.
*
```

**Program 8-2 (continued)**

```
*   STEP 4.  READ THE NEXT CARD AND GO TO STEP 2.
*
*   STEP 5.  PRINT A HEADER AND GET READY TO PROCESS ENTRIES
*            IN THE TABLE.
*
*   STEP 6.  IF ALL COUNTERS HAVE BEEN CHECKED, GO TO STEP 9.
*
*   STEP 7.  IF THE COUNTER IS NONZERO, PRINT A LINE FOR IT.
*
*   STEP 8.  POSITION TO THE NEXT COUNTER AND GO TO STEP 6.
*
*   STEP 9.  EXIT.
*
*********************************************************************
*
HALFWORD CSECT
         STM   R14,R12,12(R13)    STORE CALLER'S REGISTERS
         BALR  R12,0
         USING BASEPT,R12
BASEPT   DS    OH
         LA    R14,SAVEAREA
         ST    R14,8(R13)
         ST    R13,4(R14)
         LR    R13,R14
*
***<STEP 1>    READ THE FIRST CARD
*
         XREAD CARD,80
*
***<STEP 2>    TEST FOR END-OF-FILE
*
EOFTEST  BC    B'0100',PRTCNTRS
*
***<STEP 3>    INCREMENT THE APPROPRIATE ACCUMULATOR
*
         PACK  DWORD,CARD(4)      PACK THE NUMBER
         CVB   R2,DWORD
         AR    R2,R2              DOUBLE THE # TO GET DISP INTO TABLE
         LH    R3,TABLE(R2)
         LA    R3,1(R3)           INCREMENT THE COUNTER
         STH   R3,TABLE(R2)       RESTORE NEW VALUE
*
***<STEP 4>    READ THE NEXT CARD
*
         XREAD CARD,80
         B     EOFTEST
*
***<STEP 5>    PRINT HEADER AND POSITION TO THE FIRST COUNTER
*
PRTCNTRS XPRNT =CL22'1 NUMBER   OCCURRENCES',22
         SR    R2,R2              R2 <- FIRST NUMBER TO CHECK
         LH    R3,=H'10000'       R3 <- # COUNTERS TO CHECK
*
```

**Program 8-2 (continued)**

```
***<STEP 6>    TEST FOR END OF TABLE
*
TESTEND  SH    R3,=H'1'
         BM    EXIT
*
***<STEP 7>    IF THE VALUE IS > 0, PRINT IT
*
         LA    R4,0(R2,R2)        R4 <- DISP INTO TABLE FOR THE NUMBER
         LH    R5,TABLE(R4)
         LTR   R5,R5
         BZ    INCRCNT
*
         CVD   R2,DWORD
         MVC   NUMBER(7),=X'4020206B202120'
         ED    NUMBER(7),DWORD+5  EDIT IN THE NUMBER
*
         CVD   R5,DWORD
         MVC   VALUE(7),=X'4020206B202020'
         ED    VALUE(7),DWORD+5   EDIT IN # OCCURRENCES
*
         XPRNT PLINE,22
*
***<STEP 8>    GO TO NEXT COUNTER
*
INCRCNT  LA    R2,1(R2)
         B     TESTEND
*
***<STEP 9>    EXIT
*
EXIT     L     R13,4(R13)
         LM    R14,R12,12(R13)
         BR    R14
*
         LTORG
DWORD    DS    D                  USED FOR CONVERSIONS
CARD     DS    CL80               INPUT AREA
SAVEAREA DS    18F                REGISTER SAVE AREA
PLINE    DC    C'0'
NUMBER   DS    CL7
         DC    CL5' '
VALUE    DS    CL7
         DC    CL2' '
TABLE    DC    10000H'0'          TABLE OF COUNTERS
*
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
```

**Program 8-2 (continued)**

```
R8      EQU   8
R9      EQU   9
R10     EQU   10
R11     EQU   11
R12     EQU   12
R13     EQU   13
R14     EQU   14
R15     EQU   15
        END   HALFWORD
```

## Exercises

1. What is generated by

```
DC        F'13',H'2',F'6'
```

2. What is the difference between

```
DC        H'10'      and
DC        AL2(10)
```

3. What is the difference between using

```
LH        R1,=X'00A0'      and
LH        R1=H'10'
```

4. What is generated by

```
DC        H'-2, 3, -5'
```

## 8.6 THE MVCL, CLCL, AND EX INSTRUCTIONS

The MVCL and CLCL instructions are generalized versions of the MVC and CLC instructions. They are used to perform move and comparison operations on fields as long as $2^{24}-1$.

Each of the operands of the instruction

```
MVCL    r1,r2                    (Move Long)
```

must be an even register that is used to designate an even-odd pair of registers. Each of these register pairs specifies a field from 0 to $2^{24}-1$ bytes in length. The rightmost three bytes of each even register specify the address of a field, and the rightmost three bytes of the odd register of each pair specify the length of the corresponding field. The contents of the field specified by r2 are moved to the field specified by r1.

If the sending field is shorter than the receiving field, a pad character represented by the leftmost byte of the odd register specified by r2 is inserted into the remaining rightmost bytes of the receiving field. If a byte is simultaneously in both the sending and receiving fields and if execution of the MVCL instruction would cause this byte to receive a new value before the original contents are moved, a condition of *destructive overlap* is said to exist. In this case, no data movement occurs. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The sending and receiving fields were of equal length. |
| 1 | The sending field was longer than the receiving field. |
| 2 | The receiving field was longer than the sending field. |
| 3 | A condition of destructive overlap existed. |

If the movement of data actually takes place (that is, if a condition of destructive overlap does not exist), then the following occurs:

1. The even register designated by r1 is set to the address of the first byte past the end of the receiving field.
2. The odd register of the even-odd pair specified by r1 is set to 0.
3. The even register specified by r2 is set to the address of the first byte beyond the last byte moved from the sending field.
4. The odd register of the pair designated by r2 is decremented by the number of bytes transferred from the sending field.

Thus, use of the MVCL instruction offers the following advantages over use of the MVC instruction:

1. Fields of arbitrary length may be moved.
2. The lengths of the fields can be determined at execution time.
3. Padding occurs automatically.

The following examples illustrate use of the MVCL:

- *Example 1.* Suppose that R2 contains the address of a field and R3 contains the length of the field. To set each byte of the field to 00, the following code would be used:

```
        LR      R4,R2   R4 <- ADDRESS OF THE FIELD
        LR      R5,R3   R5 <- LENGTH
        LR      R6,R2   R6 MUST BE A VALID ADDRESS,
*                       BUT IT ISN'T USED
        SR      R7,R7   PAD CHARACTER AND LENGTH ARE 00
        MVCL    R4,R6   JUST PUTS THE PAD CHARACTER IN THE FIELD
```

- *Example 2.* Suppose that an integer number from one to six digits long has been moved to an area in main storage (say, DUMMY) and that a section of code must be written to move this number into PLINE so that the nonblank characters of DUMMY are left-justified in the field that begins at PLINE+7. Suppose further that the number in question has been moved to DUMMY by means of an XDECO instruction (in this case, DUMMY is a 12-byte field, and the number is right-justified in this field) and that PLINE has been defined as

```
PLINE    DC       CL19'0TOTAL='
```

The following segment of code represents one solution to this problem:

```
         LA       R2,DUMMY
         LA       R3,12
LOOP     CLI      0(R2),C' '     CHECK FOR THE FIRST NONBLANK
         BNE      GOTC
         LA       R2,1(R2)
         BCT      R3,LOOP
*
GOTC     O        R3,=X'40000000' PAD IS BLANK, DON'T CHANGE LENGTH
*
         LM       R4,R5,=A(PLINE+7,12)
         MVCL     R4,R2      MOVE AND PAD WITH BLANKS
*
         XPRNT    PLINE,19
```

Execution of the CLCL instruction is similar to that of the MVCL instruction except that, with the CLCL instruction, a comparison rather than a movement of data is effected.

Execution of the instruction

CLCL r1,r2 (*Compare Logical Long*)

causes a comparison to be made between two fields in main storage. The addresses and lengths of these two fields are designated in the same manner as described for the MVCL instruction. If the fields are of unequal lengths, the pad character (represented by the leftmost byte of the odd register of the pair designated by r2) is used to extend the shorter field for purposes of comparison. (No area of storage is actually altered, but the comparison occurs as if the shorter field had been extended.) The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | The fields are equal. |
| 1 | The first field is low. |
| 2 | The first field is high. |
| 3 | — |

The comparison occurs from left to right, one byte at a time. When two bytes match, the address (even) registers are incremented by 1 and the count (odd) registers are decremented by 1. The only exception occurs when one of the two fields has been exhausted. In this case, the bytes in the remaining field are compared to the pad character, and only the registers corresponding to this field are altered. Thus, if the two fields mismatch, the contents of the even registers of each pair can be used to determine the point of difference. Unlike the MVCL, the first and second fields used by a CLCL may overlap.

The MVCL and CLCL are useful for moving or comparing fields when the lengths must be computed at execution time. It is occasionally necessary to perform other operations, such as packing a number or scanning with a TRT, when the length of a field cannot be determined until execution time. In such cases, an EX instruction should be used.

Execution of the instruction

```
EX      r,D(X,B)                    (Execute)
```

initiates the following sequence of events:

1. A copy of the instruction at D(X,B) is made.
2. An OR operation is performed with the second byte of this copy of the instruction and the rightmost byte of r as operands, and the result replaces the second byte of the copy of the instruction.
3. The copy of the instruction is then executed.

Neither the contents of r nor the original instruction at D(X,B) is altered. The instruction immediately following the EX instruction will be the next instruction executed, if the instruction at D(X,B) is not a branch instruction or if it is an unsuccessful branch. If the instruction at D(X,B) represents a successful branch, of course the branch is taken. The condition code is set by the instruction at D(X,B). In case r is R0, the OR operation is not performed (i.e., Step 2 is not performed).

Note that there is no restriction on the address D(X,B). The instruction referenced in an EX instruction may be located anywhere; however, it is common practice to place it with the constants at the end of the program.

The most common use of the EX instruction is to effectively insert a particular value into the second byte of the instruction it references. This is accomplished by inserting the value in the rightmost byte of the register used as the first operand of the EX instruction and then coding the referenced instruction so that the second byte of the corresponding encoded instruction contains 00. In cases where only one hexadecimal digit of the second byte is altered, only the corresponding hexadecimal digit in the referenced instruction must be 0.

To illustrate the EX, suppose that R2 contains the address of a number in zoned (or character) format and R3 contains the length of the number. Then, the following code can be used to pack the number into DWORD:

```
         SH      R3,=H'1'        R3 NOW HAS LENGTH CODE
*                                FOR THE FIELD
         BM      ERR             BRANCH IF LENGTH WAS 0 (OR
*                                LESS)
         EX      R3,PACKIT       PACK THE FIELD
         .
         .
         .
DWORD    DS      D
PACKIT   PACK    DWORD,0(0,R2)   0 LENGTH GENERATES
*                                0 LENGTH CODE
```

In the following sections of the text, further uses of the MVCL, CLCL, and EX will be presented.

**Exercises**

**1.** Give the instructions required to compare two strings, which are not necessarily of the same length. If they are not of the same length, they are to be treated as if they were padded on the right with blanks. To be specific, suppose you have the following fields to work with:

```
S1      DS      A     ADDRESS OF FIRST STRING
LEN1    DS      H     CONTAINS LENGTH OF FIRST
*                     STRING
S2      DS      A     ADDRESS OF SECOND STRING
LEN2    DS      H     LENGTH OF SECOND STRING
```

Cause a branch to HI if the first string is high, to LOW if it is low, and to EQ if they are identical.

**2.** Suppose that R4 contains a branch mask in its rightmost 4 bits (and zeroes elsewhere). If you wanted to cause a branch to GO if the CC was set to a value that matched a bit in the branch mask, how would you achieve that goal?

## 8.7 THE TR INSTRUCTION

Occasionally it is necessary to translate the values that occur in the bytes of a given field. This translating amounts to replacing each value with a corresponding value as indicated in some fixed correspondence. As an example, suppose that a field contains the representation of a character string

that is printable except that some of the alphabetic characters in the string are encoded in their lowercase representation. Since many printers do not have the capability of printing lowercase letters, it may be necessary to translate the string before printing it. The following correspondence table should be used for this translation:

| | | | | | |
|---|---|---|---|---|---|
| original | 00 01 02...80 | 81 82...89 | 8A 8B...90 | 91 92...99 | |
| replacement | 00 01 02...80 | *C1 C2...C9* | 8A 8B...90 | *D1 D2...D9* | |
| | 9A 9B...A1 | A2 A3...A9 | AA AB...FF | | |
| | 9A 9B...A1 | *E2 E3...E9* | AA AB...FF | | |

The italicized sections in the illustration represent the new values with which the lowercase alphabetic character representations are to be replaced. Thus, the string C140A2A3899587 would be converted to C140E2E3C9D5C7, using the values specified in the table.

From this discussion, it should be clear that the result of translating a string is dependent upon the correspondence table used in the translation process. A correspondence table that is to be used in a translation is represented in storage by a translate table. A *translate table* is a 256-byte area in storage such that, if ff is the replacement value for aa in the represented correspondence table, then ff is the value in the byte with a displacement of aa from the beginning of the table. Thus,

| | |
|---|---|
| table + 00 | contains the replacement for 00 |
| table + 01 | contains the replacement for 01 |
| | . |
| | . |
| | . |
| table + FE | contains the replacement for FE |
| table + FF | contains the replacement for FF |

As an illustration, the following definition of TRANTAB generates the translate table for the specific correspondence table discussed above:

```
TRANTAB   DC   X'000102030405060708090A0B0C0D0E0F'
          DC   X'101112131415161718191A1B1C1D1E1F'
          DC   X'20...
          DC   X'30...
          DC   X'40...
          DC   X'50...
          DC   X'60...
          DC   X'70...
          DC   X'80C1C2C3C4C5C6C7C8C98A8B8C8D8E8F'
          DC   X'90D1D2D3D4D5D6D7D8D99A9B9C9D9E9F'
          DC   X'A0A1E2E3E4E5E6E7E8E9AAABACADAEAF'
          DC   X'B0...
```

```
DC    X'C0...
DC    X'D0...
DC    X'E0...
DC    X'F0...
```

The TR instruction, which is used to bring about the translation of a string, has the following format:

TR $D_1(L,B_1),D_2(B_2)$ (*Translate*)

Execution of the instruction causes the field of length L at the address $D_1(B_1)$ to be translated using the translate table at the address $D_2(B_2)$. The condition code is not altered.

Thus, execution of the instruction

```
TR        STRING(40),TRANTAB
```

causes the 40 bytes of the field STRING to be altered according to the correspondence table represented by TRANTAB.

The internal subroutine presented in Program 8-3 illustrates an unusual but helpful use of the TR instruction. This subroutine can be used to convert the contents of R1 into a string that may be utilized in printing the actual hexadecimal representation of those contents. For example, if R1 contained FFFFFF1A, a call to HEXDUMP would produce C6C6C6C6C6C6F1C1. Note that the first 240 bytes of TRANTAB in the example may contain any values whatever, since every character to be translated will have F as a zone digit. Therefore, the following TR instruction and definition of TRANTAB are equivalent to those in the example:

```
         TR        DUMMY(8),TRANTAB-C'0'
                   .
                   .
                   .
TRANTAB  DC        C'0123456789ABCDEF'
```

In this case, the original value of a byte in DUMMY is added to the value in TRANTAB – C'0', which always points at the desired replacement character from TRANTAB. Study this example carefully. Although the routine is short, its unusual elegance is attained through the use of several nonobvious techniques. Note that the address TRANTAB – C'0' must occur within the same CSECT as TRANTAB, or else an error will be detected by the assembler.

**Program 8-3**

```
         TITLE 'HEX DUMP ROUTINE'
* THE FOLLOWING ROUTINE CONVERTS THE CONTENTS OF R1 TO THE REQUIRED
* 8-CHARACTER PRINTABLE FORM.  THE RESULT IS PUT TO THE ADDRESS IN R2.
```

**Program 8-3 (continued)**

```
* R10 IS ASSUMED TO CONTAIN THE RETURN ADDRESS.  NO REGISTERS ARE AL-
* TERED BY THE ROUTINE.  THE LOGIC OF THE ROUTINE IS:
*
*        STEP 1.  STORE R1 INTO FWORD.
*
*        STEP 2.  UNPACK FWORD(5) INTO DUMMY(9).  THIS LEAVES THE HEX
*                 DIGITS FROM R1 IN THE NUMERIC HEX DIGITS OF THE 1ST 8
*                 BYTES OF DUMMY.  THE ZONE DIGITS FOR THESE 8 BYTES
*                 ARE ALL F.  THIS MEANS THAT THE DIGITS OF R1 HAVE ALL
*                 BEEN SPLIT INTO SEPARATE BYTES EACH WITH AN F AS THE
*                 ZONE DIGIT.  THUS, 0-9 ARE ALREADY IN PRINTABLE FORM.
*                 A-F ARE, HOWEVER, IN THE FORM FA, FB, FC, FD, FE, AND
*                 FF.
*
*        STEP 3.  TRANSLATE THE 1ST 8 BYTES OF DUMMY.  LET F0, F1, ...
*                 F9 BE TRANSLATED INTO THEMSELVES, AND LET FA, FB, FC,
*                 FD, FE, FF BE TRANSLATED INTO C1, C2, C3, C4, C5, AND
*                 C6, RESPECTIVELY.
*
*        STEP 4.  MOVE THE RESULT FROM DUMMY TO THE AREA INDICATED
*                 BY R2.
*                 EXIT BACK THRU R10.
         SPACE 3

***<STEP 1>     STORE INPUT REG INTO FWORD.
HEXDUMP  ST     R1,FWORD
***<STEP 2>     UNPACK TO ADD F ZONE DIGITS.
         UNPK   DUMMY(9),FWORD(5)  THE RIGHT BYTE IS GARBAGE IN BOTH
*                                  FWORD AND DUMMY
***<STEP 3>     TRANSLATE TO CORRECT THE ALPHABETIC DIGITS.
         TR     DUMMY(8),TRANTAB
***<STEP 4>     MOVE TO CALLER'S AREA.
         MVC    0(8,R2),DUMMY
         BR     R10                EXIT
         SPACE
FWORD    DS     F,CL1              1 WORD + 1 BYTE OF GARBAGE
DUMMY    DS     CL9
TRANTAB  DS     CL(X'F0')          THESE ARE NEVER USED
         DC     C'0123456789ABCDEF'
****** END OF HEX DUMP ROUTINE **********
```

## 8.8 THE TRT INSTRUCTION

The TRT instruction (Translate and Test) can be used to locate the first occurrence of a character in a string that is a member of a specified set of characters. The TRT instruction, like the TR instruction, employs a translate table. However, unlike the TR instruction, execution of the TRT instruction does not alter the string of characters specified by its first operand. The format for the TRT instruction is

$$\text{TRT} \quad D_1(L,B_1),D_2(B_2) \qquad (\textit{Translate and Test})$$

The first operand of this instruction specifies the address and length of the field to be scanned, and the second operand specifies the address of a translate table. Execution of this instruction causes each byte of the designated

field to be scanned until a character is found corresponding to a value in the translate table that is not 00. If no such character is found, the condition code is set to 0. If a character corresponding to a nonzero entry in the translate table is encountered, the scan terminates and the following events occur:

1. The address of the detected character is placed in the rightmost bytes (bits 8–31) of R1. Bits 0–7 of R1 are unaltered.
2. The corresponding nonzero entry from the translate table is inserted in the rightmost byte of R2. Bits 0–23 of R2 are unaltered.
3. The condition code is set to 2 if the detected character is in the rightmost byte in the scanned field; otherwise, it is set to 1.

The following examples should help to clarify the use of the TRT instruction:

- *Example 1.* Suppose that the address of the first nonblank character in an 80-byte field called CARD is to be found. Execution of the instructions

```
         TRT   CARD(80),SCANTABL
         BC    B'1000',ALLBLANK
         .
         .
         .
SCANTABL DC    64X'FF'
         DC    X'00'
         DC    191X'FF'
```

will cause the address of the byte in question to be inserted into the rightmost three bytes of R1, and the rightmost byte of R2 will be set to FF. If every byte in CARD represents a blank, the branch to ALLBLANK is taken and neither R1 nor R2 is altered.

The ORG instruction was introduced in Section 4.6. It can be used when generating a translate table to clarify exactly which entries are being set. For example, the previous table could be generated as follows:

```
SCANTABL DC    256X'FF'
         ORG   SCANTABL+C' '
         DC    X'00'              SKIP BLANKS
         ORG
```

- *Example 2.* Suppose that the first blank character, rather than the first nonblank character, in CARD is to be found. Then, the following code could be used:

```
            TRT     CARD(80),SCANTABL
            BC      B'1000',NOBLANKS
            .
            .
SCANTABL    DC      256X'00'
            ORG     SCANTABL+C' '        ORG TO ENTRY FOR BLANK
            DC      X'FF'                STOP ON BLANKS
            ORG
```

- *Example 3.* If the first occurrence of either a numeric digit or an alphabetic letter in a field called STRING is to be found, the following code could be used:

```
            SR      R2,R2                CLEAR R2
            TRT     STRING,TRANTAB
            B       BRANCHES(R2)
BRANCHES    B       NONEFND
            B       ALPHA
            B       NUMERIC
            .
            .
            .
TRANTAB     DC      256X'00'
            ORG     TRANTAB+C'A'         ALPHAS GET X'04'
            DC      9X'04'               A-I
            ORG     TRANTAB+C'J'
            DC      9X'04'               J-R
            ORG     TRANTAB+C'S'
            DC      8X'04'               S-Z
            ORG     TRANTAB+C'0'
            DC      10X'08'              NUMERICS GET X'08'
            ORG
```

In this case, a branch to NONEFND will occur if no alphabetic or numeric characters are found; a branch to ALPHA will occur if an alphabetic character is detected; and a branch to NUMERIC will occur if a numeric digit is detected. Note in particular the use of R2 as an index into the table of branch instructions.

- *Example 4.* Suppose that the address of the first occurrence of '$' in the field beginning at the address in R3 is to be found. Suppose further that the maximum number of bytes to be searched is represented by the value in R4. The desired result may be achieved through the use of an EX

instruction to insert the length code (length-1) into the second byte of a TRT instruction as follows:

```
         BCTR   R4,0                  R4 <- LENGTH CODE
         EX     R4,SCAN
         BC     B'1000',NONEFND
         .
         .
SCAN     TRT    0(0,R3),TABLE
TABLE    DC     256X'00'
         ORG    TABLE+C'$'
         DC     X'FF'                 SCAN FOR $
         ORG
```

An understanding of these examples should make the details of the external subroutine presented in Program 8-4 easy to follow. This subroutine, although reasonably short, illustrates the concepts presented in this section quite well and should be studied carefully.

**Program 8-4**

```
        TITLE 'GETNUM - EXTRACT A NUMBER FROM A FIELD'
*****************************************************************
*
* THE FOLLOWING SUBROUTINE CAN BE INVOKED TO CONVERT A ZONED
* DECIMAL NUMBER IN A FIELD (WITH POSSIBLE LEADING BLANKS,
* TRAILING BLANKS, AND SIGN) TO BINARY.  THE PARAMETER LIST IS AS
* FOLLOWS:
*
*       ADDRESS OF THE FIELD CONTAINING THE NUMBER
*       ADDRESS OF THE LENGTH OF THE FIELD
*
* IF THE CONVERSION IS SUCCESSFUL, R15 WILL BE SET TO 0, R0 WILL
* CONTAIN THE VALUE IN BINARY, AND R1 WILL POINT JUST PAST THE
* END OF THE NUMBER; ELSE, R15 WILL BE SET TO 4.
* NOTE THAT INVALID CHARACTERS THAT OCCUR BEFORE THE FIRST CHARACTER
* OF THE NUMBER  OR AFTER THE LAST DIGIT ARE IGNORED.
* THE LOGIC IS AS FOLLOWS:
*
*  STEP 1.  IF THE LENGTH IS POSITIVE, GO TO STEP 3.
*
*  STEP 2.  SET A FAILURE RETURN-CODE (4) AND GO TO STEP 13.
*
*  STEP 3.  SET A DEFAULT SIGN TO 'F' AND SCAN FOR THE FIRST
*           SIGN OR NUMERIC DIGIT IN THE FIELD.
*
*  STEP 4.  IF NO SIGN OR DIGIT IS FOUND, GO TO STEP 5.  ELSE,
*           YOU HAVE 3 CASES (+, -, OR DIGIT).  IF A
```

**Program 8-4 (continued)**

```
*           PLUS SIGN IS FOUND, GO TO STEP 6.  IF A MINUS SIGN
*           IS FOUND, GO TO STEP 7.  IF A NUMERIC DIGIT IS FOUND,
*           GO TO STEP 8.
*
*   STEP 5. SET A FAILURE RETURN-CODE (4) AND GO TO STEP 13.
*
*   STEP 6. INCREMENT THE SCAN POINTER PAST THE PLUS SIGN AND GO
*           TO STEP 8.
*
*   STEP 7. SET THE SIGN TO 'D' (MINUS), AND INCREMENT THE POINTER
*           PAST THE SIGN.
*
*   STEP 8. IF THE SCAN POINTER IS STILL WITHIN THE FIELD (IT
*           SHOULD POINT AT THE FIRST NUMERIC DIGIT), GO TO STEP 10.
*
*   STEP 9. SET A FAILURE RETURN-CODE (4) AND GO TO STEP 13.
*
*   STEP 10. SCAN FOR THE END OF THE STRING OF NUMERIC DIGITS.
*           IF THERE IS AT LEAST 1 DIGIT, GO TO STEP 12.
*
*   STEP 11. SET A FAILURE RETURN-CODE (4) AND GO TO STEP 13.
*
*   STEP 12. CONVERT THE NUMBER TO BINARY AND SET THE RETURN-CODE
*           TO SUCCESS (0).
*
*   STEP 13. EXIT.
*
*******************************************************************
*
GETNUM   CSECT
         STM   R14,R12,12(R13)    SAVE CALLER'S REGISTERS
         BALR  R12,0
         USING BASEPT,R12
BASEPT   DS    OH
         LA    R14,SAVEAREA
         ST    R14,8(R13)
         ST    R13,4(R14)
         LR    R13,R14
*
         LM    R3,R4,0(R1)        R3 <- A(FIELD)
*                                 R4 <- A(LENGTH)
         L     R4,0(R4)           R4 <- LENGTH
*
***<STEP 1>    CHECK FOR INVALID LENGTH (R4 IS SET TO LENGTH CODE)
*
         SH    R4,=H'1'
         BNM   SCAN
*
***<STEP 2>    SET FAILURE RC AND EXIT
*
         LA    R15,4
         B     EXIT
*
```

**Program 8-4 (continued)**

```
***<STEP 3>    SCAN FOR SIGN OR NUMERIC DIGIT
*
SCAN     MVI   SIGN,X'0F'          DEFAULT SIGN IS POSITIVE
         SR    R1,R1
         SR    R2,R2
         EX    R4,SCANTRT          SCAN FOR SIGN OR DIGIT
*
***<STEP 4>    CHECK FOR NO SIGN OR DIGITS.
*
         BC    B'0110',BRANCHTB-4(R2)  GO TO CASE STRUCTURE IF HIT
*
*
***<STEP 5>    SET FAILURE RC AND EXIT
*
         LA    R15,4               SET FAILURE RC
         B     EXIT
*
BRANCHTB B     PLUSSIGN            IF CODE IN TABLE IS 4
         B     NEGSIGN             IF CODE IN TABLE IS 8
         B     PASTSIGN            IF CODE IN TABLE IS C (DIGIT)
*
***<STEP 6>    INCREMENT SCAN POINTER PAST +
*
PLUSSIGN LA    R1,1(R1)
         B     PASTSIGN
*
***<STEP 7>    SET MINUS SIGN AND INCREMENT SCAN POINTER
*
NEGSIGN  MVI   SIGN,X'0D'
         LA    R1,1(R1)
*
***<STEP 8>    CHECK TO MAKE SURE SCAN POINTER IS WITHIN FIELD
*
PASTSIGN LR    R5,R1               SAVE START OF DIGITS
         AR    R4,R3               R4 <- A(LAST BYTE IN FIELD)
         SR    R4,R1
         BNM   GETEND              BRANCH IF POINTER IS OK
*
***<STEP 9>    SET FAILURE RC AND EXIT
*
         LA    R15,4
         B     EXIT
*
***<STEP 10>   SCAN FOR END OF STRING OF DIGITS
*
GETEND   LA    R1,1(R4,R1)         POINT R1 JUST PAST FIELD
         EX    R4,SCANEND          SCAN FOR FIRST CHAR PAST STRING
         SR    R1,R5               R1 <- # DIGITS IN STRING
         SH    R1,=H'1'            GET LENGTH - 1
         BNM   CONVERT             BRANCH IF THERE WERE DIGITS
*
***<STEP 11>   SET FAILURE RC AND EXIT
*
```

**Program 8-4 (continued)**

```
         LA    R15,4
         B     EXIT
*
***<STEP 12>   CONVERT THE NUMBER TO BINARY
*
CONVERT  EX    R1,PACKNUM          PACK THE NUMBER
         NI    DWORD+7,X'F0'       SET THE SIGN
         OC    DWORD+7(1),SIGN
         CVB   R0,DWORD            R0 HAS THE VALUE
         LA    R1,1(R1,R5)         R1 POINTS JUST PAST THE FIELD
         SR    R15,R15             SET SUCCESS RETURN-CODE
*
***<STEP 13>   EXIT
*
EXIT     L     R13,4(R13)
         L     R14,12(R13)
         LM    R2,R12,28(R13)      R15, R0, & R1 KEEP THEIR VALUES
         BR    R14
*
SCANTRT  TRT   0(0,R3),TABNUM      SCAN FOR DIGIT OR SIGN
SCANEND  TRT   0(0,R5),TABEND      SCAN FOR THE FIRST NONDIGIT
PACKNUM  PACK  DWORD,0(0,R5)
*
         LTORG
*
SIGN     DS    C                   RIGHT HEX DIGIT IS SET TO SIGN
DWORD    DS    D                   FOR CONVERSION
SAVEAREA DS    18F
*
TABNUM   DC    256X'00'
         ORG   TABNUM+C'+'
         DC    X'04'
         ORG   TABNUM+C'-'
         DC    X'08'
         ORG   TABNUM+C'0'
         DC    10X'0C'
         ORG
TABEND   DC    256X'FF'
         ORG   TABEND+C'0'
         DC    10X'00'             SKIP DIGITS
         ORG
*
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
```

**Program 8-4 (continued)**

```
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
         END
```

## Exercises

Consider the problem of "reversing the characters in a string." Construct an instruction sequence that will convert a string like

ABCDEFGHIJKLMNOP
to PONMLKJIHGFEDCBA

It is fairly easy to build a little loop to do this, However, it can be done without using a loop. Can you figure out how?

## 8.9 THE CLM, ICM, AND STCM INSTRUCTIONS

The instructions presented in this section are not available on IBM 360 computers. They first appeared on the IBM 370s and have been a standard part of the instruction set since that time.

The CLM, ICM, and STCM are RS instructions. Each of these instructions involves an operation between two fields, the first of which is composed of selected bytes from a register and the second of which is a sequence of contiguous bytes in storage. The selection of bytes from the register is, in each case, governed by a four-bit mask. The bits in the mask correspond one-to-one with the bytes in the register. The bits in the mask that have a value of 1 designate the bytes in the register that make up the first field. As an example, execution of the instruction

```
CLM      R2,B'0110',KEY
```

causes a comparison to be made between the middle two bytes in R2 and the first two bytes in the field KEY. Similarly, execution of the instruction

```
CLM      R2,B'1110',KEY
```

causes a comparison between the first three bytes of R2 and the leftmost three bytes of the field KEY. Detailed descriptions of the CLM, ICM, and STCM instructions follow.

Execution of the instruction

```
CLM     r,m,D(B)        (Compare Logical
                         Characters under Mask)
```

causes a logical comparison to be made between two fields. In a logical comparison, the contents of the fields involved are treated as unsigned binary integers. The first of the two fields participating in the comparison is designated by the first two operands:

- r specifies a register
- m is a mask designating which bytes in r are to be included in the field

The mask m should be an absolute expression that evaluates to a value in the range 0 to 15. The length of the fields to be compared is i, where i is the number of bits with a value of 1 in the binary representation of m. The field participating in the comparison is composed of i contiguous bytes starting at the address specified by D(B). The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Selected bytes are equal or the mask is 0. |
| 1 | First field is low. |
| 2 | First field is high. |
| 3 | — |

For purposes of illustration, suppose that R0 contains 00AC2B40 and FIELD contains 9F013C2F. The following table gives three CLM instructions and the CC settings that would result from the execution of each of these instructions:

| *Instruction* | *Length of Comparison* | *Resulting CC* |
|---|---|---|
| CLM R0,B'0000',FIELD | 0 | 0 |
| CLM R0,B'1010',FIELD | 2 | 1 |
| CLM R0,B'0111',FIELD | 3 | 2 |

In the second case, the condition code is set to 1, based on the comparison of 002B with 9F01. The condition code of 2 in the third case results from the comparison of AC2B40 with 9F013C. The first case has a condition code setting of 0, because the mask is 0.

The ICM and STCM instructions are generalized versions of the IC and STC instructions. While an IC or STC instruction can be used to transfer a single byte, an ICM or STCM instruction can be used to transfer as many as four bytes under the control of a mask.

Execution of the instruction

| | | |
|---|---|---|
| ICM | r,m,D(B) | (*Insert Character under Mask*) |

causes zero to four bytes in main storage at the address specified by D(B) to be inserted in the register r. The four bits in the binary representation of m determine which bytes of r are to be altered. The bytes of r that correspond to bits in m with a value of 1 receive the bytes from main storage. The insertion is made from left to right. The condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | All inserted bytes were 00 or the mask was 0. |
| 1 | The leftmost bit of the leftmost inserted byte was 1. |
| 2 | The leftmost bit of the leftmost inserted byte was 0 (but not all bits of the inserted bytes were 0). |
| 3 | — |

Note that execution of the instruction

```
ICM     r,B'1111',addr
```

has an effect similar to that produced by the execution of a Load instruction. However, in the case of the ICM instruction, the four bytes transferred need not be on a fullword boundary and the condition code is set.

Execution of the instruction

| | | |
|---|---|---|
| STCM | r,m,D(B) | (*Store Characters under Mask*) |

will cause the bytes in the register r designated by the mask m to be stored in contiguous bytes of main storage, beginning at the address specified by D(B). The condition code is unaltered.

Program 8-5 illustrates the instructions covered in this section, as well as those covered previously in this chapter.

**Program 8-5**

```
         TITLE 'GETWORDS - A SUBROUTINE TO EXTRACT CHARACTER VALUES'
*****************************************************************
*
* THE PURPOSE OF THIS SUBROUTINE IS TO SCAN A STRING FOR SUBSTRINGS
* OF THE FORM
*
*   <KEYWORD>=<VALUE>
*
* WHERE <KEYWORD> CAN BE ANY WORD IN A TABLE DEFINING THE VALID
*                 KEYWORDS, AND
*
*       <VALUE>   IS A CHARACTER STRING THAT IS DELIMITED BY A BLANK
*                 OR THE END OF THE STRING BEING SCANNED.
*
* GETWORDS MUST LOCATE THESE STRINGS (WHICH MUST BE SEPARATED BY
* BLANKS).  FOR EACH SUCH STRING THE <VALUE> MUST BE MOVED INTO
* A RECEIVING FIELD, WHICH IS SPECIFIED IN THE SAME TABLE THAT
* DEFINES THE VALID KEYWORDS.  EACH ENTRY IN THE TABLE DEFINES
* A SINGLE KEYWORD AND THE FIELD THAT IS ASSIGNED THE <VALUE>
* FOR THAT KEYWORD.  THE FORMAT OF AN ENTRY IN THE KEYWORD
* TABLE IS DEFINED BY THE FOLLOWING DSECT:
*
TABENT   DSECT
KEYWORD  DS    CL10                A KEYWORD (LEFT JUSTIFIED)
RECEIVE  DS    AL3                 ADDRESS OF THE RECEIVING FIELD
MAXLEN   DS    XL1                 MAX. ALLOWABLE LENGTH OF THE VALUE
MINLEN   DS    XL1                 MIN. ALLOWABLE LENGTH OF THE VALUE
NEXTENT  DS    OX                  START OF THE NEXT ENTRY
*
* THUS, THE TABLE DEFINES THE VALID KEYWORDS AND WHERE THE VALUES
* ARE TO BE STORED.  THE ADDRESS OF THE TABLE IS PASSED AS A
* PARAMETER TO GETWORDS.  THE FORMAT OF THE RECEIVING FIELD IS
* DESCRIBED BY THE FOLLOWING DSECT:
*
RECEIVER DSECT
LENGTH   DS    XL2                 LENGTH OF THE VALUE
VALUE    DS    OC                  THE VALUE BEGINS HERE
*
* THE FORMAT OF THE PARAMETER LIST PASSED TO GETWORDS IS DESCRIBED
* BY THE FOLLOWING DSECT:
*
PARMS    DSECT
STRINGAD DS    A                   ADDRESS OF THE STRING TO SCAN
STRNGLEN DS    A                   ADDRESS OF A HALFWORD CONTAINING
*                                  THE LENGTH OF THE STRING
TABLADDR DS    A                   ADDRESS OF THE FIRST ENTRY IN THE
*                                  KEYWORD TABLE
NUMENT   DS    A                   ADDRESS OF A HALFWORD CONTAINING
*                                  THE NUMBER OF ENTRIES IN THE TABLE
*
* R15 IS SET BY GETWORDS TO REFLECT SUCCESS OR FAILURE.  IF NO
* ERRORS ARE DETECTED, R15 WILL BE SET TO 0.  ELSE, IT WILL BE
* SET TO 4.  NOTE THAT THE ROUTINE STOPS SCANNING IF AN ERROR
* IS DETECTED.  IF AN ERROR IS DETECTED, R1 WILL POINT TO THE
* ERROR (AS CLOSE AS GETWORDS CAN DETERMINE).
*
*
```

**Program 8-5 (continued)**

```
* THE LOGIC OF GETWORDS IS AS FOLLOWS:
*
*   STEP 1.  SET THE RETURN CODE (R15) TO 0, AND R1 TO POINT AT THE
*            START OF THE STRING.
*
*   STEP 2.  IF AN ERROR HAS BEEN DETECTED, IF THERE ARE NO MORE
*            CHARACTERS LEFT TO SCAN IN THE INPUT STRING, OR IF
*            THE REMAINING CHARACTERS ARE ALL BLANKS, GO TO STEP 21.
*
*   STEP 3.  FIND THE FIRST NONBLANK CHARACTER.  IF IT OCCURS BEFORE
*            THE LAST CHARACTER IN THE STRING, GO TO STEP 5.
*
*   STEP 4.  SET R15 TO 4 (ERROR) AND LEAVE R1 POINTING TO THE LAST
*            CHARACTER IN THE STRING.  GO TO STEP 2.
*
*   STEP 5.  FIND THE FIRST '=' OR ' ' THAT OCCURS AFTER THE 1ST
*            CHARACTER IN THE WORD.  IF A BLANK OR '=' CAN BE FOUND,
*            GO TO STEP 7.
*
*   STEP 6.  SET R15 TO 4 (ERROR), SINCE THE = COULDN'T BE FOUND.
*            LEAVE R1 POINTING TO THE FIRST CHARACTER OF THE WORD,
*            AND GO TO STEP 2.
*
*   STEP 7.  IF THE CHARACTER FOUND WAS AN '=', GO TO STEP 9.
*
*   STEP 8.  SET R15 TO 4 (ERROR), SINCE THE = WAS MISSING.  LEAVE
*            R1 POINTING TO THE 1ST CHARACTER OF THE WORD, AND
*            GO TO STEP 2.
*
*   STEP 9.  INITIALIZE TO START COMPARING THE ISOLATED WORD AGAINST
*            ENTRIES IN THE KEYWORD TABLE.
*
*   STEP 10. IF YOU'VE LOOKED AT ALL THE ENTRIES, OR IF YOU'VE FOUND
*            THE ONE THAT MATCHES, GO TO STEP 12.
*
*   STEP 11. SET UP TO LOOK AT THE NEXT TABLE ENTRY AND GO BACK TO
*            STEP 10.
*
*   STEP 12. IF YOU FOUND A MATCHING ENTRY, GO TO STEP 14.
*
*   STEP 13. SET R15 TO 4 (ERROR) AND LEAVE R1 POINTING AT THE
*            '='.  GO TO STEP 2.
*
*   STEP 14. IF THE '=' DID NOT OCCUR IN THE LAST CHARACTER OF THE
*            STRING, GO TO STEP 16.
*
*   STEP 15. SET THE START-OF-VALUE AND PAST-VALUE POINTERS TO THE
*            FIRST CHARACTER PAST THE END OF THE STRING.  THIS WILL
*            INDICATE A NULL VALUE (WHICH MAY OR MAY NOT BE OK).  GO
*            TO STEP 18.
```

**Program 8-5 (continued)**

```
*
*   STEP 16. SEARCH FOR THE FIRST BLANK PAST THE '='.  IF ONE OCCURS,
*            SET THE PAST-VALUE POINTER TO IT AND GO TO STEP 18.
*
*   STEP 17. SET THE PAST-VALUE POINTER JUST PAST THE END OF THE
*            STRING.
*
*   STEP 18. CALCULATE THE LENGTH OF THE VALUE.  IF IT FALLS WITHIN
*            THE VALUES SPECIFIED IN THE KEYWORD TABLE, GO TO
*            STEP 20.
*
*   STEP 19. SET R15 TO 4 (ERROR) AND LEAVE R1 POINTING JUST PAST THE
*            VALUE.  GO TO STEP 2.
*
*   STEP 20. MOVE THE VALUE TO THE RECEIVING FIELD AND GO TO STEP 2.
*
*   STEP 21. RETURN TO THE CALLER.
*
*******************************************************************
*
GETWORDS CSECT
         STM   R14,R12,12(R13)    SAVE CALLER'S REGISTERS
         BALR  R12,0
         USING BASEPT,R12
BASEPT   DS    0H
*
         LR    R5,R1              SAVE ADDRESS OF INPUT PARAMETERS
         USING PARMS,R5
*
***<STEP 1>    INITIALIZE R15 TO 0, R1 TO START SCAN, AND R4 = LEN-1.
*
         SR    R15,R15            RC <- 0 (UNTIL WE FIND AN ERROR)
         L     R1,STRINGAD        R1 <- ADDRESS OF STRING TO SCAN
         L     R4,STRNGLEN
         LH    R4,0(R4)           R4 <- LENGTH OF STRING TO SCAN
         BCTR  R4,0               R4 <- LENGTH - 1 (LENGTH CODE)
*
***<STEP 2>    TEST FOR ERROR, END OF STRING, OR ONLY BLANKS LEFT
*
TESTEND  LTR   R15,R15            TEST FOR ERROR
         BNZ   DONE
*
         LTR   R4,R4              TEST FOR END OF STRING
         BM    DONE
*
         LR    R0,R1              SAVE ADDRESS OF START OF SCAN
         EX    R4,FINDWORD        TRT FOR THE START OF THE WORD
         BC    B'1000',DONE       BRANCH IF ONLY BLANKS LEFT
```

**Program 8-5 (continued)**

```
*
***<STEP 3>    IF THE HIT OCCURRED BEFORE THE LAST CHAR, GO TO STEP 5.
*
         BCTR  R4,0
         AR    R4,RO
         SR    R4,R1              R4 NOW HAS THE LENGTH-1 OF WHAT
*                                 REMAINS
         BNM   FNDEQ
*
***<STEP 4>    SET R15 TO 4 AND GO BACK TO STEP 2.
*
         LA    R15,4
         B     TESTEND
*
***<STEP 5>    SCAN FOR THE FIRST '=' OR ' '.  IF FOUND, GO TO STEP 7.
*
FNDEQ    LR    RO,R1              SAVE ADDRESS OF START OF WORD
         EX    R4,EQORBLNK        SCAN FOR '=' OR ' '
         BC    B'0111',GOTCHR     BRANCH IF YOU GOT ONE
*
***<STEP 6>    SET ERROR (NO =) AND GO BACK TO STEP 2.
*
         LA    R15,4
         B     TESTEND
*
***<STEP 7>    IF IT WAS AN '=', GO TO STEP 9.
*
GOTCHR   CLI   O(R1),C'='
         BE    GOTEQ
*
***<STEP 8>    SET R15 TO 4 (MISSING =) AND GO TO STEP 2.
*
         LA    R15,4
         B     TESTEND
*
***<STEP 9>    SET UP TO SEARCH THE KEYWORD TABLE.
*
GOTEQ    SR    R1,RO
         ICM   R1,B'1000',=C' '   R1 HAS BLANK AT LEFT, LENGTH
*                                 OF THE KEYWORD IN RIGHT BYTE
         STM   RO,R1,COMPREGS     SAVE FOR REPEATED COMPARES
         L     R6,TABLADDR        R6 <- ADDRESS OF FIRST ENTRY
         USING TABENT,R6
         L     R8,NUMENT
         LH    R8,0(R8)           R8 <- NUMBER OF ENTRIES
*
```

**Program 8-5 (continued)**

```
***<STEP 10>   IF YOU'VE RUN PAST THE END OR MATCHED, GO TO STEP 12.
*
LOOKUP   SH    R8,=H'1'            DECREMENT COUNT OF ENTRIES LEFT
         BM    EXLOOP              EXIT IF PAST THE END
         LM    R0,R3,COMPREGS      SET UP REGS TO COMPARE
         LR    R2,R6               R2 <- ADDRESS OF KEYWORD
         CLCL  R2,R0               COMPARE SCANNED WORD AGAINST KEYWORD
         BE    EXLOOP              EXIT ON MATCH
*
***<STEP 11>   POINT TO THE NEXT ENTRY AND GO BACK TO STEP 10.
*
         LA    R6,NEXTENT
         B     LOOKUP
*
***<STEP 12>   IF A MATCH OCCURRED, GO TO STEP 14.
*
EXLOOP   LTR   R8,R8
         BNM   GOTENT              BRANCH IF MATCH OCCURRED
*
***<STEP 13>   SET R15 TO 4 (INVALID WORD) AND GO TO STEP 2.
*
         L     R1,COMPREGS
         LA    R15,4
         B     TESTEND
*
***<STEP 14>   IF '=' WASN'T LAST CHARACTER, GO TO STEP 16.
*
GOTENT   LR    R1,R0
         LA    R0,1(R1)            R0 <- A(1ST CHAR PAST =)
         SH    R4,COMPREGS+6       DECREMENT BY LENGTH OF THE WORD
         BNM   FINDEND
*
***<STEP 15>   SET BOTH R1 AND R0 TO JUST PAST END.  GO TO STEP 18.
*
         LR    R1,R0
         B     CHKLEN
*
***<STEP 16>   FIND THE FIRST BLANK PAST =.  IF FOUND, GO TO STEP 18.
*
FINDEND  EX    R4,EQORBLNK         SCAN FOR AN = OR BLANK
         BC    B'1000',PASTEND     BRANCH IF NONE
         CLI   0(R1),C' '          WE'RE LOOKING FOR A BLANK
         BNE   FINDEND
         B     CHKLEN
*
***<STEP 17>   SET R1 TO POINT JUST PAST THE END OF THE STRING
*
PASTEND  LA    R1,2(R4,R1)         POINT R1 PAST STRING
*
```

**Program 8-5 (continued)**

```
***<STEP 18>   IF LENGTH OF VALUE IS OK, GO TO STEP 20.
*
CHKLEN   SR     R1,RO
         CLM    R1,B'0001',MAXLEN
         BH     BADLEN              BRANCH IF VALUE IS TOO LONG
         CLM    R1,B'0001',MINLEN
         BNL    VALOK
*
***<STEP 19>   SET R15 TO 4 (BAD VALUE) AND GO TO STEP 2.
*
BADLEN   LR     R1,RO               POINT R1 AT START OF VALUE
         LA     R15,4
         B      TESTEND
*
***<STEP 20>   MOVE VALUE TO RECEIVING FIELD AND GO TO STEP 2.
*
VALOK    SR     R4,R1               R4 STILL HAS LEN-1 OF REST
         ICM    R10,B'0111',RECEIVE
         USING  RECEIVER,R10
         STCM   R1,B'0011',LENGTH
         LA     R10,VALUE
         DROP   R10
         LR     R11,R1              R11 NOW HAS LENGTH OF VALUE
         MVCL   R10,RO
         LR     R1,RO               R1 POINTS TO NEXT CHAR TO SCAN
         B      TESTEND
*
***<STEP 21>   EXIT
*
DONE     L      R14,12(R13)
         L      RO,20(R13)
         LM     R2,R12,28(R13)
         BR     R14                 R1 AND R15 ARE RETURNED TO CALLER
*
         LTORG
*
FINDWORD TRT    O(O,R1),STARTAB     SCAN FOR START OF KEYWORD
EQORBLNK TRT    1(O,R1),GETDELIM    SCAN FOR BLANK OR =
*
COMPREGS DS     2F
         DC     A(O,10)
*
STARTAB  DC     256X'FF'            STOP ON ANYTHING BUT A BLANK
         ORG    STARTAB+C' '
         DC     X'00'
         ORG
*
GETDELIM DC     256X'00'            STOP ON ONLY BLANK OR =
         ORG    GETDELIM+C' '
         DC     X'FF'
         ORG    GETDELIM+C'='
         DC     X'FF'
         ORG
*
```

**Program 8-5 (continued)**

```
R0      EQU   0
R1      EQU   1
R2      EQU   2
R3      EQU   3
R4      EQU   4
R5      EQU   5
R6      EQU   6
R7      EQU   7
R8      EQU   8
R9      EQU   9
R10     EQU   10
R11     EQU   11
R12     EQU   12
R13     EQU   13
R14     EQU   14
R15     EQU   15
        END
```

### Exercises

Suppose that LITTLE is a 1-byte field that should be thought of as a number in two's-complement encoding. Give an instruction sequence that would load R8 with the value (i.e., the problem is to propagate the sign bit throughout the left three bytes of the register). This can be done in two instructions.

## 8.10 THE SPM INSTRUCTION

The reader has probably noted a certain ambiguity in the discussions concerning the effects of a fixed-point overflow condition. In particular, it was noted that an overflow may cause an error message to be generated and termination of the execution of the program to occur; however, it was also pointed out that an overflow does not necessarily have this effect. When does an overflow cause termination of the execution of a program? The answer is reasonably simple. Termination will occur if bit 36 of the Program Status Word (PSW) is 1; otherwise, execution of the program continues after the occurrence of overflow. Bit 36 is part of a segment of the PSW called the *program mask*. Bits 37–39, which form the remainder of the program mask, are used to determine what action is to be taken in other types of exceptional situations.

A natural question then is: "Can the program mask be altered?" The answer is yes. The SPM instruction is used for this purpose.

SPM r (*Set Program Mask*)

Execution of this instruction causes bits 34–39 of the current PSW to be replaced by a copy of bits 2–7 of r. Hence, the condition code as well as the program mask may be altered.

To understand the principal use of the SPM instruction, the reader should recall that execution of a BAL or BALR instruction causes a copy of the entire right half of the PSW to replace the contents of the link register. Hence, after execution of a BAL or BALR instruction, bits 2–7 of the link register contain a copy of the condition code and program mask (bits 34–39 of the PSW). Thus, if we assume that the contents of the link register have not been altered, the condition code and program mask may be restored to the values that they had before the execution of a particular BAL or BALR instruction; this restoration is done through an SPM instruction that has the link register as its operand.

A technique for altering the condition code and program mask and later restoring them to their original values can be outlined as follows:

1. Enter an instruction such as

   BALR R0,0

   in the program to save the program mask and CC.
2. Enter an SPM instruction to alter the CC and program mask to any desired value.
3. Where the original values of the CC and the program mask are to be restored, enter the instruction

   SPM R0

   (This, of course, assumes that the contents of R0 have not been altered.)

This technique is often used when common subroutines are employed. Use of this technique allows the subroutines to be invoked with an assurance that neither the condition code nor the program mask will be altered by the call.

## 8.11 THE MVN, MVZ, AND MVO INSTRUCTIONS

The SRP offers a convenient way to perform shifts on packed decimal numbers. However, no such instruction existed in the IBM 360 instruction set. (The SRP first appeared on the IBM 370.) One could shift packed decimal numbers on an IBM 360 by using sequences of instructions. In this section, the MVN, MVZ, and MVO instructions are introduced, and the use of these instructions for performing shifts on packed decimal numbers is illustrated. Note, however, that these instructions are used very rarely, since the SRP offers a far better way to shift numbers. Unless you study the code written for the IBM 360, it is unlikely (but quite possible) that you will encounter these instructions.

Execution of the instruction

MVN D1(L,B1),D2(B2) (*Move Numerics*)

has the same effect as execution of an MVC instruction except that only the numeric digits are moved. (The right hex digit in a byte is the numeric digit.) The zone digits in both fields remain unchanged.

Execution of the instruction

MVZ D1(L,B1),D2(B2) (*Move Zones*)

is analogous to execution of an MVN instruction. The difference in this case is that the zone digits, rather than the numeric digits, are moved.

Execution of the instruction

MVO D1(L1,B1),D2(L2,B2) (*Move with Offset*)

has the effect of moving the second operand to the field occupied by the first operand, with the digits of the second operand offset to the left in this field by four bits. This leaves the rightmost digit of the first operand unaltered. The details of this process are as follows:

1. The rightmost digit of the second operand is moved to the position occupied by the rightmost zone digit of the first operand. The remaining digits of the second operand are then successively moved to the field occupied by the first operand, proceeding from right to left.
2. The zone boundaries are reset.
3. Zeros are padded on the left if necessary to make the result L1 bytes long. If the second operand contains more digits than the L1 bytes of the first operand field will accommodate, the leftmost digits are ignored.

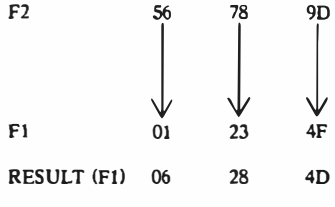
The following examples should help to clarify the above discussion of the MVN, MVZ, and MVO instructions. In these examples, it is assumed that the contents of F1 are

01234F

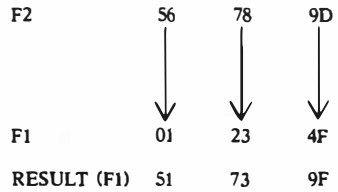
and the contents of F2 are

56789D

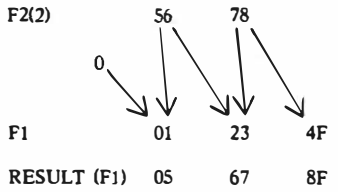
- *Example 1.* MVN F1(3),F2
  Execution of this instruction changes the contents of F1 to 06284D. This process is pictorially depicted as follows:



- *Example 2.* MVZ F1(3),F2
  Execution of this instruction has the following effect:

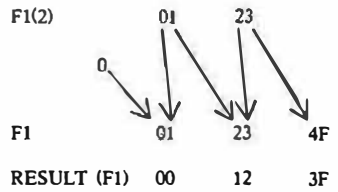



- *Example 3.* MVO F1(3),F2(2)




Note here that the zero was appended to the result as a fill character (it is not just a holdover of the original contents of F1).

- *Example 4.* MVO F1(3),F1(2)




The techniques for performing shifts on packed decimal numbers are illustrated next. For the purpose of this discussion, assume that FIELD is an eight-byte field containing a valid packed decimal number.

A shift to the right of an odd number of digits, which is equivalent to division by an odd power of 10, may be accomplished by use of an MVO instruction. Thus,

```
MVO      FIELD(8),FIELD(7)
```

has the same effect as dividing the number in FIELD by 10. If the second operand had been FIELD(6), the effect would have been a shift of three decimal digits (equivalent to division by 1000).

A shift to the right of an even number of digits may be brought about by the use of an MVN instruction. For example,

```
MVN     FIELD+6(1),FIELD+7
```

has the same effect as division of the number in FIELD by 100, and the result is left in FIELD(7). If the first operand had been FIELD+5(1), the effect would have been a shift to the right of four places (equivalent to division by 10,000) and the result would have been in FIELD(6).

Shifts to the left are somewhat more complicated to achieve. A shift to the left of a single digit (the equivalent of multiplication by 10) may be accomplished by the following pair of instructions:

```
MVO     FIELD(8),FIELD(8)
NI      FIELD+7,X'0F'
```

Shifts to the left of an odd number of digits where this number is greater than 1, can be achieved by the use of a three-instruction sequence. For example,

```
MVC     FIELD(7),FIELD+1
MVO     FIELD(7),FIELD(7)
NC      FIELD+6(2),=X'000F'
```

causes a shift to the left of three digits (the same as multiplication by 1000).

To perform a shift to the left of an even number of digits, a two-instruction sequence may be used. For instance, the sequence

```
MVC     FIELD(7),FIELD+1
NC      FIELD+6(2),=X'F00F'
```

causes a shift to the left of two digits (the equivalent of multiplication by 100).

Note that all shifts of an odd number of digits involve the use of an MVO instruction. Such shifts require a realignment of the zone boundaries, and the MVO instruction is designed to accomplish this realignment.

## Exercises

**1.** Program 8-1 uses a 6-instruction loop to count the bits in a word. The body of the loop is executed once for each bit that is on in the word. Hence, for words that are "sparse," it executes quite quickly. For cases in which many of the bits are set, there is a much faster approach. To illustrate, we will consider the problem of determining the number of bits set in an 8-bit byte (and allow you to generalize the idea to 32-bit words). Let us consider a specific byte

00101110

The first step is to view the 8 bits as eight 1-bit fields, each of which counts the number of bits set in a subword (each subword is 1-bit in this extreme case). Then, we wish to sum the eight fields pairwise producing

00 01 10 01

That is, we now have four counters whose sum is the number of bits in the word. If we sum these pairwise, we get

0001 0011

Finally, if we sum these pairwise, we get

00000100

which is the number of bits set in the original word. How can this pairwise summing be accomplished? Let us consider the first step (of summing the original bits pairwise). This can be done as follows:

a. Make two copies of the original word, and then shift one of the right by 1 bit. This gives

   00101110 and 00010111

b. Zero out the leftmost bit of each pair (using an AND instruction), giving

   00000100 and 00010101

c. Now add the two copies, giving

   00011001

   which is what we wanted!

The creation of the 4-bit counters from this set of four 2-bit counters can be accomplished by copying the 8-bits, shifting one by two bits (the size of one counter), zeroing out every second 2-bits in each of the copies, and adding the two results.

You can think of the process as taking an even number of counters, aligning the even numbered counters with the odd numbered counters, and adding the contents.

Write a subroutine based on this technique to rapidly count the number of bits in a table of words. The subroutine should take as input

> the address of a table of words
> the address of a halfword containing the number of words in the table

It should return in R0 the number of bits set in the table. Write a program that reads in a table of words, calls your subroutine, prints the table, and prints the final count.

**2.** Occasionally, "bit maps" are used by operating systems to record which sections of a disk are "not in use." That is, a large table of bits is maintained, where each bit represents whether or not the corresponding "slot" on the disk is available. In such cases, it becomes important to be able to locate the first bit in the table that is set (i.e., to locate the address of the first nonzero byte, along with the number of the first bit set in that byte). This single operation is occasionally a bottleneck in the file management software; hence, it is important that it execute rapidly.

Write a subroutine that takes in such a bit map and returns the location of the first available bit. The exact parameters are as follows:

address of a bit map
address of a halfword length (in number of bytes)

The routine should return in R0 the number of the first nonzero bit. Thus, if table contained

00 00 00 B3 ...

The answer returned in R0 would be 24 (we count from the left, calling the leftmost bit 0; another way to look at it is that 24 zero bits precede the first bit that is set in the table).

Your program should read in a bit map, call the subroutine, print the map, and print the returned answer. Note that, if the subroutine is properly coded, a single TRT can be used to both locate the first nonzero byte, along with which bit is set.

**3.** Program 8-6 is a routine to generate random numbers. The method used is covered in "Coding the Lehmer Pseudo-random Number Generator," an article by W. H. Payne, J. R. Rabung, and T. P. Bogyo that appeared in the *Communications of the ACM*, February 1969. It is not necessary to understand the material in that article to do this assignment; what must be understood is that the routine can be invoked repeatedly to generate a sequence of random integers that are uniformly distributed in a closed interval.

**Program 8-6**

```
         TITLE 'RANDOM - A PSEUDO-RANDOM NUMBER GENERATOR'
*****************************************************************
*
* THE FOLLOWING RANDOM NUMBER GENERATOR RETURNS A VALUE BETWEEN
* TWO SPECIFIED VALUES.  THE PARAMETER LIST IS AS FOLLOWS:
*
*        ADDRESS OF A WORD CONTAINING THE MINIMUM ACCEPTABLE VALUE
*        ADDRESS OF A WORD CONTAINING THE MAXIMUM ACCEPTABLE VALUE
*        ADDRESS OF A WORD THAT CONTAINS THE "SEED" VALUE ON THE
*              FIRST CALL.  IT IS ALTERED BY EACH CALL, SO THAT A
*              NEW RANDOM NUMBER IS RETURNED.
```

**Program 8-6 (continued)**

```
*
* THE ANSWER IS RETURNED IN RO (THIS IS A COMMON PRACTICE WHEN
* CODING ROUTINES THAT RETURN A SINGLE WORD).  R14 MUST HAVE BEEN
* SET BY A BRANCH-AND-LINK OPERATION (SINCE THE CALLER'S PROGRAM
* MASK IS ASSUMED TO BE IN R14); NORMAL LINKAGE CONDITIONS WILL
* ALWAYS CAUSE R14 TO CONTAIN THE CALLER'S PROGRAM MASK.
* THE SEED VALUE CAN BE ANYTHING ON THE FIRST CALL.  NOTE THAT
* THE ORIGINAL VALUE OF THE SEED DETERMINES THE SEQUENCE OF RANDOM
* NUMBERS THAT WILL BE PRODUCED.
*
*********************************************************************
*
RANDOM   CSECT
         STM   R14,R12,12(R13)    STORE CALLERS REGISTERS
         BALR  R12,0
         USING RANBASE,R12
RANBASE  DS    OH
*
         LM    R2,R4,0(R1)        R2 <- ADDRESS OF THE MINIMUM VALUE
*                                 R3 <- ADDRESS OF THE MAXIMUM VALUE
*                                 R4 <- ADDRESS OF X(N): X(0) IS THE
*                                       "SEED" VALUE
         L     R5,0(R3)           R5 <- MAX VALUE
         S     R5,0(R2)           R5 <- MAX VALUE - MIN VALUE
         LA    R5,1(R5)           R5 <- (MAX - MIN) + 1
         AR    R5,R5              R5 <- 2*(MAX-MIN+1)
*
         L     R1,=F'16807'       R1 <- MULTIPLIER K
         SR    RO,RO
         SPM   RO                 IGNORE OVERFLOW
         M     RO,0(R4)           K*X(N)
         SLDA  RO,1               ISOLATE Q(N)
         SRL   R1,1               ISOLATE R(N)
         AR    R1,RO              ADD Q(N) TO R(N)
         BNO   NOVERFLW
OVERFLOW SL    R1,=X'7FFFFFFF'
NOVERFLW ST    R1,0(R4)           STORE X(N+1)
*
         MR    RO,R5
         A     RO,0(R2)
*
         LM    R14,R15,12(R13)    RESTORE CALLER'S REGISTERS
         LM    R1,R12,24(R13)
         SPM   R14                RESTORE CALLER'S PROGRAM MASK
         BR    R14
         LTORG
```

Program 8-6, appropriately adapted, is to be used in this assignment. Input data for the program will consist of (1) a single record containing a positive integer X0, the starting seed value for the random number generator, followed by (2) a series of records, each containing either a 0 or a 1 in column 1, followed (in or after column 3) by a positive integer N. If the code

in column 1 is 1, the record will also contain two more numbers representing the lower and upper limits of the interval.

After setting the starting value to X0, your program should process each of the remaining records in one of two ways, depending on the value in column 1. The program terminates at end-of-file.

If column 1 contains 0, simply generate N random numbers in the interval 1–1000 and print them, with a suitable heading, ten to a line.

If column 1 contains 1, generate random numbers in the closed interval given by the last two numbers on the record. In this case, rather than printing out the numbers as they are generated, use a distribution table to keep a count of the occurrences of each distinct value. When at least one occurrence of each of the N numbers has been generated, print out the results in a format similar to the following sample:

```
93      **
94      ***
95      ***
96      **
97      ***
98      *
99      **
100     ****
101     **
102     ***
```

The number of asterisks in each line indicates the number of occurrences of the corresponding value. Each entry in the distribution table should be a single halfword. You may assume that a table of 100 halfwords will be large enough. Note that your program can easily determine when each entry in the table contains a nonzero value, by counting the number of times that a zero value has been changed to 1. When the counter reaches the number of elements in the range, the contents of the distribution table should be displayed.

**4.** This exercise consists of two parts. The first part is to write an external subroutine PARSTRNG that can be called to parse a string having the following format:

<delimiters><keyword> = <value><delimiters><keyword> = <value>etc.

| | | |
|---|---|---|
| where | <delimiters> | means one or more blanks or commas |
| | <keyword> | means any string of up to 11 characters that does not contain an equal sign |
| | <value> | means a legitimate zoned decimal number of up to nine digits |

For example, a valid string could be an entire record, where the record has been punched with

RATE=067500 PAYMENT=102580 PRINCIPAL=1500000

The order of the keywords on the record is not important, nor is the specific choice of keywords. For example, it should be possible to use PARSTRNG in an entirely different program, to obtain the values from the following record:

X0=1234 N=200 UPPER=99,LOWER=0

Upon entry to the routine PARSTRNG, R1 will point to a parameter list (on a fullword boundary) containing

- 4 bytes: address of the string
- 4 bytes: address of a halfword containing the length of the string
- 4 bytes: address of a table of defined keywords
- 4 bytes: address of a halfword containing the number of entries in the table

Both the parameter list and the keyword table will have been set up by the routine that calls PARSTRNG. The keyword table will consist of one entry for each keyword that PARSTRNG should recognize as legitimate. Each entry in the table will be 16 bytes long, with the following format:

- 1 byte: length of keyword
- 11 bytes: keyword (padded on the right with blanks)
- 4 bytes: address of a fullword where PARSTRNG is to place the value associated with the keyword

To address elements of the keyword table, you should use the following DSECT:

```
$KT       DSECT
$KTLEN    DS      XL1
$KTKEY    DS      CL11
$KTPOINT  DS      A
$KTEND    DS      0F
```

It might also be convenient to DSECT the parameter list.

PARSTRNG will cause the computer to perform the following operations on the string:

1. Scan for beginning of keyword (first character that is not a comma or a blank). If all bytes in the string have been scanned, exit with a return code indicating successful completion of the parse.
2. Find end of keyword (marked by an equal sign) and calculate length of keyword.
3. Search for a matching entry in the keyword table. If none exists, exit with a return code indicating that an error occurred.

4. Obtain from the table the address of the fullword field where the value is to be placed.
5. Find the value (string of digits) assigned to the keyword in the string, calculate its length, and EXecute a PACK instruction to put the value into a doubleword. Convert the value to a fullword with a CVB and store the result in the target field.
6. Go back to Step 1.

It might be convenient to make the search of the keyword table in Step 3 a subroutine.

NOTE: A good PARSTRNG routine would normally check for errors in the input string (missing parts, invalid value, etc.). Rather than print error messages itself, it would send back a return code in R15. The register with the return code would not be restored upon exiting from PARSTRNG; on return, the calling program would test the register and print any necessary error messages.

You may assume that the string will not contain any errors and omit such checking. However, you should return an error code if a keyword cannot be found in the keyword table (perhaps 0 if no errors were detected, and 1 otherwise).

Two translate tables will probably be needed: one for finding the beginning of a keyword (first byte not containing a comma or a blank) and a second for finding the end of the value associated with the keyword (first byte that is a comma or a blank). The second table can also be used to find out where the keyword ends and its value begins, provided the equal sign has a nonzero-function byte (probably different from the one for the comma or the blank).

The second part of Exercise 2 is to write a program TEST that can be used to test PARSTRNG. This program should read records, each containing two values. One value on each record will follow the keyword RATE=, and one will follow HOURS=. The program should invoke PARSTRNG to obtain the two values from the record and to print the product of these two numbers. For example, for the record

```
HOURS=20                                  RATE=200
```

the program should print

```
HOURS=20        RATE=$2.00        WAGE=$40.00
```

TEST should invoke PARSTRNG, as follows:

```
            L       R15,=V(PARSTRNG)
            BALR    R14,R15
              .
              .
              .
PARMLIST    DC      A(CARD,SLEN,KEYWORDS,NUMKEY)
```

```
CARD        DS    CL80
KEYWORDS    DC    X'04',CL11'RATE',A(DRATE)
            DC    X'05',CL11'HOURS',A(DHOURS)
DRATE       DS    F
DHOURS      DS    F
SLEN        DC    H'30'
NUMKEY      DC    H'2'
```

**5.** The Julian format of a date has the form

YY NNN

where YY are the last two digits of the year and NNN is the number of the day in the year. Thus, the date May 31, 1975 would be represented in Julian format as

75 151

since May 31 is the 151st day of the year 1975.

In many applications, it is necessary to perform operations on dates. The basic operations normally required are as follows:

a. Convert a date from one format to another.
b. Compare two dates and determine which one occurs first.
c. Add a number of days to a date to determine the date of some future event.
d. Subtract a number of days from a date to determine the date of some past event.

In this assignment you are to program a module called DATEPROC that performs these basic operations. The three formats for dates manipulated by DATEPROC are as follows:

- A date in the Julian format will be in a three-byte packed decimal field. Thus, 75 151 would be stored as

  X'75151F'

- A date can be stored in what will be referred to here as its character format. In this format, the date occupies an eight-byte field and would appear as

  05/31/75

- A date can be stored in what will be referred to here as its packed decimal format. In this case, the date occupies a four-byte field and is stored as

  X'0053175F'

Upon entrance to DATEPROC, R1 will contain the address of a parameter list composed of three or four words. The first word will contain the address of a four-byte field conforming to the following format:

- *2 bytes.* These two bytes indicate the type of operation DATEPROC should perform. The following values will be used:

  00 — Convert a date from one format to another.
  04 — Compare two dates.
  08 — Add a number of days to a date. In this case, the number of days will be taken from a three-byte packed decimal field.
  0C — Subtract a number of days from a date. In this case, the number of days will be taken from a three-byte packed decimal field.

- *1 byte.* This byte specifies in its rightmost two bits the format of the first date. The values are as follows:

  00 — The date is in Julian format.
  01 — The date is in character format.
  11 — The date is in packed decimal format.

  Note that a single TM instruction can be used to determine the setting. The BZ, BM, and BO instructions can be used to determine the exact setting.

- *1 byte.* This byte specifies the format of the second date, using the same codes as above.

The second word in the parameter list contains the address of the first date, and the third word contains the address of the second date field. If the operation is an addition or subtraction, a fourth word will contain the address of a three-byte field containing the number of days.

If a conversion operation is requested, DATEPROC should convert the first field into the format specified for the second field. If a comparison is requested, DATEPROC should set the condition code as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Dates are equal. |
| 1 | First date is less than the second date. |
| 2 | Second date is less than the first date. |
| 3 | — |

If addition or subtraction is requested, the number of days should be added to or subtracted from the first date. The result should be put into the second field in the format specified for the second date.

The coding of DATEPROC will be facilitated by first coding the following six subroutines:

- CHARPDEC: a subroutine to convert a date from character format to packed decimal format
- PDECCHAR: a subroutine to convert a date from packed decimal format to character format
- PDECJUL: a subroutine to convert a date from packed decimal format to Julian format
- JULPDEC: a subroutine to convert a date from Julian format to packed decimal format
- JULADD: a subroutine to add a number of days to a date in Julian format
- JULSUB: a subroutine to subtract a number of days from a date in Julian format

**6.** The *Soundex* system is used to convert names into four-character codes. It has the useful property that most names that sound the same are converted to the same code. Thus, SMITH and SMYTHE are assigned the same four-character code. This is useful for applications where records must be looked up based on names. The technique was invented by Margaret K. Odell and Robert C. Russell—c.f. U.S. Patents 1261167 (1918), 1435663 (1922). The conversion is accomplished by using the following steps:

1. Keep the first letter of the name, but drop all occurrences of a, e, h, i, o, u, w, or y that occur after the first character.
2. For each character except the first, assign the character a number as follows:

| | |
|---|---|
| b, f, p, v | ->1 |
| c, g, j, k, q, s, x, z | ->2 |
| d, t | ->3 |
| l | ->4 |
| m, n | ->5 |
| r | ->6 |

3. If two or more letters that were adjacent in the original name (before Step 1) were assigned the same numeric value, delete all but the first.
4. If the result has less than four characters, pad on the right with zeros. If it is longer, truncate the rightmost characters.

Thus, SMYTHE would be converted as follows:

1. YHE is deleted, leaving SMT.
2. SMT gets converted to S53.
3. Since there are no identical adjacent numbers from characters that were adjacent in the original name, no characters are deleted in this step.

4. Since S53 is less than four characters, it is padded to S530.

Write a program that reads cards, each containing a last name starting in column 1. The program should print the name and the Soundex code for the name.

**7.** Write a subroutine called XXXXDUMP that can be invoked to print a hexadecimal display of an area in memory. The subroutine should assume that, upon entrance, R1 points to a parameter list conforming to the following format:

- *word 1:* address of an area
- *word 2:* address of a halfword containing the length of the area
- *word 3:* address of a halfword containing the identifier number

XXXXDUMP should round the address of the area down to the next lowest multiple of 16 and round the ending address up to the next multiple of 16, minus 1, so that memory can be displayed in groups of 16 bytes. For example, if R1 pointed to a three-word list containing

000A1436
00000237
0000000A

then XXXXDUMP should display from address 0A1430 to 0A166F. The output produced by XXXXDUMP should conform to the following format:

```
          ID#  IS  10

0A1430    404040F5    40F1F2F3    40F0F0F0    F1F1F3F4
0A1440
                .           .           .           .
                .           .           .           .
                .           .           .           .
                            .           .           .
```

Write a short program invoking XXXXDUMP to display several areas in memory.

**8.** Write three subroutines that can be used to facilitate the encoding and decoding of messages. The first subroutine, SETCODE, is used to establish the correspondence between letters in a message and the encoded form of the message. The second subroutine, ENCODE, can be called to convert a message into its encoded form, using the correspondence table established by a call to SETCODE. The third subroutine, DECODE, can be called to convert an encoded message back to its original form. Specifically, the requirements for each of the three modules are as follows:

### *SETCODE*

Upon entrance to this subroutine, R1 will point to a parameter list in the following format:

- *word 1:* address of a fullword number of character pairs in the correspondence table used to encode the messages (Each character pair specifies an original character and the character into which it should be encoded.)
- *word 2:* address of the list of character pairs (Each two bytes in the list represent a pair.)
- *word 3:* address of a translate table to be used to encode messages
- *word 4:* address of a translate table to be used to decode messages

SETCODE must simply fill the appropriate characters into the two translate tables. For example, if AQ were a character pair, then the following should occur.

a. The entry in the position for A in the encoding table should be set to Q.
b. The entry for Q in the decoding table should be set to A.

### *ENCODE*

Upon entrance to this subroutine, R1 will contain the address of a parameter list conforming to the following format:

- *word 1:* address of a string to encode
- *word 2:* address of a halfword containing the length of the string
- *word 3:* address of the area where the encoded string is to be constructed (Unless this is the same as the first word, the original string should not be altered.)
- *word 4:* address of the translate table to be used to encode the message

ENCODE should simply move the string to the area indicated in the third word of the parameter list and then translate it to the encoded format.

### *DECODE*

Upon entrance to this subroutine, R1 will contain the address of a parameter list conforming to the following format:

- *word 1:* address of a string to be decoded
- *word 2:* address of a halfword containing the length of the string
- *word 3:* address of the area where the decoded string is to be constructed
- *word 4:* address of the translate table to be used to decode the string

DECODE should simply move the encoded string to the area indicated in

the third word of the parameter list, and decode it back to its original contents.

To test the three subroutines, write a short program called TEST to execute the following logic:

*Step 1.* Read in a single record containing up to 40 character pairs. Call SETCODE to set up the two translate tables. Note that a character pair of two blanks will have no effect, so the call to SETCODE can always specify a list of 40 character pairs.

*Step 2.* Read in two records containing a message. Only the 40 characters specified in the first record may occur in the message. Print the two input records.

*Step 3.* Call ENCODE to encode the message. Print the encoded message.

*Step 4.* Call DECODE to decode the message. Print the decoded message. Stop.

**9.** In many data processing applications, it is necessary to validate the contents of numeric fields. Frequently, it is necessary to determine whether a given field contains a valid number and, if the number is valid, to pack it into a designated second field.

In this exercise you are to code an external subroutine, NUMCHK, which can be called to verify the contents of a set of numeric fields. Optionally, the calling program can request that NUMCHK pack the contents of any field into a second field and check that the packed result falls within a specified range. NUMCHK may not alter the contents of any inspected field.

Upon entrance to NUMCHK, R1 will contain the address of a parameter list containing a single address, the address of the block of parameters in Table 8-2.

**Table 8-2**

| *Displacement* | *Length* | *Contents* |
|---|---|---|
| 0 | 4 | Number of fields to check |
| 4 | 28*n* | One set of parameters for each of *n* fields (28 bytes are used to specify the parameters for each field.) |
| *Parameters for each field* | | |
| 0 | 4 | Address of the field to be checked |
| 4 | 4 | Length of the field to check |
| 8 | 1 | A byte containing bit flags that specify editing options (see below) |
| 9 | 1 | A byte that NUMCHK will set to X'F0' if no errors are detected, and to X'F1' if errors are detected |
| 10 | 2 | Unused |

**Table 8-2 (continued)**

| | | |
|---|---|---|
| 12 | 4 | Address of a receiving field (This parameter, as well as the following three parameters, is specified only if the option to pack legitimate fields is specified in the flag byte.) |
| 16 | 4 | Length of the receiving field |
| 20 | 4 | Address of a field containing the maximum legitimate value for the number (The length of the designated field is assumed to be the same as that of the receiving field.) |
| 24 | 4 | Address of a field containing the minimum legitimate value for the number (The length of the designated field is assumed to be the same as that of the receiving field.) |

The settings of the bits in the flag byte describe the field to be verified and whether it should be packed into a receiving field. Four bits in the flag byte will be utilized. Their meanings are as follows:

| | | |
|---|---|---|
| *bits 0,1,3,4* | | (Unused) |
| *bit 2* | 0: | If the field is valid, pack it into the receiving field. |
| | 1: | The number is not to be packed into a receiving field, and no check should be made to determine whether or not the number falls within specified limits. |
| *bit 5* | 0: | Leading blanks are legitimate. |
| | 1: | No leading blanks are allowed. |
| *bit 6* | 0: | The field does not contain a sign. In this case, the zone digit on all nonblank bytes must be an F. |
| | 1: | The field may contain a sign. In this case, bit 7 should be examined to determine whether the sign precedes the first numeric digit or is overpunched onto the rightmost digit. |
| *bit 7* | 0: | The sign was overpunched into the rightmost byte of the field. C and F are valid plus zone digits and D is the only acceptable minus zone. |
| | 1: | The optional sign should immediately precede the first numeric digit. The valid signs in this case are + and −. If the sign is omitted, the value in the field is assumed to be positive. |

The scanning of a field by NUMCHK should utilize the TRT instruction twice. Two translate tables are used. The table for scanning past leading blanks is as follows:

| *Position* | *Contents* |
|---|---|
| C' ' | X'00' |
| C'+' and C'–' | X'08' |
| C'0'–C'9' | X'0C' |
| X'C0'–X'C9' and X'D0'–X'D9' | X'10' |
| All other positions | X'04' |

The table for scanning past digits is as follows:

| *Position* | *Contents* |
|---|---|
| C'0'–C'9' | X'00' |
| X'C0'–X'C9' and X'D0'–X'D9' | X'08' |
| All other positions | X'04' |

The basic scanning will then be as follows:

```
        SR    R2,R2
        TRT   addr,1st table
        B     *+4(R2)
        B                 error routine—empty field
        B                 error routine—invalid 1st character
        B                 routine to check leading sign
        B                 routine to check leading blanks
        B                 a routine to check overpunched sign
OVPNCHED
        .
        .
        SR    R2,R2
        TRT   addr,2nd table
        B     *+4(R2)
        B                 routine to process legitimate field
        B     error routine—field contains an invalid character

CHECK                     routine to process trailing sign (make sure
                          it's legal and in rightmost byte)
        .
        .
```

To test NUMCHK, use the assembler language program shown in Program 8-7.

**Program 8-7**

```
         TITLE 'A MODULE TO TEST NUMCHK'
*  THIS SHORT PROGRAM CAN BE USED TO TEST THE 'NUMCHK' MODULE,
*  WHICH IS CALLED TO VERIFY THE CONTENTS OF SEVERAL NUMERIC FIELDS.
*  THE LOGIC OF THE MODULE IS AS FOLLOWS:
*
*  STEP 1.  SET UP R13 AS THE BASE REGISTER.
*
*  STEP 2.  CALL 'NUMCHK' TO CHECK THE 8 FIELDS DESCRIBED IN THE
*           PARAMETER LIST.
*
*  STEP 3.  DUMP THE AREA OF CORE ALTERED BY THE CALL.
*
*  STEP 4.  EXIT.
*
*
*  FOR THE DESCRIPTION OF THE FORMAT OF THE PARAMETER LIST, SEE THE
*  DOCUMENTATION FOR THE 'NUMCHK' MODULE.
         SPACE 5
         PRINT NOGEN
TEST     CSECT
***<STEP 1>***     SAVE CALLER'S REGISTERS AND ESTABLISH R13 AS A BASE
         STM    R14,R12,12(R13)    STORE CALLERS REGISTERS
         BAL    R14,80(R15)        NOW LINK SAVE AREAS
         DS     18F                REGISTER SAVE AREA
         ST     R14,8(R13)         STORE FORWARD LINK INTO OLD SAVE AREA
         ST     R13,4(R14)         STORE BACK LINK INTO NEW SAVE AREA
         LR     R13,R14            R13<- ADDRESS OF NEW SAVE AREA
         USING TEST+8,R13
         SPACE 2
***<STEP 2>***     CALL NUMCHK
         LA     R1,P=A(PLIST)      LOAD ADDRESS OF 1-WORD PARAMETER LIST
         L      R15,=V(NUMCHK)     NOW CALL NUMCHK
         BALR   R14,R15
         SPACE
***<STEP 3>***     DUMP OUT THE ALTERED AREAS OF CORE
         XDUMP PLIST,400           DUMP ALTERED AREAS OF CORE
         SPACE
***<STEP 4>***     EXIT
         L      R13,4(R13)         LOAD ADDRESS OF OLD SAVE AREA
         LM     R14,R12,12(R13)    RESTORE CALLER'S REGISTERS
         BR     R14                EXIT
         SPACE
                LTORG
PLIST    DC     F'8'               TOTAL OF 8 FIELDS TO VERIFY
         DC     A(F1,7)
         DC     C'C'               FLAG1--PACK, LEADING BLANKS, LD SIGN
         DC     X'00'              ERR1
         DS     2X
         DC     A(T1,5,MAX1,MIN1)
         SPACE
         DC     A(F2,4)
         DC     C'7'               DONT PACK, NO LEADING BLANKS, LD SIGN
         DC     X'00'
         DS     2X
         DC     A(0,0,0,0)
         SPACE
         DC     A(F3,4)
         DC     C'3'               DONT PACK,LEADING BLANKS,LEADING SIGN
         DC     X'00'
         DS     2X
         DC     A(0,0,0,0)
         SPACE
```

**Program 8-7 (continued)**

```
         DC     A(F4,5)
         DC     C'3'                DONT PACK,LEADING BLANKS,LEADING SIGN
         DC     X'00'
         DS     2X
         DC     A(0,0,0,0)
         SPACE
         DC     A(F5,3)
         DC     C'B'                PACK,LEADING BLANKS, TRAILING SIGN
         DC     X'00'
         DS     2X
         DC     A(T5,6,MAX5,MIN5)
         SPACE
         DC     A(F6,3)
         DC     C'4'                DONT PACK,NO LEADING BLANKS,NO SIGN
         DC     X'00'
         DS     2X
         DC     A(0,0,0,0)
         SPACE
         DC     A(F7,3)
         DC     C'C'                PACK,LEADING BLANKS AND SIGN
         DC     X'00'
         DS     2X
         DC     A(T7,6,MAX7,MIN7)
         SPACE
         DC     A(F8,3)
         DC     C'C'                PACK,LEADING BLANKS AND SIGN
         DC     X'00'
         DS     2X
         DC     A(T8,7,MAX8,MIN8)
         SPACE 5
F1       DC     C'  + 123'          INVALID
F2       DC     C'-12A'             INVALID BECAUSE OF ILLEGAL RIGHT ZONE
F3       DC     C' -24'             VALID
F4       DC     C'    +'            INVALID
F5       DC     X'F1F2D3'           VALID
F6       DC     C'12M'              INVALID — SIGN NOT SPECIFIED IN FLAG
F7       DC     C' -2'              OUT OF RANGE
F8       DC     C'+10'              OUT OF RANGE
         SPACE 5
T1       DC     PL5'0'
T5       DC     XL6'0'
T7       DC     XL6'0'
T8       DC     XL7'0'
         SPACE 5
MAX1     DC     PL5'100'
MIN1     DC     PL5'0'
MAX5     DC     PL6'200'
MIN5     DC     PL6'-200'
MAX7     DC     PL6'10'
MIN7     DC     PL6'0'
MAX8     DC     PL7'9'
MIN8     DC     PL7'-100'
         EQUREGS
         END    TEST
```

**10.** Let a sentence be defined as either of the following sequences:

a. ARTICLE NOUN VERB ARTICLE NOUN
b. PRONOUN VERB ARTICLE NOUN

| | | |
|---|---|---|
| where | ARTICLE | is one of (the, a) |
| | NOUN | is one of (boy, girl, dog, lady) |
| | VERB | is one of (loves, hates, walks, needs) |
| | PRONOUN | is one of (he, she, it) |

Write a program that will read a data record containing a set of words that satisfies, except for order, the definition of a sentence given above (either a or b). The program should print the words in their original order, recognize which definition has been used, arrange them into proper order, and print the sentence out with one space between each word and a period following the last word. Using definition a, there will be two articles and two nouns. Use the first one on the record as the first in your printed sentence.

Your program should contain four tables, one for each class of words. The format of entries in each table should be

- *2 bytes:* length of the word
- *10 bytes:* the word (left-justified)

Also, the number of entries in each table should be kept in a separate half-word. For example,

```
#ARTICLE    DC    H'2'
ARTICLES    DC    H'3',CL10'THE'
            DC    H'1',CL10'A'
```

would be used to define the set of valid articles. Keeping the information in tables allows the convenient addition of more words.

**11.** Using the definitions in Exercise 8 and the random number generator presented in Exercise 1, write a program that generates random sentences. The general technique is to use a random number generator to select one of the available options—e.g., generate randomly a 1 or a 2 that selects the sentence definition a or b. If b is selected, then randomly select one of the choices for PRONOUN, VERB, ARTICLE, and NOUN, and print the sentence. Print at least ten sentences.

**12.** Write two subroutines, one to convert a hexadecimal number in character format as it would appear on a card to a value in R0, and one to convert a value in R0 to the character form of the hexadecimal representation of the number. For example, the first subroutine (CHARHEX) could be used to convert

F1C1C3

on a card to 000001AC in R0, and the second subroutine (HEXCHAR) could be used to convert 000001AC in R0 to

F1C1C3

The routine HEXCHAR would be useful if one wished to display the contents of an area in storage. CHARHEX could be used to accept the hexadecimal representations of input values. The exact descriptions of the routines are as follows:

*CHARHEX*

Upon entrance to this subroutine, R1 will point to the address of an eight-digit hexadecimal number in character format (00000000 to FFFFFFFF). Convert the number and return the value in R0.

*HEXCHAR*

Upon entrance to this subroutine, R1 points to the address of an eight-byte area. The contents of R0 should be converted to character format, and the result should be put into the designated area.

To test your subroutines, write a program that can be used to add hexadecimal numbers. As input, the program should accept cards, each containing a hexadecimal number in columns 1–8 and another number in columns 9–16. The program should print a line similar to the following, for each pair of numbers:

```
0014A1FE        0C001A01        SUM=0C14BBFF
```

# 9

# Macros and Conditional Assembly

The material covered in this chapter centers on the use of a macro language. Unfortunately, the original versions of ASSIST had a very limited macro capability, and ASSIST/I does not support any ability to define macros. Hence, you will need to run the programming exercises from this chapter using an assembler provided by vendors of machines that utilize the IBM 360/370 instruction set.

## 9.1 SYMBOLIC PARAMETERS AND MACROS

A *macro language* is a powerful extension to a basic assembler language. This language facility provides a means for generating at assembly time a commonly used sequence of assembler-language statements as many times as required. The sequence of statements is specified, just once, in a *macro definition;* then, at any point where these statements are to be generated, a single *macro instruction* will suffice. The judicious use of macros will:

1. greatly simplify the coding of programs
2. significantly reduce the number of programming errors
3. ensure that common functions are performed by standard routines

An introduction to variable symbols and, in particular, symbolic parameters is a necessary prelude to a discussion of macros.

*Variable symbols* (as distinguished from ordinary symbols or labels) are symbols that can be assigned different values by either the programmer or the assembler. When assembler-language instructions are generated according to a macro definition, the variable symbols are replaced by the values that have been assigned to them. Variable symbols are of three types: symbolic parameters, system variables, and SET variables. Each of the three types of variable symbols serves a distinct function. Only the function of the symbolic parameter will be discussed in this section.

The rules of formation for variable symbols are as follows:

1. A variable symbol consists of from two to eight characters, the first of which must be an ampersand.
2. The second character must be a letter and the remaining characters, if any, must be either letters or digits.

Thus,

```
&VARLEN    &GEN2
&TABSIZE   &RIOPARM
&SORT1     &LIST1
```

are all valid variable symbols.

*Symbolic parameters* are used in the macro definition and are assigned values by the programmer in each macro instruction that references the particular macro.

A macro definition consists of the following items in the given order:

1. A header composed solely of the operation symbol MACRO
2. A prototype statement
3. A sequence of model statements that make up the body of the macro definition
4. A trailer that is simply the operation symbol MEND

The prototype statement does not necessarily have a label; but, if it does, the label must be a symbolic parameter. The operation field must contain a symbol that is the mnemonic operation code that must appear in all macro instructions referencing the macro definition. The operand field may contain from 0 to 200 symbolic parameters, separated by commas, which serve as a vehicle for passing information to the macro. The following are examples of macro prototype statements:

```
&LABEL   EXIT
&LABEL   INVOKE  &NAME
&NAME    PARSE   &LEN,&ADDR,&PARMTAB,&NUM
```

The body of the macro may contain two types of comment records. A comment record that contains an asterisk in column 1 is reproduced with the assembler instructions generated by the macro. A comment record with a period in column 1 followed by an asterisk in column 2 is not reproduced with the instructions generated by the macro. A simple example of a macro definition follows:

```
         MACRO
&LABEL   EXIT
.*
.* THIS MACRO GENERATES THE CODE REQUIRED TO RETURN FROM A MODULE.
.* IT ASSUMES NORMAL OS LINKAGE CONVENTIONS.
.*
```

```
* NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
* WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
* IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
&LABEL   L      R13,4(R13)
         LM     R14,R12,12(R13)
         BR     R14
         MEND
```

A macro instruction may have any valid label or it may have no label. The operation field must contain the mnemonic operation code of a macro definition and the operand field may contain from 0 to 200 operands, separated by commas. These positional parameters replace the symbolic parameters in the macro definition when the code corresponding to a particular macro instruction is generated. As an example, the macro instruction

```
LEAVE    EXIT
```

can be utilized to reference the previous macro definition. In this case, the sequence of generated code would be

```
* NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
* WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
* IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
LEAVE    L      R13,4(R13)
         LM     R14,R12,12(R13)
         BR     R14
```

Note that the symbolic parameter &LABEL in the macro definition is replaced by the label LEAVE from the macro instruction in the generated code. If the macro instruction had included no label, &LABEL would have been replaced by the null string. Also note that the comments following the instructions are reproduced in the generated code, as are the comment records with an asterisk in column 1, but that the comment records beginning with .* are not reproduced.

As a second example, consider the following macro, which could be used to generate calls to external subroutines:

```
         MACRO
&LABEL   INVOKE  &NAME
&LABEL   L       R15,=V(&NAME)
         BALR    R14,R15
         MEND
```

In this case the macro instruction

```
         INVOKE  SUBRTN
```

would cause the following code to be generated:

```
         L       R15,=V(SUBRTN)
         BALR    R14,R15
```

Here the symbolic parameter &NAME in the macro definition is replaced by the operand SUBRTN from the operand field of the macro instruction. The symbolic parameter &LABEL is replaced by the null string, because the macro instruction did not have a label.

When macro definitions are included in a source program, the macro definitions must precede all assembler-language statements in the program. However, a title record and comment records may precede the macro definitions. In the program listing produced by the assembler, each macro instruction is followed by the assembler-language statements generated from the macro. Of course, the object module produced by the assembler corresponds to the code in this listing.

An important concept must be grasped: When the assembler processes a macro instruction, assembler-language code is generated according to the specifications inherent in the macro definition. Object code is generated only when the assembler processes assembler-language instructions. To understand how source files containing macro definitions and instructions are processed, it is useful to think of the assembler as containing two distinct programs: a macro processor and an assembler code processor. Then, the actual processing can be visualized as occurring according to the steps depicted in Figure 9-1.

Program 9-1 is the listing of a source file that includes the macro definitions illustrated in the examples in this section.

Program 9-2 is a copy of the assembler listing generated by this source deck. Note that, in the assembler listing, each statement generated by a

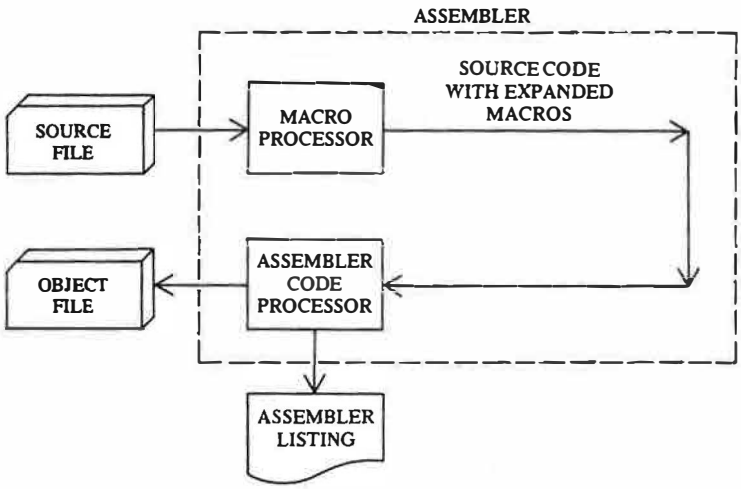



**Figure 9-1**

**Program 9-1**

```
         MACRO
&LABEL   EXIT
.*
.* THIS MACRO GENERATES THE CODE REQUIRED TO RETURN FROM A MODULE.
.* IT ASSUMES NORMAL OS LINKAGE CONVENTIONS.
.*
 * NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
 * WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
 * IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
&LABEL   L      R13,4(R13)          LOAD ADDRESS OF CALLER'S SAVE AREA
         LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
         BR     R14
         MEND
         MACRO
&LABEL   INVOKE &NAME
.*
.* THIS MACRO CAN BE USED TO INVOKE AN EXTERNAL ROUTINE.  THE NAME
.* OF THE ROUTINE TO BE CALLED SHOULD BE GIVEN AS THE FIRST OPERAND.
.*
&LABEL   L      R15,=V(&NAME)       LOAD ADDRESS OF ROUTINE TO CALL
         BALR   R14,R15             CALL THE ROUTINE
         MEND
MAIN     CSECT
         STM    R14,R12,12(R13)     STORE CALLER'S REGISTERS
         BAL    R14,80(R15)         NOW SET UP R13 AS THE BASE
         DS     18F                 REGISTER SAVE AREA
         ST     R13,4(R14)          STORE BACK POINTER
         ST     R14,8(R13)          STORE FORWARD POINTER
         LR     R13,R14             R13 IS THE BASE REGISTER
         USING MAIN+8,R13
         LM     R2,R3,=A(TABLE,10) LOAD PARAMETERS FOR CALL TO 'SORT'
         INVOKE SORT                CALL THE ROUTINE SORT
LEAVE    EXIT
         LTORG
TABLE    DC     F'4,-10,9,43,32,-8,12,0,1,64'
CARD     DS     CL80                INPUT CARD AREA
R2       EQU    2
R3       EQU    3
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
         END
```

macro instruction is distinguished by a plus sign appearing to its left. These listings should be studied carefully, along with the material in this section, before proceeding.

## 9.2 CONDITIONAL ASSEMBLY

The conditional assembly instructions provide a facility for altering the sequence in which source program statements are processed by the assembler. They in fact provide the means for instructing the assembler to branch and loop among such statements in much the same way as the computer branches and loops among statements in an executable program. Although

**Program 9-2**

```
LCC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                  1          MACRO
                                  2 &LABEL   EXIT
                                  3 .*
                                  4 .* THIS MACRO GENERATES THE CODE REQUIRED TO RETURN FROM A MODULE.
                                  5 .* IT ASSUMES NORMAL OS LINKAGE CONVENTIONS.
                                  6 .*
                                  7 * NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
                                  8 * WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
                                  9 * IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
                                 10 &LABEL   L      R13,4(R13)          LOAD ADDRESS OF CALLER'S SAVE AREA
                                 11          LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
                                 12          BR     R14
                                 13          MEND
                                 14          MACRO
                                 15 &LABEL   INVOKE &NAME
                                 16 .*
                                 17 .* THIS MACRO CAN BE USED TO INVOKE AN EXTERNAL ROUTINE.  THE NAME
                                 18 .* OF THE ROUTINE TO BE CALLED SHOULD BE GIVEN AS THE FIRST OPERAND.
                                 19 .*
                                 20 &LABEL   L      R15,=V(&NAME)       LOAD ADDRESS OF ROUTINE TO CALL
                                 21          BALR   R14,R15             CALL THE ROUTINE
                                 22          MEND
000000                           23 MAIN     CSECT
000000 90EC D00C        0000C    24          STM    R14,R12,12(R13)     STORE CALLER'S REGISTERS
000004 45EF 0050        00050    25          BAL    R14,80(R15)         NOW SET UP R13 AS THE BASE
000008                           26          DS     18F                 REGISTER SAVE AREA
000050 50DE 0004        00004    27          ST     R13,4(R14)          STORE BACK POINTER
000054 50ED 0008        00008    28          ST     R14,8(R13)          STORE FORWARD POINTER
000058 18DE                      29          LR     R13,R14             R13 IS THE BASE REGISTER
                        00008    30          USING  MAIN+8,R13
00005A 9823 D068        00070    31          LM     R2,R3,=A(TABLE,10)  LOAD PARAMETERS FOR CALL TO 'SORT'
                                 32          INVOKE SORT                CALL THE ROUTINE SORT
00005E 58F0 0070        00078    33+         L      R15,=V(SORT)        LOAD ADDRESS OF ROUTINE TO CALL
000062 05EF                      34+         BALR   R14,R15             CALL THE ROUTINE
                                 35 LEAVE    EXIT
                                 36++ NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
                                 37++ WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
                                 38++ IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
000064 58DD 0004        00004    39+LEAVE    L      R13,4(R13)          LOAD ADDRESS OF CALLER'S SAVE AREA
000068 98EC D00C        0000C    40+         LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
00006C 07FE                      41+         BR     R14
000070                           42          LTORG
000070 0000007C000000A0          43                 =A(TABLE,10)
000078 00000000                  44                 =V(SORT)
00007C 00000004FFFFFFF6          45 TABLE    DC     F'4,-10,9,43,32,-8,12,0,1,64'
000084                           46 CARD     DS     CL80                INPUT CARD AREA
                        00002    47 R2       EQU    2
                        00003    48 R3       EQU    3
                        0000C    49 R12      EQU    12
                        0000D    50 R13      EQU    13
                        0000E    51 R14      EQU    14
                        0000F    52 R15      EQU    15
                                 53          END
```

conditional assembly statements can be used in other portions of a source program, only their use in macro definitions, which is far more common, will be discussed in this section.

Several definitions must be given before proceeding to the discussion of conditional assembly. For the purposes of the discussion in this section, an *arithmetic expression* is an expression that can be formed from

- self-defining terms
- the operators +, −, *, and /
- variable symbols
- parentheses to indicate grouping

A *logical expression,* for the present purpose, is one of the following:

- A 0 or a 1 with or without enclosing parentheses
- Two arithmetic expressions separated by a relational operator and enclosed within parentheses. The valid relational operators are

| | |
|---|---|
| EQ | equal |
| NE | not equal |
| LT | less than |
| GT | greater than |
| LE | less than or equal |
| GE | greater than or equal |

  When such a logical expression is evaluated, 1 is assigned as the value if the two expressions stand in the given relation; otherwise, 0 is assigned as the value.
- A character string of from 0 to 255 characters enclosed within apostrophes, and a symbolic parameter enclosed within apostrophes, separated by a relational operator, and enclosed within parentheses. When an expression of this type is evaluated, the character string is compared to the character value assigned to the symbolic parameter and, if these two strings satisfy the given relation, 1 is assigned as the value; otherwise, 0 is assigned as the value.

A more inclusive definition of a logical expression will be given in Section 9.3.

A *sequence symbol* is any symbol formed according to the following rules:

- A sequence symbol consists of from two to eight characters, the first of which must be a period.
- The second character must be a letter, and the remaining characters, if any, must be letters or digits.

Sequence symbols are used in statement name fields and are the only names that can be used in the operand fields of the conditional-assembly branch instructions.

The AIF instruction is the conditional-assembly, conditional-branch instruction. This instruction has the following format:

sequence symbol AIF (logical expression) sequence symbol

The first sequence symbol is optional. When the assembler processes this instruction, the logical expression in the operand field is evaluated. If the value of this expression is 1, a branch is taken to the statement named by the sequence symbol in the operand field. Otherwise, the statement immediately following the AIF instruction is processed by the assembler.

The AGO instruction is the conditional-assembly, unconditional-branch instruction. The format for this instruction is

sequence symbol AGO sequence symbol

As in the case of the AIF instruction, the name field is optional. When the assembler processes this instruction, an unconditional branch is taken to the statement named by the sequence symbol in the operand field.

The ANOP instruction provides a means for branching to statements that have symbols or variable symbols in their name fields. This is a necessary facility, since the statements referenced in the operand fields of AIF and AGO statements must be named by sequence symbols. The format for this instruction is

sequence symbol ANOP

When a branch is taken to an ANOP instruction, the effect is the same as when the branch is taken to the statement immediately following the ANOP instruction.

It is important to remember that the AIF, AGO, and ANOP instructions cause no code to be generated. The sole function of these instructions is to conditionally alter the sequence in which the assembler processes source-program or macro-definition statements.

The following example illustrates the use of the AIF, AGO, and ANOP instructions and sequence symbols:

```
         MACRO
&LABEL   ROUND &WAY,&REG
.* THIS MACRO GENERATES THE CODE REQUIRED TO ROUND THE ADDRESS IN
.* THE REGISTER &REG TO A FULLWORD BOUNDARY.  THE VALUE IS ROUNDED
.* UP IF &WAY IS UP, AND DOWN IF &WAY IS DOWN.
         AIF   ('&WAY' EQ 'UP').UP
         AIF   ('&WAY' NE 'DOWN').END
&LABEL   N     &REG,=X'FFFFFFFC'
         AGO   .END
.UP      ANOP
&LABEL   LA    &REG,3(&REG)
         N     &REG,=X'FFFFFFFC'
.END     MEND
```

If this macro definition were referenced by the macro instruction

```
ALIGN    ROUND UP,2
```

the following code would be generated:

```
ALIGN    LA     2,3(2)
         N      2,=X'FFFFFFFC'
```

In this case, the first AIF instruction in the macro definition causes a branch to the ANOP instruction with the sequence symbol .UP in its name field. Since the ANOP serves only to establish a branch point, the code corresponding to the two following model statements is then generated. Note that the AIF, AGO, and ANOP instructions cause no code to be generated, but simply determine the sequence in which the macro processor processes the statements in the macro definition. Also note the use of the sequence symbol .END as a name for the MEND statement.

The following alternative definition of the ROUND macro is less cumbersome than the previous one.

```
         MACRO
&LABEL   ROUND &WAY,&REG
.* THIS MACRO GENERATES THE CODE REQUIRED TO ROUND THE ADDRESS IN
.* THE REGISTER &REG TO A FULLWORD BOUNDARY.  THE VALUE IS ROUNDED
.* UP IF &WAY IS UP, AND DOWN IF &WAY IS DOWN.
&LABEL   DS    0H                GENERATE A LABEL
         AIF   ('&WAY' EQ 'DOWN').AND
         AIF   ('&WAY' NE 'UP').END
         LA    &REG,3(&REG)
.AND     N     &REG,=X'FFFFFFFC'
.END     MEND
```

Parameters can be omitted in the operand field of a macro instruction, provided that the commas separating the parameters are appropriately placed to indicate which parameters have been omitted. Two adjacent commas in the operand field indicate the omission of a parameter in the interior of the list. A leading comma and a final comma indicate omission of a parameter at the beginning and end of a list, respectively. If a parameter is omitted, the corresponding symbolic parameter is assigned the null string as a value.

A symbolic parameter in a model statement of a macro definition can be immediately preceded or followed by other characters or another symbolic parameter. When this occurs, the other characters or those assigned to the other symbolic parameter are combined with the characters assigned to the symbolic parameter in question. Such a combining of characters is called *concatenation*. There is just one restriction: If a symbolic parameter is to be combined with a character string that begins with a letter, a left parenthesis, or a period, then a period must be inserted immediately following

the symbolic parameter. A symbolic parameter followed by a period is simply replaced by the value assigned to the symbolic parameter. Hence, excessive use of periods in such cases can do no harm.

The following example should serve to illustrate some of the ideas in the preceding discussion:

```
         MACRO
&LABEL   BHLE  &REG1,&REG2,&HIGH,&LOW,&EQ
.* THIS MACRO MAY BE USED TO COMPARE THE VALUE IN &REG1 WITH THE
.* VALUE IN &REG2 AND EFFECT A BRANCH TO &HIGH, &LOW, OR &EQ
.* DEPENDING UPON THE VALUES IN THE REGISTERS.  ANY COMBINATION
.* OF THE PARAMETERS &HIGH, &LOW, AND &EQ MAY BE OMITTED.
&LABEL   CR    R&REG1,R&REG2
         AIF   ('&HIGH' EQ '').LOW
         BH    &HIGH
.LOW     AIF   ('&LOW' EQ '').EQ
         BL    &LOW
.EQ      AIF   ('&EQ' EQ '').END
         BE    &EQ
.END     MEND
```

If the macro BHLE is referenced by the macro instruction

```
COMPARE     BHLE   3,4,,LOWVAL,EQVAL
```

the following code is generated:

```
COMPARE     CR     R3,R4
            BL     LOWVAL
            BE     EQVAL
```

Note that the R&REG1 in the operand field of the CR instruction has been replaced by R3. This is an example of concatenation. Note also that, in the first AIF instruction, &HIGH has been compared to the null string (indicated by adjacent apostrophes) and, since the parameter corresponding to &HIGH was omitted, the branch to .LOW was taken.

The reader should by now be quite familiar with symbolic parameters and the way that values are assigned to this type of variable symbol. Here a second type of variable symbol, the system variable symbol, will be introduced. System variable symbols are automatically assigned values by the assembler. In this section, only &SYSNDX will be covered.

The system variable symbol &SYSNDX provides the means for creating unique names for any number of statements that can be generated from the same model statement. This is accomplished by concatenating &SYSNDX with other characters in the name field of a model statement. Then, when the macro in which the model statement appears is invoked, these characters and the value assigned by the system to &SYSNDX become the label of the statement generated from that model statement.

The value assigned to &SYSNDX by the system is a four-digit number. When the first macro instruction in a program is encountered, &SYSNDX

is assigned a value of 0001. Then, as each subsequent macro instruction is encountered, the value of &SYSNDX is incremented by 1.

The following example illustrates how &SYSNDX can be used:

```
         MACRO
&LABEL   INVOKE &NAME
.* THE INVOKE MACRO CAN BE USED TO GENERATE A CALL TO THE MODULE
.* DESIGNATED BY THE SINGLE PARAMETER.  BOTH REGISTER 14 AND
.* REGISTER 15 ARE AUTOMATICALLY RESTORED TO THEIR ORIGINAL VALUES
.* AFTER THE CALL.
&LABEL   STM   R14,R15,IN&SYSNDX
         L     R15,=V(&NAME)
         BALR  R14,R15
         LM    R14,R15,IN&SYSNDX
         B     LV&SYSNDX
IN&SYSNDX DS   2F
LV&SYSNDX DS   0H
         MEND
```

If the macro INVOKE were referenced somewhere in the program by the macro instruction

```
INVOKE   READ
```

and if this were the twenty-third macro instruction to be processed, the following code would be generated:

```
         STM     R14,R15,IN0023
         L       R15,=V(READ)
         BALR    R14,R15
         LM      R14,R15,IN0023
         B       LV0023
IN0023   DS      2F
LV0023   DS      0H
```

It is important to note that no other macro instruction in the program that references the macro INVOKE would cause the same labels to be generated.

The assembler listing in Program 9-3 illustrates the use of a macro called ARRIVE.

## Exercises

**1.** Occasionally, it is necessary to compute the first power of two greater than a known value. Write a macro, NEXTP2 such that

```
&LABEL    NEXTP2   &REG
```

sets R0 to the first power of 2 greater than the value in the register &REG. For example,

```
FINDNUM   NEXTP2   R10
```

**Program 9-3**

```
LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                  1          MACRO
                                  2 &LABEL   EXIT
                                  3 .*
                                  4 .* THIS MACRO GENERATES THE CODE REQUIRED TO RETURN FROM A MODULE.
                                  5 .* IT ASSUMES NORMAL OS LINKAGE CONVENTIONS.
                                  6 .*
                                  7 * NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
                                  8 * WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
                                  9 * IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
                                 10 &LABEL   L      R13,4(R13)          LOAD ADDRESS OF CALLER'S SAVE AREA
                                 11          LM     R14,R12,12(R13)     RESTORE CALLER'S REGISTERS
                                 12          BR     R14
                                 13          MEND
                                 14          MACRO
                                 15 &LABEL   INVOKE &NAME
                                 16 .*
                                 17 .* THIS MACRO CAN BE USED TO INVOKE AN EXTERNAL ROUTINE.  THE NAME
                                 18 .* OF THE ROUTINE TO BE CALLED SHOULD BE GIVEN AS THE FIRST OPERAND.
                                 19 .*
                                 20 &LABEL   L      R15,=V(&NAME)       LOAD ADDRESS OF ROUTINE TO CALL
                                 21          BALR   R14,R15             CALL THE ROUTINE
                                 22          MEND
                                 23          MACRO
                                 24 &NAME    ARRIVE &BR
                                 25 .*
                                 26 .* THIS MACRO CAN BE INVOKED TO ESTABLISH A CSECT, SET
                                 27 .* UP A SAVE AREA, AND INITIALIZE A BASE REGISTER.  THE
                                 28 .* SINGLE OPERAND SPECIFIES THE BASE REGISTER.
                                 29 .* THE REGISTER NUMBER MUST BE SPECIFIED AS A NUMERIC VALUE; FOR
                                 30 .* EXAMPLE BR12 SHOULD BE SPECIFIED AS 12.
                                 31 .*
                                 32 &NAME    CSECT
                                 33          STM    R14,R12,12(R13)     SAVE CALLER'S REGISTERS
                                 34          AIF    (&BR EQ 13).BASE13  BRANCH IF R13 IS TO BE THE BASE
                                 35          BALR   R&BR,0              SET UP THE BASE REGISTER
                                 36          USING *,R&BR
                                 37          LA     R14,SAVE&SYSNDX     R14 <- ADDRESS OF THE SAVE AREA
                                 38          B      ST&SYSNDX           BRANCH AROUND THE SAVE AREA
                                 39          AGO    .NOT13
                                 40 .BASE13  BAL    R14,80(R15)         R14 <- ADDRESS OF THE SAVE AREA
                                 41 .NOT13   ANOP
                                 42 SAVE&SYSNDX DS 18F                  REGISTER SAVE AREA
                                 43          SPACE
                                 44 ST&SYSNDX ST    R13,4(R14)          SET BACK LINK IN THE SAVE AREA
                                 45          ST     R14,8(R13)          SET THE FORWARD POINTER
                                 46          LR     R13,R14             R13 IS THE BASE
                                 47          AIF    (&BR NE 13).END
                                 48          USING SAVE&SYSNDX,R13
                                 49 .END     MEND
```

**Program 9-3 (continued)**

```
                                                                                                  PAGE    2

  LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT

                                    51 * THIS SIMPLE PROGRAM ILLUSTRATES THE USE OF MACROS.  IT SIMPLY

                                    52 * CALLS A SUBROUTINE TO SORT A TABLE.  TWO MACROS ARE USED,
                                    53 * ONE TO GENERATE THE CALL TO SORT AND ONE TO GENERATE THE
                                    54 * INSTRUCTIONS TO CAUSE AN EXIT FROM THE PROGRAM.
                                    55 MAIN     ARRIVE 13
000000                              56+MAIN     CSECT
000000 90EC D00C          00000C    57+         STM   R14,R12,12(R13)      SAVE CALLER'S REGISTERS
000004 45EF 0050          00050     58+         BAL   R14,80(R15)          R14 <- ADDRESS OF THE SAVE AREA
000008                              59+SAVE0001 DS    18F                  REGISTER SAVE AREA

000050 50DE 0004          00004     61+ST0001   ST    R13,4(R14)           SET BACK LINK IN THE SAVE AREA
000054 50ED 0008          00008     62+         ST    R14,8(R13)           SET THE FORWARD POINTER
000058 18DE                         63+         LR    R13,R14              R13 IS THE BASE
                          00008     64+         USING SAVE0001,R13
00005A 9823 0068          00070     65          LM    R2,R3,=A(TABLE,10)   LOAD PARAMETERS FOR CALL TO 'SORT'
                                    66          INVOKE SORT                CALL THE ROUTINE SORT
00005E 58F0 0070          00078     67+         L     R15,=V(SORT)         LOAD ADDRESS OF ROUTINE TO CALL
000062 05EF                         68+         BALR  R14,R15              CALL THE ROUTINE
                                    69 LEAVE    EXIT
                                    70** NOTE THAT THIS MACRO GENERATES THE CODE TO EXIT FROM A MODULE
                                    71** WHICH HAS ESTABLISHED A SAVE AREA FOR CALLS TO LOWER LEVEL MODULES.
                                    72** IT SHOULD NOT BE USED TO EXIT FROM A LOWEST LEVEL SUBROUTINE.
000064 58DD 0004          00004     73+LEAVE    L     R13,4(R13)           LOAD ADDRESS OF CALLER'S SAVE AREA
000068 98EC D00C          0000C     74+         LM    R14,R12,12(R13)      RESTORE CALLER'S REGISTERS
00006C 07FE                         75+         BR    R14
000070                              76          LTORG
000070 0000007C0000000A             77                =A(TABLE,10)
000078 00000000                     78                =V(SORT)
00007C 00000004FFFFFFF6             79 TABLE    DC    F'4,-10,9,43,32,-8,12,0,1,64'
0000A4                              80 CARD     DS    CL80                 INPUT CARD AREA
                          00002     81 R2       EQU   2
                          00003     82 R3       EQU   3
                          0000C     83 R12      EQU   12
                          0000D     84 R13      EQU   13
                          0000E     85 R14      EQU   14
                          0000F     86 R15      EQU   15
                                    87          END
```

might generate

```
FINDNUM  LA    R0, 1
         CR    R0, R10
         BNL   *+10
         AR    R0, R0
         B     *-8
```

Note that this code includes 4 instructions in the tight loop. Can you reduce the number of instructions in the loop? Can you easily generalize your macro to allow you to compute the next power of any number? For example, let

```
NEXTP R10, 5
```

set R0 to the first power of 5 greater than or equal to R10.

**2.** It is occasionally necessary to move more than 256 bytes of data from one field to another. Commonly, the length of the move cannot be determined until execution time. With an IBM 370, you can simply use the MVCL instruction to perform the required operation. No such instruction exists on an IBM 360, however. Code a macro BIGMVC that can be invoked to execute long moves on an IBM 360. The first two operands of BIGMVC should specify the addresses of the receiving and sending fields, respectively. The third operand should specify a register containing the number of bytes to be moved. For example,

```
MOVE     BIGMVC     FIELD1,FIELD2,R8
```

should generate something similar to

```
MOVE     STM    R14,R1,SAVR0023
         LR     R0,R8
         LA     R14,FIELD1
         LA     R15,FIELD2
         LA     R1,255
LP0023   CR     R0,R1
         BH     *+8
         LR     R1,R0
         BCTR   R1,0
         EX     R1,MOV0023
         LA     R14,1(R1,R14)
         LA     R15,1(R1,R15)
         SH     R0,=H'256'
         BP     LP0023
         LM     R14,R1,SAVR0023
         B      SAVR0023+16
MOV0023  MVC    0(0,R14),0(R15)
SAVR0023 DS     4F
```

**3.** In Section 4.7, routines were given to add, subtract, or compare two-word, fixed-point integers. Write the macros to generate the appropriate code. The prototype instructions should be as follows:

```
&LABEL   ADDL    &DWD1,&DWD2
&LABEL   SUBL    &DWD1,&DWD2
&LABEL   COMPL   &DWD1,&DWD2
```

Thus,

```
         ADDL    NUM1,NUM2
```

should generate something similar to

```
         STM     R0,R1,SAVR0004
         LM      R0,R1,NUM1
         AL      R1,NUM2+4
         BC      B'1100',*+8
         A       R0,=F'1'
         A       R0,NUM2
         STM     R0,R1,NUM1
         LM      R0,R1,SAVR0004
         B       SAVR0004+8
SAVR0004 DS      2F
```

**4.** In Exercise 3 following Section 8.11, you were asked to code an external subroutine that could be invoked to generate random numbers. Write a macro, RANGEN, that can be invoked to generate a call to the random number generator. The prototype statement of RANGEN should be

```
&NAME    RANGEN    &UPPER,&LOWER,&XVALUE
```

where &UPPER is the address of a one-word field containing the upper bound

&LOWER is the address of a one-word field containing the lower bound

&XVALUE is an optional parameter giving the address of a word that should be used to reset the XVALUE field

Thus,

```
         RANGEN    UP,LOW.
```

should generate something similar to

```
         STM     R14,R15,SAVR0010
         L       R15,=V(RANDOM)
         LA      R1,PLST0010
         BALR    R14,R15
         LM      R14,R15,SAVR0010
```

```
            B       NXT0010
SAVR0010    DS      2F
PLST0010    DC      A(UP)
            DC      X'80'
            DC      AL3(LOW)
NXT0010     DS      0H
```

**5.** Write a macro called INCR that can be used to increment a fullword in memory. The prototype of INCR should be

```
&LABEL    INCR    &ADDR,&INCR
```

where &ADDR is the address of the word in storage
&INCR is a decimal number specifying the increment

The code generated by the macro might destroy the contents of R0.

---

## 9.3 ARITHMETIC SET SYMBOLS

SET symbols constitute the third type of variable symbols that can be used in macro definitions. SET symbols are classified as arithmetic, binary, or character, depending upon the nature of the values that can be assigned to them. As in the case of system variables, each SET symbol is assigned an initial value by the macro processor. However, unlike system variables or symbolic parameters, the values assigned to SET symbols can be altered during the expansion of a macro instruction.

SET symbols are of two types, *local* and *global*. A local SET symbol is assigned an initial value every time that a macro instruction references a macro definition containing an occurrence of that SET symbol. If several macro definitions contain occurrences of the same local SET symbol, these occurrences are treated as distinct SET symbols. Thus, if &VAR were a local SET symbol occurring in two separate macro definitions, it would be processed as if these occurrences had been given different names in the two macro definitions. On the other hand, global SET symbols are initialized just once—the first time that a macro definition containing an occurrence of the given symbol is invoked. Thus, the use of global SET symbols allows values to be passed between the different macro instructions occurring in a program. A detailed example of this technique will be presented later in this section. Only the arithmetic SET symbols will be discussed further in this section. Detailed discussions of the binary and character SET symbols are deferred to Sections 9.4 and 9.5, respectively.

The following instructions can be used to define and to alter the values of arithmetic SET symbols:

1. One or more statements of the form

GBLA symbol1,symbol2, . . .

must be used in a macro definition to declare all of the global arithmetic SET symbols occurring in that definition. This statement or statements should immediately follow the prototype statement in the macro definition. The first time that a macro definition containing an occurrence of a GBLA statement defining a given global arithmetic SET symbol is invoked, a value of 0 is assigned to that SET symbol. On any subsequent invocation of this macro definition (or other macro definitions containing an occurrence of a GBLA statement defining the SET symbol under discussion), the value last assigned to that SET symbol is unaltered.

2. One or more statements of the form

LCLA symbol1,symbol2, . . .

must be used in a macro definition to declare all of the local arithmetic SET symbols occurring in that definition. This statement or statements should immediately follow the declarations of global SET symbols, if any. If no global SET symbols are declared in the macro definition, then the statements declaring the local symbols must immediately follow the prototype statement. Every time that the macro processor processes an LCLA statement, the value of each local arithmetic symbol defined in that statement is initialized to 0.

3. Statements of the form

symbol SETA arithmetic-expression

can be used to assign the value represented by arithmetic-expression to a global or local arithmetic SET symbol. Integer values in the range $-2^{31}$ to $2^{31}-1$ are allowable. For example, the statement

&RANGE SETA (&VALUE*16)/X'A'

could be used to assign a value to the arithmetic SET symbol &RANGE. Because SETA statements are used to assign values to arithmetic SET symbols, these symbols themselves are sometimes called SETA symbols.

The following example illustrates how local SETA symbols can be used in a macro definition:

```
         MACRO
         EQUREGS
         LCLA  &REG
.*
.* THIS MACRO CAN BE INVOKED TO GENERATE THE SIXTEEN REGISTER EQUATES
.* REQUIRED TO REFERENCE REGISTERS AS R0, R1, R2, ...
.*
.LOOP    ANOP
R&REG    EQU   &REG
&REG     SETA  &REG+1
         AIF   (&REG LE 15).LOOP
         MEND
```

Since &REG has been declared to be a local SETA symbol, its value is initialized to 0 each time the macro EQUREGS is invoked. Therefore,

```
R0          EQU     0
```

is, inevitably, the first statement generated in the expansion of this macro. The SETA statement causes &REG to be incremented by 1 each time the loop is executed, and a branch to .LOOP occurs in case all 16 EQUates have not been generated.

A somewhat more complex example is required to illustrate the use of global SETA symbols. The two macros COUNT and GENTAB in Program 9-4 provide the programmer with a convenient means of keeping a count of how many times any given section of code in a program is executed.

**Program 9-4**

```
         MACRO
&LABEL   COUNT &ENTRY
         GBLA  &MAX
         LCLA  &DISP
.*
.* THIS MACRO CAN BE INVOKED TO ADD 1 TO THE ENTRY IN 'COUNTERS' GIVEN
.* BY THE ONLY OPERAND.  THE USES OF THE VARIABLE SYMBOLS ARE AS
.* FOLLOWS:
.*
.*       &ENTRY      GIVES THE NUMBER OF THE ENTRY IN THE TABLE.  THIS
.*                   ENTRY WILL BE INCREMENTED BY 1.  THE ENTRIES IN THE
.*                   TABLE ARE NUMBERED STARTING WITH 1.
.*
.*       &MAX        IS SET TO THE MAXIMUM ENTRY REFERENCED SO FAR BY A
.*                   COUNT MACRO.  IT WILL BE USED BY GENTAB TO
.*                   DETERMINE HOW MANY ENTRIES SHOULD BE IN 'COUNTERS'.
.*
.*       &DISP       IS SET TO THE DISPLACEMENT INTO 'COUNTERS' OF THE
.*                   REFERENCED 5-BYTE ENTRY.
.*
         AIF   (&MAX GE &ENTRY).GETDISP
.* NOW &MAX IS RESET, SINCE &ENTRY IS THE HIGHEST NUMBERED ENTRY
.* REFERENCED SO FAR.
&MAX     SETA  &ENTRY
.GETDISP ANOP
.* &DISP IS NOW SET TO THE DISPLACEMENT INTO 'COUNTERS' REQUIRED TO
.* REFERENCE THE DESIGNATED ENTRY.
&DISP    SETA  (&ENTRY-1)*5
&LABEL   AP    COUNTERS+&DISP.(5),=P'1'  INCREMENT THE COUNTER
         MEND
         MACRO
         GENTAB
         GBLA  &MAX
.* THIS MACRO SIMPLY GENERATES A TABLE OF 5-BYTE PACKED DECIMAL
.* COUNTERS.  THE NAME OF THE TABLE IS 'COUNTERS', AND IT WILL CONTAIN
.* &MAX ENTRIES.
COUNTERS DC    &MAX.PL5'0'        TABLE OF COUNTERS
         MEND
```

When these macros are included in a program, a macro instruction of the form

```
name        COUNT  n
```

will cause 1 to be added to the nth counter in a table of counters each time it is executed; a macro instruction of the form

```
            GENTAB
```

causes a table called COUNTERS to be generated at the end of the program along with the constants. The following sequence of code illustrates the use of these macros:

```
LOOP        .
            .
            .
            .
            BE        ROUT2
ROUT1       COUNT     1
            .
            .
            .
            B         LOOP
ROUT2       COUNT     2
            .
            .
            .
            B         LOOP
END         XDUMP     COUNTERS,10
            .
            .
            .
            LTORG
            GENTAB
            END
```

A careful study of the macros will indicate that, if the preceding sequence of code were executed, the XDUMP instruction would display the table COUNTERS in such a way that (1) the first entry would indicate the number of times that ROUT1 was executed and (2) the second entry would indicate the number of times that ROUT2 was executed.

Note how the global SETA symbol is used to pass a value from the COUNT macro instructions to the GENTAB macro. For the variable &MAX to be set properly to the number of entries required in the table COUNTERS, the occurrence of the GENTAB macro instruction in a program must follow all occurrences of macro instructions invoking the COUNT macro.

Program 9-5 presents a simple program, along with the output produced, as an illustration of exactly what code is produced by the COUNT and GENTAB macros.

**Program 9-5**

```
BALANCE-AN ILLUSTRATION OF THE COUNT AND GENTAB MACRUS                                                    PAGE    2

 LCC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                    52 *
                                    53 * THIS SIMPLE PROGRAM ILLUSTRATES THE USE OF THE COUNT AND
                                    54 * GENTAB MACRUS.  IT READS CARDS REPRESENTING CHECKS AND DEPOSITS
                                    55 * AGAINST A BANK ACCOUNT AND CALCULATES THE RESULTING BALANCE.
                                    56 * IN THE CODE THE AMOUNT OF A DEPOSIT IS COMPLEMENTED AND THEN
                                    57 * PROCESSED IN THE SAME MANNER AS THAT OF A CHECK.  IF THERE
                                    58 * WERE ACTUALLY MORE DEPOSITS THAN CHECKS, IT WOULD BE FASTER
                                    59 * TO COMPLEMENT THE CHECKS.  TO TEST WHICH ACTUALLY OCCURS
                                    60 * MORE, TWO COUNT MACRO INSTRUCTIONS ARE USED.
                                    61 *
 000000                             62 BALANCE  CSECT
                                    63 *
                                    64 ***<STEP 1>    SAVE REGISTERS AND ESTABLISH THE BASE REGISTER
 000000 90EC D00C            0000C  65          STM   R14,R12,12(R13)     SAVE ORIGINAL CONTENTS OF REGISTERS
 000004 18CF                        66          LR    R12,R15             R12 WILL BE THE BASE REGISTER
 000000                             67          USING BALANCE,R12
                                    68          EQUREGS
 000000                             69+R0       EQU   0
 000001                             70+R1       EQU   1
 000002                             71+R2       EQU   2
 000003                             72+R3       EQU   3
 000004                             73+R4       EQU   4
 000005                             74+R5       EQU   5
 000006                             75+R6       EQU   6
 000007                             76+R7       EQU   7
 000008                             77+R8       EQU   8
 000009                             78+R9       EQU   9
 00000A                             79+R10      EQU   10
 00000B                             80+R11      EQU   11
 00000C                             81+R12      EQU   12
 00000D                             82+R13      EQU   13
 00000E                             83+R14      EQU   14
 00000F                             84+R15      EQU   15
                                    85 *
                                    86 ***<STEP 2>    ZERO THE ACCUMULATOR
                                    87 *
                                    88 *
                                    89 ***<STEP 3>    READ IN A CARD. ON EOF GO TO STEP 6.
                                    90 *
 000006 1822                        91          SR    R2,R2               R2 ACCUMULATES THE BALANCE
 000008 E000 C053 0050 00053        92 LOOP     XREAD CARD,80             READ A CHECK OR DEPOSIT CARD
 00000E 4740 C032            00032  93          BC    8'0100',EOF         BRANCH ON END-OF-FILE
                                    94 *
 000012 5330 C054            00054  95          XDECI R3,CARD+1           GET THE AMOUNT
                                    96 *
                                    97 ***<STEP 4>    IF IT'S A DEPOSIT, COMPLEMENT THE AMOUNT.
                                    98 *
                                    99 *
 000016 95C3 C053            00053  100         CLI   CARD,C'C'           C => A CHECK; ELSE, IT'S A DEPOSIT
                                    101 *
                                    102 * THE NEXT FEW INSTRUCTIONS CAUSE THE AMOUNT TO BE COMPLEMENTED
                                    103 * IF THE CARD REPRESENTED A DEPOSIT.  THIS IS MORE EFFICIENT
                                    104 * THAN COMPLEMENTING THE CHECKS, ASSUMING THAT MORE CHECKS ARE
                                    105 * PROCESSED THAN DEPOSITS.  THIS ASSUMPTION CAN BE TESTED WITH
                                    106 * THE COUNT MACRO.  IF THE 1ST COUNTER IS MORE THAN HALF OF THE
```

## Program 9-5 (continued)

```
        BALANCE-AN ILLUSTRATION OF THE COUNT AND GENTAB MACROS                                                    PAGE    3
 LOC  OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                   107 * SECOND, THEN THE CODE IS INEFFICIENT.
                                   108 *
00001A 4780 C026             00026 109          BE    DONTCOMP          BRANCH IF IT WAS A CHECK
00001E 1333                        110          LCR   R3,R3             COMPLEMENT A DEPOSIT
                                   111 *
                                   112          COUNT 1
000020 FA40 C049 C048 00049 00048  113+         AP    COUNTERS+0(5),=P'1'       INCREMENT THE COUNTER
                                   114 *
                                   115 *
                                   116 ***<STEP 5>    SUBTRACT THE AMOUNT FROM THE ACCUMULATOR AND GO BACK.
                                   117 *
                                   118 DONTCOMP COUNT 2
000026 FA40 C04E C048 0004E 00048  119+DONTCOMP AP    COUNTERS+5(5),=P'1'       INCREMENT THE COUNTER
                                   120 *
00002C 1823                        121          SR    R2,R3             ACCUMULATE THE BALANCE
00002E 47F0 C008             00008 122          B     LOOP
                                   123 *
                                   124 *
                                   125 ***<STEP 6>    PRINT THE FINAL ANSWER AND EXIT.
000032 5220 C0A8             000A8 126 EOF      XDECO R2,OUTVAL         PRINT THE BALANCE
000036 E020 C0A3 0014 000A3        127          XPRNT ANSWER,20
                                   128 *
00003C E060 C049 0008 00049        129          XDUMP COUNTERS,8
                                   130 *
000042 98EC D00C             0000C 131          LM    R14,R12,12(R13)   RESTORE ORIGINAL CONTENTS OF THE REGS
000046 07FE                        132          BR    R14               EXIT
                                   133 *
                                   134          LTORG
000048 1C                          135                =P'1'
                                   136 *
                                   137          GENTAB
000049 000000000C000000            138+COUNTERS DC    2PL5'0'           TABLE OF COUNTERS
                                   139 *
000053                             140 CARD     DS    CL80              READ CARDS INTO HERE
000A3 F0                           141 ANSWER   DC    C'0'              CARRIAGE CONTROL
000A4 C1D5E2E6C5D97E               142          DC    C'ANSWER='
000A8                              143 OUTVAL   DS    CL12              BALANCE IS PUT HERE
                                   144          END   BALANCE

***  NO   STATEMENTS FLAGGED -  NO   WARNINGS,  NO   ERRORS

*** DYNAMIC CORE AREA USED:  LOW:     5884 HIGH:     624 LEAVING:   59028 FREE BYTES. AVERAGE:       44 BYTES/STMT ***

*** ASSEMBLY TIME =    0.676 SECS,      214 STATEMENTS/SEC ***

*** PROGRAM EXECUTION BEGINNING - ANY OUTPUT BEFORE EXECUTION TIME MESSAGE IS PRODUCED BY USER PROGRAM ***

ANSWER=        3306

BEGIN XSNAP - CALL      1 AT 00000042 USER STORAGE

                                CORE ADDRESSES SPECIFIED-      000049 TO 000051
000040   00089BEC 000C07FE 1C000000 002C0000    00008CC3 F2F4F040 40404040 40404040   *.....................C240          *
```

Although it may not be readily apparent to the reader, the COUNT and GENTAB macros can be quite useful. For example, in complex routines that must be coded as efficiently as possible, these macros could be used to determine which sections of code are executed most frequently. The information thus obtained could then be utilized in deciding which constants should be kept in registers. The capacity to make such decisions correctly can sometimes radically reduce the execution time required by a complex routine.

## 9.4 BINARY SET SYMBOLS

The binary SET symbols are SET symbols that can be assigned a value of only 0 or 1. The statements used to define binary SET symbols and to assign values to these symbols are as follows:

1. A statement or statements of the form

   ```
   GBLB     symbol1,symbol2, . . .
   ```

   must be used in a macro definition to declare all of the global binary SET symbols that occur in that definition. Although the order within the sequence of statements declaring global SET symbols in a macro definition is not critical, the sequence of all such statements should immediately follow the prototype statement. As in the case of the global SETA symbols, a global binary SET symbol is initialized to a value of 0 just once—the first time a macro definition containing a GBLB statement that contains an occurrence of that particular symbol is invoked.

2. A statement or statements of the form

   ```
   LCLB     symbol1,symbol2, . . .
   ```

   must be used to declare all of the local binary SET symbols occurring in a macro definition.

3. Statements of the form

   ```
   symbol     SETB     logical-expression
   ```

   can be used to alter the values assigned to binary SET symbols. Here, logical-expression includes the class of logical expressions defined in Section 9.2; in addition, a binary SET symbol enclosed within parentheses is also considered to be a logical expression. Thus, the two statements

   ```
   &BSYM     SETB     ('&WAY' EQ 'DOWN')
   ```

   and

   ```
   &BSYM     SETB     (&SYM2)
   ```

   are both valid if it is assumed that &SYM2 is a binary SET symbol. Just as the arithmetic SET symbols are sometimes referred to as SETA symbols, the binary SET symbols are often referred to as SETB symbols.

The expanded class of logical expressions introduced in item 3 above can also be used in conjunction with AIF statements. For example, the statement

```
AIF      (&BSYM).SEQSYM
```

causes a branch to .SEQSYM only when &BSYM has an assigned value of 1.

Global SETB symbols are used far more frequently than local SETB symbols, and in the vast majority of cases these symbols perform a similar function. To illustrate the function for which these symbols are most commonly used, we shall reconsider the macro EQUREGS introduced in the last section. Suppose that a subroutine containing a macro instruction to invoke EQUREGS has been coded. Then, if a calling routine that also contains a macro instruction to invoke EQUREGS is assembled along with this subroutine, two occurrences of the sequence of instructions

```
R0       EQU    0
R1       EQU    1
         .
         .
         .
R15      EQU    15
```

would be generated. Suppose also that there are occasions when it would be desirable to assemble the subroutine by itself. Then, if the macro instruction to invoke EQUREGS were removed from the subroutine, errors would occur. The following version of EQUREGS could be used to overcome this difficulty:

```
         MACRO
         EQUREGS
         GBLB  &EQUREGS
         LCLA  &REG
.*
.* THIS MACRO CAN BE INVOKED TO GENERATE THE SIXTEEN REGISTER EQUATES
.* REQUIRED TO REFERENCE REGISTERS AS R0, R1, R2, ...
.*
.* IF MORE THAN 1 EQUREGS OCCUR IN THE SAME PROGRAM,
.* THERE WILL STILL BE ONLY 1 SET OF EQUATES GENERATED
.* (&EQUREGS=1 -> ONE SET OF EQUATES HAS BEEN
.* GENERATED).
.*
         AIF   (&EQUREGS).END
&EQUREGS SETB  1
.LOOP    ANOP
R&REG    EQU   &REG
&REG     SETA  &REG+1
         AIF   (&REG LE 15).LOOP
.END     MEND
```

Program 9-6 illustrates the implementation of a similar technique to increase the flexibility of the COUNT and GENTAB macros introduced in Section 9.3.

**Program 9-6**

```
         MACRO
&LABEL   COUNT &ENTRY
         GBLA  &MAX
         GBLB  &COUNT
         LCLA  &DISP
.*
.* THIS MACRO CAN BE INVOKED TO ADD 1 TO THE ENTRY IN 'COUNTERS' GIVEN
.* BY THE ONLY OPERAND.  THE USES OF THE VARIABLE SYMBOLS ARE AS
.* FOLLOWS:
.*
.*       &ENTRY      GIVES THE NUMBER OF THE ENTRY IN THE TABLE.  THIS
.*                   ENTRY WILL BE INCREMENTED BY 1.  THE ENTRIES IN THE
.*                   TABLE ARE NUMBERED STARTING WITH 1.
.*
.*       &MAX        IS SET TO THE MAXIMUM ENTRY REFERENCED SO FAR BY A
.*                   COUNT MACRO.  IT WILL BE USED BY GENTAB TO
.*                   DETERMINE HOW MANY ENTRIES SHOULD BE IN 'COUNTERS'.
.*
.*       &DISP       IS SET TO THE DISPLACEMENT INTO 'COUNTERS' OF THE
.*                   REFERENCED 5-BYTE ENTRY.
.*
.*       &COUNT      CAN BE SET TO 1 TO SUPPRESS GENERATION
.*                   OF ANYTHING BUT A LABEL.
.*                   THE SETTING OF &COUNT CAN BE ALTERED WITH
.*                   THE SETCNT MACRO.
.*
         AIF   (&MAX GE &ENTRY).GETDISP
.* NOW &MAX IS RESET, SINCE &ENTRY IS THE HIGHEST NUMBERED ENTRY
.* REFERENCED SO FAR.
&MAX     SETA  &ENTRY
.GETDISP ANOP
.* &DISP IS NOW SET TO THE DISPLACEMENT INTO 'COUNTERS' REQUIRED TO
.* REFERENCE THE DESIGNATED ENTRY.
&DISP    SETA  (&ENTRY-1)*5
&LABEL   DS    0H   GENERATE THE LABEL
         AIF   (&COUNT).END
         AP    COUNTERS+&DISP.(5),=P'1'  INCREMENT THE COUNTER
.END     MEND
         MACRO
         GENTAB
         GBLA  &MAX
         GBLB  &COUNT
.* THIS MACRO SIMPLY GENERATES A TABLE OF 5-BYTE PACKED DECIMAL
.* COUNTERS.  THE NAME OF THE TABLE IS 'COUNTERS', AND IT WILL CONTAIN
.* &MAX ENTRIES.  IF &COUNT HAS BEEN SET TO 1, GENERATION
.* OF THE TABLE WILL BE SUPPRESSED.
         AIF   (&COUNT).END
COUNTERS DC    &MAX.PL5'0'        TABLE OF COUNTERS
.END     MEND
```

In this case, the code necessary to define the table and to increment the counters is generated only when &COUNT has a value of 0. This would allow the counting facility to be turned on or off in a program without the necessity of adding or removing a large number of statements. The following macro SETCNT could, in fact, be used to set the variable &COUNT:

```
         MACRO
         SETCNT &ONOFF
         GBLB  &COUNT
.*
.* THIS MACRO CAN BE USED TO CONTROL THE GENERATION OF CODE BY THE
.* COUNT AND GENTAB MACROS BY ALTERING THE SETTING OF &COUNT.
.*
.*    &ONOFF = ON MEANS THAT &COUNT WILL BE SET TO 0.
.*
.*    &ONOFF = OFF MEANS THAT &COUNT WILL BE SET TO 1.
.*
.*    &ONOFF = ANY OTHER VALUE WILL HAVE NO EFFECT.
.*
         AIF   ('&ONOFF' NE 'ON').TRYOFF
&COUNT   SETB  0
         AGO   .END
.TRYOFF  AIF   ('&ONOFF' NE 'OFF').END
&COUNT   SETB  1
.END     MEND
```

Thus, the macro instruction

```
LOOP      COUNT  4
```

will cause the instructions

```
LOOP      DS     0H
          AP     COUNTERS+15(5),=P'1'
```

to be generated if &COUNT has a value of 0. However, only the instruction

```
LOOP      DS     0H
```

is generated if the macro instruction

```
          SETCNT OFF
```

is inserted at the start of the program.

## 9.5 CHARACTER SET SYMBOLS

Character SET symbols are SET symbols that can be assigned character strings of from zero to eight characters in length as values. Because the way in which the GBLC and LCLC statements function is so similar to the way in which the global and local declaration statements discussed in Sections 9.3 and 9.4 function, no detailed discussion of these statements should be necessary. It must be noted, however, that the values of character SET symbols are initialized to the null string—rather than to 0, as is the case with arithmetic and binary SET symbols. On the other hand, an understanding of how the SETC statement can be used requires some knowledge of what constitutes a character expression.

A character expression can be formed by enclosing within apostrophes any of the following:

- a character string
- a variable symbol immediately followed by a period
- a concatenation of the preceding two

The character string to which a character expression of this form evaluates is determined by replacing each variable symbol in the expression, along with its associated period, with the value assigned to that variable symbol and removing the enclosing apostrophes. For example, if &SYM1 has an assigned value of AB% and &SYM2 has an assigned value of REG, the character expression

'AZ.&SYM1.C&SYM2.'

evaluates to the character string

AZ.AB%CREG

A substring of a character expression can be specified by placing two arithmetic expressions, separated by a comma and enclosed within parentheses, immediately following the character expression. The substring thus specified can be determined by the following method:

1. Evaluate the character expression and the two arithmetic expressions.
2. The result of evaluating the first arithmetic expression indicates which character in the character string is the first character of the substring.
3. The result of evaluating the second arithmetic expression specifies the length of the substring.

Thus, the substring specification

'ABCDEF'(2,2)

evaluates to BC. Similarly, if &VAR has an assigned value of 2 and &STR has an assigned value of ABCD, then the substring specification

'&STR.%'(2,&VAR*2)

will evaluate to BCD%.

A substring specification is a character expression, and more complex character expressions may be formed from sequences of character expressions by separating the individual expressions in the sequences by periods. For example, the character expression

'AB'.'CD'.'EFG'(1,2).'G'

evaluates to ABCDEFG.

The SETC instruction has the format

```
symbol      SETC      character-expression
```

The value assigned to the SETC symbol is determined by evaluating the character expression. If the result of this evaluation is a string of more than

eight characters in length, only the leftmost eight characters are assigned as a value to the SETC symbol.

Before the next macro example is presented, one more detail must be considered. Each macro instruction operand has certain attributes associated with it. One of these attributes, the *count attribute*, is the number of symbols in the operand. This attribute can be referenced by

```
K'&sym
```

where &sym is the symbolic parameter corresponding to the appropriate operand. For example, the prototype statement of the macro presented in Program 9-7 is

```
&LABEL   GET#    &FIELD
```

If the macro instruction

```
         GET#    F1(4)
```

were issued, K'&FIELD would be assigned a value of 5, since there are five symbols in F1(4). The count attribute of a symbolic parameter can be used in the composition of arithmetic expressions.

The following macro, GET#, can be used to generate a call to the GETNUM subroutine presented in Section 8.8. In this case, a two-word parameter list must be generated by the macro. The information from which the list is generated is extracted from the single operand of the GET# macro. For example, if the macro instruction

```
         GET#    F1(4)
```

were coded, the parameter list generated for the call to GETNUM would be

```
         DC      A(F1,*+4)
                 A(4)
```

The definition of GET# is as shown in Program 9-7.

## 9.6 THE MNOTE AND MEXIT INSTRUCTIONS

The two instructions introduced in this section, MNOTE and MEXIT, can be used only in macro definitions.

The MNOTE instruction is used to generate an error message in an assembler listing. It is normally good practice to utilize this statement wherever error checks are made in macro definitions. The most common format for the MNOTE instruction is

```
         MNOTE   'error message'
```

**Program 9-7**

```
         MACRO
&LABEL   GET#  &FIELD
         LCLC  &ADDR,&LEN,&SUF
         LCLA  &SCANNER
.*
.* THIS MACRO CAN BE USED TO GENERATE A CALL TO 'GETNUM', THE MODULE
.* PRESENTED IN CHAPTER 8.  THE PARAMETER LIST FOR 'GETNUM' IS AS
.* FOLLOWS:
.*
.*       ADDRESS OF A FIELD CONTAINING A NUMBER
.*       ADDRESS OF A WORD CONTAINING THE LENGTH OF THE FIELD
.*
.* THE MEANINGS OF THE VARIABLE SYMBOLS USED BY GET# ARE:
.*
.*       &FIELD     SHOULD BE THE LABEL OF A FIELD IMMEDIATELY
.*                  FOLLOWED BY THE LENGTH IN PARENTHESES.  FOR
.*                  EXAMPLE, F1(7) WOULD SPECIFIY THAT THE NUMBER
.*                  IS IN F1, WHICH IS A 7-BYTE FIELD.
.*
.*       &ADDR      IS SET TO THE SUBSTRING OF &FIELD THAT CONTAINS
.*                  THE NAME OF THE FIELD
.*
.*       &LEN       IS SET TO THE LENGTH OF THE FIELD
.*
.*       &SUF       IS SET TO THE VALUE OF &SYSNDX.  THIS ALLOWS
.*                  THE PROGRAMMER TO AVOID THE USE OF NAMES SUCH
.*                  AS TABL&SYSNDX, WHICH IS OVER 8 CHARACTERS LONG
.*
.*       &SCANNER   IS USED TO INDEX THE CHARACTER IN &FIELD THAT
.*                  IS CURRENTLY BEING SCANNED
.*
.* BRANCH TO .END IF &FIELD WAS ASSIGNED TOO FEW CHARACTERS
         AIF   (K'&FIELD LT 4).END
.* START SCANNING THE CHARACTERS IN &FIELD, STARTING WITH THE 2ND
&SCANNER SETA  2
.* THE FOLLOWING LOOP SCANS FOR THE LEFT PARENTHESIS IN &FIELD
.TESTL   AIF   ('&FIELD'(&SCANNER,1) EQ '(').GOTLEFT
         AIF   (&SCANNER EQ K'&FIELD-1).END
.* THE PRECEDING BRANCH IS TAKEN ONLY IF &FIELD IS INVALID
&SCANNER SETA  &SCANNER+1
         AGO   .TESTL
.GOTLEFT ANOP
&ADDR    SETC  '&FIELD'(1,&SCANNER-1)
         AIF   ('&FIELD'(K'&FIELD,1) NE ')').END
.* THE PRECEDING BRANCH IS TAKEN ONLY IF THE RIGHT PARAN IS MISSING
&LEN     SETC  '&FIELD'(&SCANNER+1,K'&FIELD-&SCANNER-1)
&SUF     SETC  '&SYSNDX'
&LABEL   ST    R14,SAVE&SUF
         LA    R1,PLST&SUF
         L     R15,=V(GETNUM)
         BALR  R14,R15
         L     R14,SAVE&SUF        RESTORE R14 (ONLY R0, R1, AND
*                                  R15 ARE ALTERED)
         B     SAVE&SUF.+4
PLST&SUF DC    A(&ADDR.,*+4)
         DC    A(&LEN.)            THIS WORD CONTAINS THE LENGTH
SAVE&SUF DS    F                   R14 IS SAVED HERE
.END     MEND
```

Execution of this instruction will cause the error message to be displayed in the assembler listing.

Optionally, the user can assign a severity code to the error through use of the format

```
        MNOTE   code,'error message'
```

The severity code, which will in this case be printed along with the error message, can be given an integer value in the range 0 to 255. If this code is omitted, a severity code of 1 is assigned by the assembler.

The MEXIT instruction can be used to terminate the processing of a macro definition. As an illustration, the sequence of code

```
        MACRO
        .
        .
        .
        MNOTE   '***MISSING OPERAND***'
        MEXIT
```

could be used rather than the sequence

```
        MACRO
        .
        .
        .
        MNOTE   '***MISSING OPERAND***'
        AGO     .END
        .
        .
        .
.END    MEND
```

Here the advantage is that, in the first sequence of code, an exit is made from the macro instruction immediately upon encountering the MEXIT instruction. In the second case, the assembler, having encountered the AGO instruction, must scan ahead for an instruction with a label .END. A significant time savings can be effected through the judicious use of MEXIT statements.

A rewritten version of the GET# macro is presented in Program 9-8 as an illustration of how the MEXIT and MNOTE instructions should be used.

**Program 9-8**

```
         MACRO
&LABEL   GET#  &FIELD
         LCLC  &ADDR,&LEN,&SUF
         LCLA  &SCANNER
.*
.* THIS MACRO CAN BE USED TO GENERATE A CALL TO 'GETNUM', THE MODULE
.* PRESENTED IN CHAPTER 8.  THE PARAMETER LIST FOR 'GETNUM' IS AS
.* FOLLOWS:
.*
.*       ADDRESS OF A FIELD CONTAINING A NUMBER
.*       ADDRESS OF A WORD CONTAINING THE LENGTH OF THE FIELD
.*
.* THE MEANINGS OF THE VARIABLE SYMBOLS USED BY GET# ARE:
.*
.*       &FIELD     SHOULD BE THE LABEL OF A FIELD IMMEDIATELY
.*                  FOLLOWED BY THE LENGTH IN PARENTHESES.  FOR
.*                  EXAMPLE, F1(7) WOULD SPECIFIY THAT THE NUMBER
.*                  IS IN F1, WHICH IS A 7-BYTE FIELD.
.*
.*       &ADDR      IS SET TO THE SUBSTRING OF &FIELD THAT CONTAINS
.*                  THE NAME OF THE FIELD
.*
.*       &LEN       IS SET TO THE LENGTH OF THE FIELD
.*
.*       &SUF       IS SET TO THE VALUE OF &SYSNDX.  THIS ALLOWS
.*                  THE PROGRAMMER TO AVOID THE USE OF NAMES SUCH
.*                  AS TABL&SYSNDX, WHICH IS OVER 8 CHARACTERS LONG
.*
.*       &SCANNER   IS USED TO INDEX THE CHARACTER IN &FIELD THAT
.*                  IS CURRENTLY BEING SCANNED
.*
.* BRANCH TO .END IF &FIELD WAS ASSIGNED TOO FEW CHARACTERS
         AIF   (K'&FIELD LT 4).END
.* START SCANNING THE CHARACTERS IN &FIELD, STARTING WITH THE 2ND
&SCANNER SETA  2
.* THE FOLLOWING LOOP SCANS FOR THE LEFT PARENTHESIS IN &FIELD
.TESTL   AIF   ('&FIELD'(&SCANNER,1) EQ '(').GOTLEFT
         AIF   (&SCANNER NE K'&FIELD-1).TRYNXT
.* AT THIS POINT AN ERROR HAS BEEN DETECTED; THERE WAS NO LEFT PAREN.
         MNOTE '*** MISSING LEFT PARENTHESIS ***'
         MEXIT
.TRYNXT  ANOP
&SCANNER SETA  &SCANNER+1
         AGO   .TESTL
.GOTLEFT ANOP
&ADDR    SETC  '&FIELD'(1,&SCANNER-1)
         AIF   ('&FIELD'(K'&FIELD,1) EQ ')').GOTRGHT
.* AT THIS POINT AN ERROR HAS BEEN DETECTED; THE LAST CHARACTER
.* IS NOT A RIGHT PARENTHESIS.
         MNOTE '*** MISSING RIGHT PARENTHESIS ***'
         MEXIT
```

**Program 9-8 (continued)**

```
.GOTRGHT ANOP
.* THE PRECEDING BRANCH IS TAKEN ONLY IF THE RIGHT PARAN IS MISSING
&LEN     SETC  '&FIELD'(&SCANNER+1,K'&FIELD-&SCANNER-1)
&SUF     SETC  '&SYSNDX'
&LABEL   ST    R14,SAVE&SUF
         LA    R1,PLST&SUF
         L     R15,=V(GETNUM)
         BALR  R14,R15
         L     R14,SAVE&SUF        RESTORE R14 (ONLY R0, R1, AND
*                                  R15 ARE ALTERED)
         B     SAVE&SUF.+4
PLST&SUF DC    A(&ADDR.,*+4)
         DC    A(&LEN.)            THIS WORD CONTAINS THE LENGTH
SAVE&SUF DS    F                   R14 IS SAVED HERE
.END     MEND
```

## 9.7 OPERAND SUBLISTS

Any single operand in a macro instruction can itself contain a list of operands. To achieve this, the list of operands must be written in the form of a sublist; that is, the elements in the list must be separated by commas and enclosed within parentheses. For example,

INVOKE SORT,(TABLE,20),2

is a macro instruction with three operands. The second operand is a sublist containing two elements. A discussion of the techniques used in processing operand sublists follows.

To motivate this discussion, the INVOKE macro introduced in Section 9.2 will be reconsidered. The version of INVOKE presented there can be used to generate a call to a subroutine. Now, consider the problem of recoding INVOKE in such a way that it could also be used to generate the parameter list to be passed to the subroutine that it invokes. There is no convenient general way to do this without utilizing sublists, because the number of parameters to be included in the parameter list varies with the module to be called.

However, if sublists are used, the prototype statement for INVOKE could be

&LABEL INVOKE &NAME,&PARMS,&NUM

where &PARMS can be assigned any sublist of parameters as its value and &NUM can be assigned a numeric value indicating the number of parameters in this sublist.

To reference an individual element in a sublist, a subscript is used with the symbolic parameter that corresponds to the sublist. For example, the second element of the sublist assigned to &PARMS is referenced by

&PARMS(2)

Although the subscript can be represented by more complex arithmetic expressions, an integer or a variable symbol is normally used for this purpose.

The version of INVOKE in Program 9-9 can be used to generate both a parameter list and the code required to call any module that may be needed.

**Program 9-9**

```
         MACRO
&LABEL   INVOKE &NAME,&PARMS,&NUM
         LCLA  &ELEMENT
.*
.* THIS VERSION OF THE INVOKE MACRO WILL NOT ONLY GENERATE A CALL TO
.* THE DESIRED MODULE; IT WILL GENERATE THE PARAMETER LIST FOR THE CALL
.* AS WELL.  THE MEANINGS OF THE VARIABLE SYMBOLS ARE:
.*
.*       &NAME     IS THE NAME OF THE MODULE WHICH IS TO BE CALLED.
.*
.*       &PARMS    GIVES THE PARAMETERS TO BE PUT IN THE PARAMETER
.*                 LIST.  *** NOTE *** THIS IS A SUBLIST OPERAND.
.*
.*       &NUM      GIVES THE NUMBER OF ELEMENTS IN THE SUBLIST
.*                 ASSIGNED TO &PARMS.
.*
.*       &ELEMENT  INDEXES THE ELEMENTS IN &PARMS AS THE PARAMETER
.*                 LIST IS BEING GENERATED.
.*
&LABEL   STM   R14,R15,IN&SYSNDX  STORE ALTERED REGISTERS
         L     R15,=V(&NAME.)     LOAD ADDRESS OF MODULE TO CALL
         AIF   ('&PARMS' EQ '').NOPARM1
*** NOTE THAT THE VALUE IN R1 IS DESTROYED BY THE CALL
         LA    R1,PLST&SYSNDX
.NOPARM1 BALR  R14,R15            CALL THE MODULE
         LM    R14,R15,IN&SYSNDX  RESTORE ALTERED REGISTERS
         B     LV&SYSNDX          BRANCH PAST STORAGE AREAS
IN&SYSNDX DS   2F                 STORE R14 AND R15 HERE
         AIF   ('&PARMS' EQ '').NOPARM2
.* NOW GENERATE THE PARAMETER LIST
PLST&SYSNDX DS OA                 PARAMETER LIST
.GENLOOP ANOP
&ELEMENT SETA  &ELEMENT+1
         DC    A(&PARMS(&ELEMENT).)
         AIF   (&ELEMENT LT &NUM).GENLOOP
.NOPARM2 ANOP
LV&SYSNDX DS   0H
         MEND
```

In Section 9.5, it was pointed out that the operands in macro instructions are assigned certain attributes and the count attribute was discussed. Another attribute, the *number attribute*, can be referenced to obtain the number of elements in an operand sublist. The number attribute is referenced by using

N'&operand

where &operand is the symbolic parameter corresponding to the operand sublist. Thus, if the macro instruction

```
INVOKE      SORT,(TABLE,20),2
```

were issued, N'&PARM would be assigned a value of 2. This eliminates the need for the third symbolic parameter in the prototype statement of INVOKE. That statement could be replaced by the statement

```
&LABEL   INVOKE  &NAME,&PARMS
```

and the statement

```
AIF      (&ELEMENT LT &NUM).GENLOOP
```

could be replaced by the statement

```
AIF      (&ELEMENT LT N'&PARMS).GENLOOP
```

In most cases, it is much more convenient to access the number attribute of an operand than to burden the programmer with filling in an additional operand, a task that can only lead to unnecessary mistakes.

&SYSLIST is a system variable that, like &SYSNDX, will prove to be quite useful. When a macro definition is processed, &SYSLIST is treated as if it were a symbolic parameter corresponding to an operand sublist, the elements of which are all of the operands in the macro instruction that invoked the macro. Thus, &SYSLIST(1) would refer to the first operand in the macro instruction, &SYSLIST(2) to the second, and so forth. If one of the operands is a sublist, double subscripts can be used with &SYSLIST to reference any individual element of the sublist. For example, if the macro instruction

```
TRANTAB     TRTAB X'00',(X'04',C' ')
```

were issued, &SYSLIST(2,2) in the macro definition would refer to C' '. The macro definition in Program 9-10 illustrates the use of &SYSLIST. The macro TRTAB can be used to generate a translate table.

## 9.8 KEYWORD MACRO DEFINITIONS

It is occasionally desirable to code a macro definition that involves parameters, some of which may be omitted or assume default values during most expansions of the macro. In such instances, keyword macro definitions should be used. A keyword macro definition is written in the same way as any other macro definition except that the operands in the prototype statement are different and &SYSLIST cannot be used in these definitions. The operands in the prototype statement are formed by immediately following a symbolic

**Program 9-10**

```
         MACRO
&TNAME   TRTAB
         LCLA  &PTR
.*
.* THE TRTAB MACRO CAN BE USED TO GENERATE A TRANSLATE TABLE.  THE
.* VARIABLE &TNAME WILL BE ASSIGNED AS THE NAME OF THE GENERATED
.* TABLE.  ALL OPERANDS ARE REFERENCED AS ELEMENTS OF &SYSLIST.
.* THE FIRST OPERAND GIVES THE DEFAULT CHARACTER TO BE ASSIGNED
.* TO ALL POSITIONS IN THE TABLE WHICH ARE NOT SPECIFIED IN LATER
.* OPERANDS.  ALL FOLLOWING OPERANDS ARE OF ONE OF THE TWO
.* FOLLOWING FORMS:
.*
.*     (<CHAR>,<POS>)              IN THIS CASE <CHAR> SHOULD BE PUT
.*                                 IN THE POSITION OF THE TABLE GIVEN
.*                                 BY <POS>.
.*
.*     (<CHAR>,<START>,<END>)      IN THIS CASE <CHAR> SHOULD BE PUT
.*                                 INTO ALL POSITIONS OF THE TABLE
.*                                 FROM <START> TO <END>.
.*
.* FOR EXAMPLE
.*
.*TAB      TRTAB X'00',(X'04',C'0',C'9'),(X'08',C' ')
.*
.* WOULD CAUSE A TABLE TO BE GENERATED WITH 04 IN THE POSITIONS
.* CORRESPONDING TO THE 10 NUMERIC DIGITS, 08 IN THE POSITION FOR
.* A BLANK, AND 00 IN ALL THE REMAINING POSITIONS.
.*
.* THE VARIABLE &PTR IS USED TO INDEX THE ELEMENTS OF &SYSLIST.
.*
         AIF   ('&TNAME' EQ '').ERR
         AIF   (N'&SYSLIST GE 2).OK
.ERR     MNOTE '*** TOO FEW OPERANDS ***'
         MEXIT
.OK      ANOP
&TNAME   DC    256&SYSLIST(1)
&PTR     SETA  1
.LOOP    ANOP
&PTR     SETA  &PTR+1
         ORG   &TNAME.+&SYSLIST(&PTR,2)
         AIF   (N'&SYSLIST(&PTR) EQ 2).JUSTTWO
         DC    (&SYSLIST(&PTR,3)-&SYSLIST(&PTR,2)+1)&SYSLIST(&PTR,1)
         AIF   (&PTR LT N'&SYSLIST).LOOP
         AGO   .TABDONE
.* THE FOLLOWING SECTION IS PROCESSED FOR TWO ELEMENT OPERANDS.
.JUSTTWO DC    &SYSLIST(&PTR,1)
         AIF   (&PTR LT N'&SYSLIST).LOOP
.TABDONE ORG
         MEND
```

parameter with an equals sign that is, optionally, immediately followed by a default value. For example, the statement

&LABEL ARRIVE &REGS=NO,&BR=, &CSECT=NO,&SAVE=NO

is a valid prototype statement for a keyword macro definition. When a keyword macro instruction is written, the operands in this instruction can occur in any order. These operands consist of symbolic parameters, with the ampersands omitted, followed immediately by an equal sign that is, in turn, followed by a value. For example,

ARRIVE BR=10,REGS=YES

is a valid keyword macro instruction. If this macro instruction were issued, &BR would be assigned 10 as its value, &REGS would be assigned YES as a value, and &CSECT and &SAVE would both be assigned their default value NO.

Three distinct advantages may be gained through the use of keyword macro definitions:

1. There is no need for the programmer to remember the order of the operands.
2. If operands are omitted, no specific actions are required (such as adding commas to indicate where the omissions occur).
3. Default values can be specified.

The first two advantages are significant only for macros that require more than a few operands.

The definition of the ARRIVE macro presented in Program 9-11 illustrates how a keyword macro definition should be coded. One interesting aspect of this macro is that the macro EQUREGS is invoked in the definition of ARRIVE. This use of a macro instruction in a macro definition is perfectly legal. This feature of the macro language allows a programmer to create hierarchies of more and more powerful macro definitions.

## Exercises

**1.** Write a macro called GETBITS that can be used to extract a range of bits from a register, putting them into the rightmost bits of a second register. For example

```
LAB     GETBITS R4,3,10,R10
```

would extract bits 3-10 from R4, placing them in the rightmost bits of R10. That is, code similar to the following should be generated:

```
LAB     LR      R10,R4
        SLL     R10,21
        SRL     R10,24
```

**2.** If you are programming on an IBM 370, you have the SRP instruction to shift packed decimal fields. However, on an IBM 360, short routines of the sort described in Section 8.11 are normally used.

**a.** Write a macro RSHIFT with the prototype

```
&LABEL  RSHIFT  &FIELD,&NUM
```

where &FIELD is a label followed by the length enclosed within parentheses

**Program 9-11**

```
         MACRO
&LABEL   ARRIVE &REGS=NO,&BR=,&CSECT=YES,&SAVE=YES
.*
.* THE ARRIVE MACRO GENERATES THE CODE REQUIRED TO ENTER A MODULE,
.* SET UP A BASE REGISTER, AND (OPTIONALLY) SET UP A SAVE AREA.
.* THE PARAMETERS ARE ALL KEYWORDS AND HAVE THE FOLLOWING
.* MEANINGS:
.*
.*     &REGS        - NO -> DO NOT GENERATE REGISTER EQUATES.
.*                    YES -> GENERATE REGISTER EQUATES.
.*
.*     &BR          - GIVES THE REGISTER TO BE SET UP AS THE BASE
.*                    REGISTER.
.*
.*     &CSECT       - YES -> GENERATE A CSECT STATEMENT.
.*                    NO -> DD NOT GENERATE A CSECT STATEMENT.
.*
.*     &SAVE        - YES -> GENERATE A SAVE AREA
.*                    NO -> THIS IS A LOWEST LEVEL SUBROUTINE, SO
.*                          DON'T GENERATE A SAVE AREA.
.*
         AIF   ('&REGS' EQ 'NO').NOREGS
         AIF   ('&REGS' NE 'YES').ERR1
         EQUREGS
.NOREGS  AIF   ('&CSECT' EQ 'NO').NOTCS
         AIF   ('&CSECT' NE 'YES').ERR2
&LABEL   CSECT
         STM   R14,R12,12(R13)    STORE CALLER'S REGS
.COMMON  AIF   ('&SAVE' EQ 'NO').NOSAVE
         AIF   ('&SAVE' NE 'YES').ERR3
         AIF   ('&BR' NE 'R13').NBR13
         BAL   R14,80(R15)
         USING *,R13
         DS    18F                REGISTER SAVEAREA
         ST    R14,8(R13)         SET UP LINKS
         ST    R13,4(R14)
         LR    R13,R14
         MEXIT
.NOTCS   USING *,R15
.* NOTE THAT IT IS ASSUMED THAT R15 CONTAINS THE ADDRESS OF THE
.* ENTRY POINT.
&LABEL   STM   R14,R12,12(R13)    STORE CALLER'S REGS
         AGO   .COMMON
.NOSAVE  AIF   ('&BR' EQ 'R13').ERR4
.SETBASE BALR  &BR,R0
         USING *,&BR
         MEXIT
.NBR13   BAL   R14,80(R15)
         DS    18F                REGISTER SAVEAREA
         ST    R14,8(R13)         SET UP LINKS
         ST    R13,4(R14)
         LR    R13,R14
         AGO   .SETBASE
.ERR1    MNOTE '*** BAD REGS PARAMETER ***'
         MEXIT
.ERR2    MNOTE '*** BAD CSECT PARAMETER ***'
         MEXIT
.ERR3    MNOTE '*** BAD SAVE PARAMETER ***'
         MEXIT
.ERR4    MNOTE '*** INVALID USE OF R13 ***'
         MEND
```

&NUM is the number of positions that the field should be shifted to the right

For example,

```
RSHIFT  F1(7),1
```

should generate

```
MVO     F1(7),F1(6)
```

**b.** Write a macro LSHIFT that can be used to generate the code required to shift a packed decimal field to the left. The prototype statement should be

```
&LABEL   LSHIFT  &FIELD,&NUM
```

where the operands are identical to those of RSHIFT.

**3.**

**a.** Modify COUNT and GENTAB so that the table COUNTERS contains the number of entries in the first word of the table.

**b.** Write a macro with the following prototype statement:

```
&NAME    TPRNT   &TABLE
```

The macro should generate a call to the subroutine TABPRINT, passing a parameter list containing only the address of the table to be displayed. TABPRINT should produce the following output:

```
THE TABLE CONTAINS n ENTRIES

COUNTER1 = c1
COUNTER2 = c2
      .
      .
      .
COUNTERn = cn
```

Thus,

```
TPRNT    COUNTERS
```

would cause the entries in COUNTERS to be printed. The macro may cause only registers R14, R15, and R1 to be altered.

**c.** Do the same as in Exercise 2b, but save and restore the values in R14, R15, and R1.

**4.** In Exercise 2 at the end of Section 9.2 you were asked to write three macros—ADDL, SUBL, and COMPL—which could be used to manipulate

64-bit fixed-point integers. Rewrite them so that both of the following are true:

**a.** The first time one of the macros occurs in a program, a short internal subroutine is generated, as well as a call to the subroutine.

**b.** On all subsequent occurrences, only the instructions required to call the subroutine are generated.

For example, suppose that

```
        ADDL    NUM1,NUM2
```

were the first occurrence of ADDL in a program. Then

```
*  NOTE THAT NEITHER R1, R2, R14, NOR R15 MAY BE
*  USED AS A BASE REGISTER.
        STM     R14,R2,SAV0005
        LM      R14,R15,=A(NUM1,NUM2)
        BAL     R2,ADDLRT
        LM      R14,R2,SAV0005
        B       SAV0005+20
ADDLRT  LM      R0,R1,0(R14)
        AL      R1,4(R15)
        BC      B'1100',*+8
        A       R0,=F'1'
        A       R0,0(R15)
        STM     R0,R1,0(R14)
        BR      R2
SAV0005 DS      5F
```

should be generated. If

```
ADD2    ADDL    NUM3,NUM4
```

were to occur later in the same program,

```
*  NOTE THAT NEITHER R1, R2, R14, NOR R15 MAY BE
*  USED AS A BASE REGISTER.
        STM     R14,R2,SAV0008
        LM      R14,R15,=A(NUM1,NUM2)
        BAL     R2,ADDLRT
        LM      R14,R2,SAV0008
        B       SAV0008+20
SAV0008 DS      5F
```

should be generated.

**5.** Write a macro called PARSE that can be used to call the subroutine PARSTRNG described in Exercise 4 at the end of Section 8.11. The prototype for PARSE should be

```
&LABEL   PARSE   &STRING,&KWORDS
```

where &STRING is a label followed by a length and is used to define the address and length of the string to be scanned

&KWORDS is a sublist operand with two elements per keyword to be scanned for: (1) the keyword and (2) the address of the doubleword into which the value should be packed.

Thus,

```
         PARSE   CARD(80),(TIME,DTIME, RATE,DRATE)
```

should generate something similar to

```
*  NOTE THAT R14, R15, R0, and R1 ARE ALTERED.
*  THE ERROR CODE WILL BE RETURNED IN R0.
         L       R15,=V(PARSTRNG)
         LA      R1,PLST0028
         BALR    R14,R15
         B       NXT0028
PLST0028 DC      A(CARD)
         DC      A(SLN0028)
         DC      A(*+8)
         DC      A(KNM0028)
         DC      FL1'4',CL11'TIME',A(DTIME)
         DC      FL1'4',CL11'RATE',A(DRATE)
SLN0028  DC      H'80'
KNM0028  DC      H'2'
NXT0028  DS      0H
```

**6.** In Exercise 2 at the end of Section 9.2, you were asked to code a macro BIGMVC that could be used to move a field of arbitrary length in situations where the length was not known at assembly time. Now write a macro called BMVC that can be used to move a field of arbitrary, but known, length. For example,

```
MOVE     BMVC    FIELD1(494),FIELD2
```

should generate

```
MOVE     MVC     FIELD1(256),FIELD2
         MVC     FIELD1+256(238),FIELD2+256
```

**7.** In this exercise you are to write four macros. Three will be used by the fourth, $CALL, which can be used to generate a call to an external subroutine. The definition of $CALL is as follows:

```
&LABEL    $CALL    &MOD,&LIST,&SAVE=NO
```

where &MOD is the name of the module to be invoked
&LIST specifies the contents of the parameter list (and is described below)
&SAVE is a keyword parameter. NO means R0, R1, R14, and R15 may be altered. YES means R0, R1, R14, and R15 must be stored and restored if they are altered. If &LIST is specified (i.e., if it is nonnull), all four registers should be stored and restored. If &LIST is omitted, only R14 and R15 should be saved.

&LIST will be of the form

(<P1>,<P2>, . . . ,<Pn>)

where <Pi> can be any of the following:

a. a register in parentheses
b. an address suitable for use in an RX instruction (such as an LA) preceded by an asterisk
c. a value that can be generated by an address constant (A-con)

For example, if &LIST is

(WORD,(R14),*10(R1),20)

the parameter list will eventually be composed of

- the address of WORD (generated by an A-con)
- the value from register 14
- the address generated by LA r,10(R1)
- the value 20 (generated by an A-con)

Thus,

```
GENCALL  $CALL    MYMOD,(WORD,(R14),*10(R1),20)
```

should generate

```
GENCALL  DS      0H
         ST      R14,PLST0023+4
         LA      R0,10(R1)
         ST      R0,PLST0023+8
         LA      R1,PLST0023
         L       R15,=V(MYMOD)
         BALR    R14,R15
         B       NXT0023
```

```
PLST0023  DS    0A
          DS    A(WORD)
          DS    A
          DS    A
          DC    A(20)
NXT0023   DS    0H
```

Note the following:

a. If SAVE = YES had been specified, then R0,R1,R14, and R15 would have to have been saved and restored. (This would also require generating a four-word area to save them.)
b. The values in &LIST that are registers in parentheses should be stored before the RX-type addresses. This allows (R0) as an element in the list.
c. Values that can be generated as A-cons should be generated in the parameter list.
d. &SYSNDX should be used to create unique labels.

The coding of $CALL will be significantly simplified if the following three macros are coded first:

```
&LABEL    RRPARM &ADDR,&LIST
```

where &ADDR is the label of the parameter list
&LIST is the same as for $CALL

RRPARM should just generate the ST instructions for those elements of &LIST that are registers in parentheses. For example,

```
RRPARM PLIST,((R0),TWO,10,(R14),(R15))
```

should generate

```
ST      R0,PLIST+0
ST      R14,PLIST+12
ST      R15,PLIST+16
```

Thus, RRPARM could be invoked by $CALL in the form

```
RRPARM    PLST&SYSNDX,&LIST
```

to generate the required ST instructions to fill in the parameter list.

```
&LABEL    RXPARM &ADDR,&LIST
```

RXPARM is similar to RRPARM except that it should generate the LA-ST pairs required for those elements of &LIST beginning with an asterisk. Thus,

```
RGEN      RXPARM MYLIST,(WORD,*DSTART,*4(R1))
```

should generate

```
RGEN     DS     0H
         LA     R0,DSTART
         ST     R0,MYLIST+4
         LA     R0,4(R1)
         ST     R0,MYLIST+8

&LABEL   PGEN   &LIST
```

This macro should generate the parameter list described by &LIST. All A-con entries should be DC'ed in, while all RR and RX entries should be DS'ed in. Thus,

```
PLIST    PGEN   (WORD,*DSTART,*4(R1))
```

should generate

```
PLIST    DS     0A
         DC     A(WORD)
         DS     A
         DS     A
```

To see exactly how these four macros are related, examine the definition of $CALL in Program 9-12.

**Program 9-12**

```
         MACRO
&LABEL   $CALL  &MOD,&LIST
.*
.* THIS SIMPLIFIED VERSION OF $CALL DOES NOT
.* ALLOW THE 'SAVE=' OPERAND.  IT SIMPLY
.* GENERATES A CALL TO &MOD, PASSING
.* THE PARAMETER LIST DETERMINED BY
.* &LIST.  NO CHECK IS MADE TO SEE IF
.* &LIST IS OMITTED, WHICH SHOULD BE
.* INCLUDED IN THE READER'S VERSION OF
.* $CALL.  THE MEANING OF THE OPERANDS ARE
.* AS FOLLOWS:
.*
.*     &MOD <=  THE NAME OF THE EXTERNAL
.*              SUBROUTINE TO BE INVOKED.
.*
.*     &LIST <= A LIST OF VALUES TO MAKE
.*              UP THE PARAMETER LIST
.*              PASSED TO &MOD.  EACH
.*              ELEMENT CAN BE
.*
.*                    A.  A VALID EXPRESSION
.*                        TO BE USED IN AN
.*                        A-TYPE CONSTANT.
.*
.*                    B.  A VALID RX-TYPE
.*                        ADDRESS PRECEDED BY
.*                        AN *.
```

```
.*
.*                    C.  A REGISTER ENCLOSED BY
.*                        PARENTHESIS.
.*
.* REGISTERS R0, R1, R14, AND R15, ARE ALTERED.
&LABEL   DS    0H                 GENERATE THE LABEL
         RRPARM PLST&SYSNDX,&LIST
.*
.* THE PRECEDING CALL GENERATES THE INSTRUCTIONS TO STORE THE REGISTERS
.* INTO THE PARAMETER LIST.
.*
         RXPARM PLST&SYSNDX,&LIST
.*
.* THE PRECEDING CALL GENERATES THE INSTRUCTIONS TO STORE THE RX-TYPE
.* ADDRESSES INTO THE PARAMETER LIST.
.*
         L      R15,=V(&MOD.)
         LA     R1,PLST&SYSNDX      LOAD ADDR. OF PARAMETERS
         BALR   R14,R15             CALL THE SUBROUTINE
         B      NXT&SYSNDX
PLST&SYSNDX PGEN &LIST
NXT&SYSNDX DS   0H                  GENERATE LABEL FOR CONTINUATION POINT
         MEND
```

**8.** In Exercise 5 at the end of Section 8.11 you were asked to code a subroutine called DATEPROC to perform manipulations on dates. Write a macro called DATES with the following prototype statement:

&LABEL DATES &OPER,&DATE1,&DATE2,&DAYS

where &OPER can be any of the following:

a. CONVERT (meaning that a conversion is desired)
b. COMPARE (meaning that a comparison is desired)
c. ADD (meaning that an addition is desired)
d. SUBTRACT (meaning that a subtraction is desired)

and where &DATE1 is (type,address): type can be JUL, CHAR or PDEC and address is the label of a field containing the date

&DATE2 is (type,address): the meanings are the same as for &DATE1

&DAYS gives the address of a three-byte field containing a number of days to be added or subtracted from the first date (This operand is optional.)

DATES should generate the appropriate parameter list and invoke DATEPROC to perform the desired operation. No registers should be altered (i.e., DATES should store and restore the contents of R14, R15, R0, and R1).

## 9.9 ADDITIONAL USES OF CONDITIONAL ASSEMBLY

Although the techniques of conditional assembly are most frequently used in macro definitions, these techniques can also be used in programs that do not utilize macros. The following statements can all be used outside macro definitions:

| | | | |
|---|---|---|---|
| GBLA | LCLA | SETA | AIF |
| GBLB | LCLB | SETB | AGO |
| GBLC | LCLC | SETC | ANOP |

The intelligent employment of these statements enables a programmer to create programs that are more easily debugged, maintained, and altered.

There are two uses of conditional assembly that very frequently occur in the *open code* (the code outside macro definitions) of a program. The most common of these involves the setting of critical parameters through the use of SETA symbols. For example, suppose that a program is to perform the following simple tasks:

- Read a list of integers into a table.
- Print the integers that have been read.
- Sort the integers in the table into ascending order.
- Print the sorted list of integers.

Clearly, the size of the table limits the number of integers that can be used as input. No matter what size is chosen, it may very well have to be altered later (downward for use on small computers or upward if the program is to be transferred to a larger machine). To facilitate such alterations, the table could be declared as

```
                macro definitions
                LCLA   &TSIZE
*&TSIZE SHOULD BE SET TO THE MAXIMUM
*NUMBER OF INTEGERS TO BE SORTED.
&TSIZE          SETA      500
SORTPROG        CSECT
                .
                .
                .
TABLE           DS        &TSIZE.F
                .
                .
                .
                END       SORTPROG
```

The declaration statement must immediately follow the macro definitions, but the SETA statement could occur anywhere in the program. If all critical parameters are set in the beginning of a program, it will not be necessary to search through the entire listing when alterations must be made.

The second most common use of conditional assembly in open code involves the use of SETB symbols to control the generation of debugging statements. In very large projects, the task of detecting the causes of errors can be incredibly complex. Statements that cause the contents of critical storage locations to be printed for inspection should be included at critical points in all modules. At a minimum, each module should contain statements that cause the values of all incoming variables and returned values to be displayed. Rather than removing these debugging statements once the modules have been partially debugged (modules are seldom completely debugged), the following scheme should be used:

```
                macro definitions
                LCLB      &DEBUG
&DEBUG          SETB      1
                .
                .
                .
                AIF       (&DEBUG).SKIP1
                debugging statements
.SKIP1          ANOP
                .
                .
                .
                AIF       (&DEBUG).SKIP2
                debugging statements
.SKIP2          ANOP
                .
                .
                .
                END
```

In this case, if a need arises for generating the debugging statements at a later date, the SETB statement can be removed and the program reassembled.

# 10

# Floating-Point Arithmetic

## 10.1 INTRODUCTION

The floating-point instruction set is used primarily for performing scientific calculations. These instructions allow the manipulation of numbers in a far wider range of magnitudes than do the binary or decimal instructions. In addition, the clerical work involved in keeping track of the decimal point is automatically handled by the computer.

The scheme for representing floating-point numbers is based on the familiar scientific notation that is taught in high school physics and chemistry classes. In this notation, numbers are represented as a fraction times a power of 10. The fraction is sometimes called the *mantissa* and the exponent of 10 is called the *characteristic*. For example, 421,000 could be expressed in scientific notation as

$$.421 \times 10^6$$

and .00421 could be expressed as

$$.421 \times 10^{-2}$$

It should be pointed out that

$$.0421 \times 10^7$$

represents the same decimal number as

$$.421 \times 10^6$$

If the first digit of the fraction is nonzero, the number representation is said to be normalized.

This scheme for representing numbers is certainly not dependent upon the number base. For example, the hexadecimal number 4AEF could be represented as

$$.4AEF \times 16^4$$

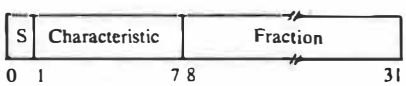
Since the computers we are discussing are, in some sense, hexadecimal machines, this last example more accurately reflects how a floating-point number would be represented in the computer.

There are two formats in which floating-point data may be represented. The short (or single-precision) format occupies 32 bits, while the long (or double-precision) format occupies 64 bits. Four floating-point registers are provided for use with data in either the short or long format. The instructions are in either RR or RX format. Load, Store, Compare, Add, Subtract, Multiply, Divide, and sign control instructions are available for use with operands in either the long or short format.

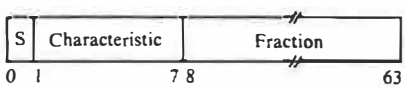
## 10.2 FLOATING-POINT NUMBER REPRESENTATIONS

In computer memory, a short-format, floating-point data item occupies a fullword, while the long format requires a doubleword. These formats are:

*Short Floating-Point Format*




*Long Floating-Point Format*




where S is a binary sign bit (The sign bit is 0 for a positive number and 1 for a negative number.)

and where, if it is assumed that the number is in hexadecimal scientific notation, then the following are true:

- Characteristic is a seven-bit representation of the exponent of 16. The characteristic is in excess 64 notation. The decimal number represented by these seven bits can range from 0 to 127. The actual characteristic is obtained by subtracting 64 from this number.
- Fraction is a binary representation of the fraction.

In both the long and short formats, a characteristic in the range −64 to 63 can be represented. The short format allows for six hexadecimal digits in the fraction, while the long format allows for 14 digits. The maximum range of decimal numbers that can be represented in either format is approximately

$$5.4 \times 10^{-79} \text{ to } 7.2 \times 10^{75}$$

The following examples of corresponding representations of numbers should help clarify these concepts.

| *Short Format* | *Scientific Notation* |
|---|---|
| 1. C3478100 | $-.478100 \times 16^{3}$ |
| 2. 43478100 | $.478100 \times 16^{3}$ |
| 3. 85130101 | $-.130101 \times 16^{-59}$ |
| 4. C5130101 | $-.130101 \times 16^{5}$ |

In the first example, the binary expansion of the first two hexadecimal digits is

1100 0011

The first binary digit is 1, indicating a negative number. The second binary digit is also 1, thus ensuring that the characteristic will be nonnegative. The magnitude of the representation of the characteristic in bits 1 through 7 is 67. Thus, the actual characteristic is

$$67 - 64 = +3$$

In the second example, the binary expansion of the first two hexadecimal digits is

0100 0011

The first digit is 0, indicating a positive sign. The second digit is 1, again ensuring that the characteristic will be nonnegative. The characteristic is again determined to be

$$67 - 64 = +3$$

In the third example, the binary expansion of the first two hexadecimal digits is

1000 0101

The 1 in the first bit indicates a negative number. The 0 in the second bit position indicates a characteristic representation less than 64; hence the actual characteristic will be negative. The characteristic is calculated to be

$$5 - 64 = -59$$

It should be noted that, if the first hexadecimal digit in a floating-point data item is greater than 7, a negative number is indicated, and if the second binary digit is not 1, a negative characteristic is indicated. The second binary bit is called the *bias bit*.

## Exercises

**1.** Represent the following hexadecimal numbers as short-format, floating-point numbers.

**a.** FE6.478 × $16^{3}$
**b.** 64.21A6 × $16^{-4}$
**c.** AE.1234 × $16^{-43}$
**d.** .BCDEFA × $16^{14}$
**e.** .1234AE × $16^{63}$

**2.** Represent the following hexadecimal numbers as long-format, floating-point numbers.

**a.** 1234.56789ABCDE × $16^{14}$
**b.** AE.CBDF12345F1B × $16^{-23}$
**c.** .000AECBDF12345 × $16^{3}$
**d.** .123456789ABCDE × $16^{-72}$
**e.** 123456789.ABCDE × $16^{-9}$

**3.** Convert the following short-format, floating-point numbers to hexadecimal numbers in scientific notation.

**a.** C5478100
**b.** 46478100
**c.** 8A123456
**d.** C7ABCDEF
**e.** 6FCDEF01

**4.** Convert the following long-format, floating-point numbers to hexadecimal numbers in scientific notation.

| | | |
|---|---|---|
| **a.** | C5478100 | ABCDEF01 |
| **b.** | 46478100 | 12345678 |
| **c.** | 8A123456 | F12345BC |
| **d.** | C7ABCDEF | 01234567 |
| **e.** | 6FCDEF01 | FEDCBA98 |

**5.** Represent the following hexadecimal numbers as short-format, floating-point numbers.

**a.** F6.872 × $16^{4}$
**b.** 1187.735 × $16^{-6}$
**c.** AA.E88F × $16^{18}$

**6.** Represent the following hexadecimal numbers as long-format, floating-point numbers.

**a.** A11FE.7249FDD42A $\times$ $16^{-62}$
**b.** .000FF12FE1A6B54 $\times$ $16^{13}$

**7.** Convert the following short-format, floating-point numbers to hexadecimal format.

**a.** 88467900
**b.** DE5634EF

**8.** Convert the following long-format, floating-point numbers to hexadecimal numbers in scientific notation.

**a.** 88467900 440283BC
**b.** DE5634EF F6AB39A8

---

## 10.3 E- AND D-TYPE DC AND DS STATEMENTS

E- and D-type DC statements are used to generate floating-point constants in the short and long format, respectively. Provided that no length modifier is specified, an E-type DC statement forces alignment to a fullword boundary, and a D-type DC statement forces alignment to a doubleword boundary. In either case, the constant is written as a decimal number. The decimal point and sign are optional.

The constant may be followed by a decimal exponent of the form

En

where n is a signed or unsigned decimal number. The number is adjusted by shifting the decimal point (assumed to follow the last digit, if not specified) to the right or left the number of places indicated by the decimal exponent. The number is then converted to the appropriate floating-point format. The floating-point number is normalized to retain the maximum number of significant digits. Since the result is normalized, any padding of zeros or truncation of excess digits occurs on the right.

The following are valid floating-point DC statements with their corresponding generated values:

| | *Statement* | *Generated Result* | |
|---|---|---|---|
| DC | E'6' | 41600000 | |
| DC | D'3.1416' | 413243FE5C91D14E | |
| DC | E'-1234.567E5' | C775BCCC | |
| DC | D'567.89E-4' | 3FE89B951C5C5719 | |
| DC | D'31416E-4' | 413243FE5C91D14E | |
| DC | 2D'1.27' | 411451EB851EB852 | 411451EB851EB852 |

Note that multiple constants can be used in an operand and that duplication factors are allowed.

E- and D-type DS statements are used to define storage areas for floating-point numbers. Boundary alignment is forced as in the case of the corresponding DC statements. Values may be specified in the operand field but, of course, no constants are generated.

## 10.4 CONVERSIONS BETWEEN DECIMAL AND FLOATING-POINT NUMBERS

The following brief discussion of conversion algorithms should allow the reader to verify the generated results shown in Section 10.3. Algorithms for converting between decimal and hexadecimal integers were given in Chapter 1. For this reason, here we will deal only with the conversion of fractions.

The following algorithm can be used to convert a hexadecimal fraction to a decimal fraction:

*Step 1.* Express the hexadecimal fraction as an integer times a power of 16.
*Step 2.* Convert the resulting integer to a decimal integer.
*Step 3.* Multiply this decimal integer by the power of 16 in the representation resulting from Step 1.

For example, consider $.4ABC_{16}$.

1. $.4ABC = 4ABC \times 16^{-4}$
2. $4ABC = 19{,}132$
3. $19{,}132 \times 16^{-4} = 19{,}132/65{,}536 = .2919$

### Exercises

**1.** Convert the following hexadecimal numbers to decimal numbers.

**a.** ACE.1234
**b.** 12.09AC
**c.** .FEDC
**d.** .0987
**e.** .0099

**2.**

**a.** 1F.63E
**b.** 9.001
**c.** B19.B19

The following algorithm can be used to convert a decimal fraction to a hexadecimal fraction.

*Step 1.* Multiply the decimal fraction by 16, and convert the resulting integer part of the result to a hexadecimal digit. (This is the next digit of the hexadecimal fraction that is sought.)

*Step 2.* If enough digits have been generated, stop. Otherwise, take the fraction part of the result and go to Step 1.

For example, consider .2919.

1. $.2919 \times 16 = \boxed{4}\ .6704$
2. $.6704 \times 16 = \boxed{10}\ .7264$
3. $.7264 \times 16 = \boxed{11}\ .6224$
4. $.6224 \times 16 = \boxed{9}\ .9584$

Therefore, $.2919 \approx .4AB9_{16}$.

The error results from the fact that only four fractional digits were carried in the intermediate calculations. Check the result, using six fractional digits in the intermediate calculations, and round the result.

### Exercises

**1.** Convert the following decimal numbers to hexadecimal numbers.

**a.** 9876.3456
**b.** .9876
**c.** .0099
**d.** 123.7654
**e.** 9999.9987

**2.**

**a.** 636.12
**b.** 56.003

## 10.5 NORMALIZATION AND FLOATING-POINT REGISTERS

As mentioned in Section 10.1, if the high-order fraction digit of a floating-point data item is nonzero, the number is said to be normalized. In any other case, the data item is said to be unnormalized. It should be noted that the leftmost three binary bits of a normalized floating-point fraction could be zeros.

An unnormalized floating-point number is normalized as follows:

1. The fraction is shifted, one hexadecimal digit at a time, until the high-order digit is nonzero.
2. The characteristic is reduced by the number of digits that the fraction was shifted.

The initial operands in a floating-point arithmetic operation need not be normalized. However, except in the case of the unnormalized Add and Subtract instructions, the final result is normalized, since normalization is performed on the intermediate result to produce the final result. This is called *postnormalization.*

Only the algorithms for performing multiplication and division cause the operands to be normalized before performing the arithmetic operation. This is called *prenormalization.*

A floating-point data item with a zero fraction cannot be normalized. In this case, the characteristic is unchanged when normalization is called for.

A floating-point number with a zero characteristic, a zero fraction, and a positive sign is called a *true zero* number.

Four registers are provided solely for use in performing floating-point operations. These registers, each 64 bits in length, are numbered 0, 2, 4, and 6. For the remainder of this discussion, the floating-point registers will be referred to as FPR0, FPR2, FPR4, and FPR6, respectively.

A complete dual set of floating-point instructions exists for short- and long-format operands. When short-format instructions are performed, all operands must be in short format and, with the exception of multiplication, only the leftmost 32 bits of the registers participate. The results are in short format. In the case of multiplication, the result occupies the full 64 bits of the participating result register and is in long format. When long-format instructions are performed, all operands and results are in the 64-bit long format.

## 10.6 THE FLOATING-POINT LOAD AND STORE INSTRUCTIONS

The mnemonics for the floating-point instructions should be transparent, if the conventions for naming these instructions are understood. These conventions are as follows:

1. The first letter or two of the mnemonic is the standard mnemonic for the function to be performed by the instruction (for example, L for Load, A for Add, M for Multiply, ST for Store).
2. The letter following the function mnemonic indicates whether the operands of the instruction are in short or long format. E or U indicates short operands, and D or W indicates long operands.

3. If the instruction is of the RR type, an R is appended to the mnemonic to indicate this.

One exception to these rules is that a new function mnemonic, H, is introduced. H indicates a special type of divide function, Halve, which is the equivalent of division by 2.

With the above conventions in mind, the reader should easily guess the results of execution of the Load instructions LE, LER, LD, LDR, LTER and LTDR.

| | | |
|---|---|---|
| LE | r,D(X,B) | (*Load Short*) |

Execution of this instruction causes a copy of the fullword at the address specified by D(X,B) to replace the leftmost (high-order) 32 bits of the floating-point register specified by r. The low-order 32 bits of r are unaltered.

| | | |
|---|---|---|
| LER | r1,r2 | (*Load Register Short*) |

Execution of this instruction causes a copy of the 32 high-order bits of the register specified by r2 to replace the 32 high-order bits of r1. The contents of r2 and the 32 low-order bits of r1 are unaltered.

| | | |
|---|---|---|
| LD | r,D(X,B) | (*Load Long*) |
| LDR | r1,r2 | (*Load Register Long*) |

Execution of either of these instructions causes the entire 64 bits of the first operand to be replaced by a copy of the second operand. The second operand of the LD instruction must be aligned on a doubleword boundary.

| | | |
|---|---|---|
| LTER | r1,r2 | (*Load and Test Register Short*) |
| LTDR | r1,r2 | (*Load and Test Register Long*) |

Execution of the first of these two instructions causes the 32 high-order bits of r1 to be replaced by a copy of the 32 high-order bits of r2. Execution of the second instruction causes the entire 64 bits of r1 to be replaced by a copy of the 64 bits of r2. In either case, the condition code is set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Result fraction is 0. |
| 1 | Result < 0. |
| 2 | Result > 0. |
| 3 | — |

The two Store instructions are STE and STD:

| | | |
|---|---|---|
| STE | r,D(X,B) | (*Store Short*) |
| STD | r,D(X,B) | (*Store Long*) |

Execution of the first instruction causes a copy of the 32 high-order bits of r to replace the fullword specified by D(X,B). Execution of the second instruction causes a copy of the entire 64 bits of r to replace the doubleword specified by D(X,B).

## 10.7 THE FLOATING-POINT ADD, SUBTRACT, AND COMPARE INSTRUCTIONS

In the case of the Add, Subtract, Compare, Halve, and Multiply instructions, all intermediate calculations are performed using one more digit than the six (in short format) or 14 (in long format) in the operands and final result. This additional digit, called the *guard digit*, increases the accuracy of the final result.

The instructions for addition and subtraction of short-format operands (AE, AER, SE, and SER) cause only the high-order 32 bits of the result operand to be altered, while the corresponding instructions for long-format operands (AD, ADR, SD, and SDR) alter the entire 64 bits of the result register. Each Add and Subtract instruction causes the condition code to be set as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Result fraction is 0. |
| 1 | Result < 0. |
| 2 | Result > 0. |
| 3 | — |

The short-format Add instructions are AE and AER:

| | | |
|---|---|---|
| AE | r,D(X,B) | (*Add Short*) |
| AER | r1,r2 | (*Add Register Short*) |

Execution of either of these instructions causes copies of both operands to be moved to special unaddressable work areas. A guard digit, initially zero, is kept with each copy. The guard digit may be thought of as an additional low-order hexadecimal digit appended to the right of the number representation. The operand with the smaller characteristic is right shifted one digit at a time, increasing the characteristic by 1 for each shift, until the characteristics agree. The digits shifted off the right successively replace the guard digit; so when the alignment is complete, the guard digit contains the last digit shifted out of the affected operand. Addition is then performed on the fractions of the operands, and the result is normalized. If normalization results in a left shift of at least one digit, the guard digit becomes part of the final result. Additional digits created on the right by the left shift are

padded with zeros. This intermediate result then replaces the 32 high-order bits of the first operand.

The long format Add instructions are AD and ADR:

| | | |
|---|---|---|
| AD | r,D(X,B) | (*Add Long*) |
| ADR | r1,r2 | (*Add Register Long*) |

Execution of these instructions is the same as in the case of the corresponding short-format instructions except that, in this case, 64 bits are involved rather than 32. A guard digit is again retained in all intermediate calculations.

The floating-point Subtract instructions are SE, SER, SD, and SDR:

| | | |
|---|---|---|
| SE | r,D(X,B) | (*Subtract Short*) |
| SER | r1,r2 | (*Subtract Register Short*) |
| SD | r,D(X,B) | (*Subtract Long*) |
| SDR | r1,r2 | (*Subtract Register Long*) |

Execution of each of these instructions causes copies of both operands to be placed in work areas. The sign of the working copy of the second operand is reversed. Addition is then performed in the same manner as for the corresponding add operation. The short-format Subtract instructions alter only the 32 high-order bits of the first operand.

The floating-point Compare instructions are CE, CER, CD, and CDR:

| | | |
|---|---|---|
| CE | r,D(X,B) | (*Compare Short*) |
| CER | r1,r2 | (*Compare Register Short*) |
| CD | r,D(X,B) | (*Compare Long*) |
| CDR | r1,r2 | (*Compare Register Long*) |

The operations performed by each of these instructions are the same as those performed by the corresponding Subtract instructions except that, in this case, neither operand is altered. The condition code is set just as for the Subtract instructions but, for the Compare instructions, the interpretation is as follows:

| *CC* | *Meaning* |
|---|---|
| 0 | Operands are equal. |
| 1 | First operand is low. |
| 2 | First operand is high. |
| 3 | — |

It should be pointed out that a Compare Short instruction involving two operands with values such as

4400 0C00

and

41C0 00BB

will set the condition code to 0. This occurs because right shifting of the operand with the smaller characteristic will cause the rightmost two digits to be lost. The remaining digits of the two operands (including the guard digit) are then identical.

## 10.8 THE FLOATING-POINT MULTIPLY, DIVIDE, AND HALVE INSTRUCTIONS

Dual sets of RR and RX instructions are provided for the multiplication and division of short- and long-format, floating-point operands.

The instructions for multiplication of short-format operands are

| | | |
|---|---|---|
| ME | r,D(X,B) | (*Multiply Short*) |

and

| | | |
|---|---|---|
| MER | r1,r2 | (*Multiply Register Short*) |

The corresponding instructions for long-format operands are

| | | |
|---|---|---|
| MD | r,D(X,B) | (*Multiply Long*) |

and

| | | |
|---|---|---|
| MDR | r1,r2 | (*Multiply Register Long*) |

The algorithm governing the execution of these instructions can be described as follows:

*Step 1.* Copies of the two operands are normalized (by prenormalization) in work areas. With short operands, prenormalization affects only the 32 high-order bits of the operands.

*Step 2.* The sign of the result is determined in accordance with the rules of algebra. This amounts to performing an EXCLUSIVE OR operation on the sign bits of the two operands.

*Step 3.* The characteristic of the result is determined. This is equivalent to adding the characteristics of the operands and then subtracting the bias quantity ($40_{16}$).

*Step 4.* Multiplication of the fractions of the normalized operands is performed with the following results:

a. In the case of short operands, the six-hexadecimal-digit fractions of the operands are multiplied, yielding a 12-hexadecimal-digit result. Since the contents of the entire result register will be

replaced by the final result, the rightmost two hexadecimal digits of that register will be hexadecimal zeros.

b. In the case of long operands, the 14-hexadecimal-digit fractions of the operands are multiplied, yielding a 28-digit result. This result is truncated to 15 digits (including the guard digit).

*Step 5.* The intermediate result determined by Steps 1–4 is then normalized (this could result in, at most, a shift of one digit to the left) to create the final result, which replaces the contents of the result register. The second operand is not altered by these operations.

The following examples should help to clarify these concepts.

- *Example 1.* Suppose that FPR2 contains 43003000 00000000 and FLOAT1 contains 43453211 23450032. Then, execution of the instruction

```
ME          2,FLOAT1
```

can be described as follows:

1. Prenormalization results in

```
FPR2:    41300000  00000000
FLOAT1:43453211  23450032
```

2. The sign of the result is determined as

   0 (EXCLUSIVE OR) 0 = 0

3. The characteristic of the result is determined as

   41 + 43 − 40 = 44

4. Multiplication of the normalized operands yields

   0CF963  30000000

5. Postnormalization yields the final result

   43CF9633  00000000

- *Example 2.* Assume the same original contents of FPR2 and FLOAT1 as in Example 1. Then, execution of the instruction

```
MD          2,FLOAT1
```

is as follows:

(The first three steps are exactly as described in Example 1.)

4. Multiplication of the fractions and subsequent truncation yields

   0CF963  369CF009  6

5. Postnormalization yields the final result

43CF9633 69CF0096

Note that the guard digit participates in the final result in Example 2. We should emphasize that only the first 32 bits of the operands are affected in the prenormalization process, in operations on short operands.

The instructions for division of short-format operands are

| | | |
|---|---|---|
| DE | r,D(X,B) | (*Divide Short*) |

and

| | | |
|---|---|---|
| DER | r1,r2 | (*Divide Register Short*) |

The corresponding instructions for long-format operands are

| | | |
|---|---|---|
| DD | r,D(X,B) | (*Divide Long*) |

and

| | | |
|---|---|---|
| DDR | r1,r2 | (*Divide Register Long*) |

Execution of these instructions is as follows:

*Step 1.* Copies of the two operands are prenormalized in work areas.

*Step 2.* The sign of the result is determined in the same manner as in the corresponding multiply operation.

*Step 3.* The characteristic of the result is determined by subtracting the characteristic of the normalized second operand from the characteristic of the normalized first operand and adding $40_{16}$.

*Step 4.* Division of the fraction of the first operand by the fraction of the second operand is performed, and the result becomes the fraction of the intermediate quotient. No remainder is retained. In the case of short-operand instructions, only six hexadecimal digits of the fractions participate in this operation.

*Step 5.* Postnormalization of the intermediate result is never necessary. A shift to the right of one hexadecimal digit and corresponding adjustment of the characteristic, however, may be necessary to arrive at the final result.

The following examples illustrate the operation of the Divide instructions.

- *Example 1.* Suppose that FPR2 contains 42080000 23456789 and FLOAT1 contains 420C0000 00000000. Then, execution of the instruction

DE 2,FLOAT1

proceeds as follows:

1. Prenormalization of the operands yields

| | | |
|---|---|---|
| FPR2 : | 41800000 | 23456789 |
| FLOAT1: | 41C00000 | 00000000 |

2. The sign is determined by

   0 (EXCLUSIVE OR) 0 = 0

3. The characteristic is determined by

   41 − 41 + 40 = 40

4. Division of the fractions yields

   800000 / C00000 = AAAAAA

5. No shift is necessary, so the final result is

   40AAAAAA

- *Example 2.* Suppose that FPR4 contains 41600000 00000000 and FPR6 contains 41400000 00000000. Then execution of the instruction

```
DDR     4,6
```

is as follows:

1. No prenormalization is necessary.
2. The sign is determined by

   0 (EXCLUSIVE OR) 0 = 0

3. The characteristic is determined by

   41 − 41 + 40 = 40

4. Division of the fractions yields

   600000 00000000 / 400000 00000000 = 1800000 00000000

   The 1 in the result represents a carry digit.

5. A right shift of one digit and an increase of 1 in the exponent yields the final result

   41180000 00000000

The Halve instructions HER and HDR cause the contents of the second operand to be divided by 2, and this result replaces the contents of the first operand.

```
HER     r1,r2
HDR     r1,r2
```

Execution of these instructions yields the same result as would be obtained by regular division by a constant 2.

## 10.9 SIGN CONTROL

The floating-point instruction set provides dual sets of RR instructions for performing load complement, load negative, and load positive operations. These instructions are:

| | | |
|---|---|---|
| LCER | r1,r2 | (*Load Complement Short*) |
| LCDR | r1,r2 | (*Load Complement Long*) |
| LNER | r1,r2 | (*Load Negative Short*) |
| LNDR | r1,r2 | (*Load Negative Long*) |
| LPER | r1,r2 | (*Load Positive Short*) |
| LPDR | r1,r2 | (*Load Positive Long*) |

Execution of each of these instructions replaces the first operand with the result obtained by adjusting the sign bit of the second operand appropriately. These adjustments are made as follows:

1. For the Load Complement instructions, an EXCLUSIVE OR operation is performed on the sign bit of the second operand and a 1.
2. For the Load Negative instructions, an OR operation is performed on the sign bit of the second operand and a 1.
3. For the Load Positive instructions, an AND operation is performed on the sign bit of the second operand and a 0.

## 10.10 UNNORMALIZED ADD AND SUBTRACT INSTRUCTIONS

Dual sets of RR and RX instructions for performing unnormalized addition and subtraction operations are provided. These instructions are:

| | | |
|---|---|---|
| AU | r,D(X,B) | (*Add Unnormalized Short*) |
| AUR | r1,r2 | (*Add Register Unnormalized Short*) |
| AW | r,D(X,B) | (*Add Unnormalized Long*) |
| AWR | r1,r2 | (*Add Register Unnormalized Long*) |
| SU | r,D(X,B) | (*Subtract Unnormalized Short*) |
| SUR | r1,r2 | (*Subtract Register Unnormalized Short*) |
| SW | r,D(X,B) | (*Subtract Unnormalized Long*) |
| SWR | r1,r2 | (*Subtract Register Unnormalized Long*) |

Execution of each of these instructions is the same as execution of the corresponding normal instruction except that no postnormalization is performed.

The principal reason for including these instructions in the floating-point package is to implement schemes to record the significance of digits in results of sequences of floating-point operations. Two factors, however, severely limit the utility of these instructions for this purpose:

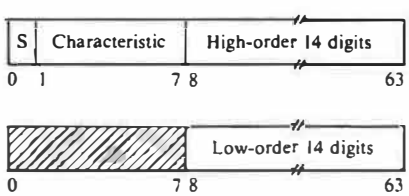
1. Since the computations are done in hexadecimal arithmetic, the loss of decimal digits would, at best, be measured rather crudely.
2. The multiply and divide operations force complete prenormalization of the operands. The inclusion of these operations in any sequence of floating-point operations would, therefore, make it almost impossible to keep track of significance with any accuracy.

Other schemes have been developed to record the significance of digits, but these are beyond the scope of this book.

## 10.11 EXTENDED-PRECISION ARITHMETIC AND ROUNDING

The set of instructions discussed in this section includes the five extended-precision arithmetic instructions that utilize 28-digit operand or result formats. In addition, two Load instructions that can be utilized to round from longer to shorter formats are included. One of these instructions rounds an extended-precision operand to long format, and the other rounds a long-format operand to short format.

An extended-precision, floating-point number consists of two long-precision, floating-point numbers in consecutive registers. Only the register pairs FPR0, FPR2 and FPR4, FPR6 can be used to represent extended-precision, floating-point numbers. The long floating-point number in the first register of the pair is called the *high-order part* and the long floating-point number in the second register of the pair is called the *low-order part* of the extended-precision number. The sign and characteristic of the high-order part are taken as the sign and characteristic of the extended-precision number. The extended-precision format is illustrated as follows:



If the high-order part is normalized, the extended-precision number is considered to be normalized. The sign and characteristic of the low-order part are ignored.

When extended-precision results are calculated, the sign of the low-order part of the result is made to match the sign of the high-order part; the characteristic of the low-order part is made to be 14 less than the characteristic of the high-order part, provided that the high-order characteristic is at least 14. If subtracting 14 from the high-order characteristic results in a negative number, then the characteristic of the low-order part is made 128 larger than its correct value.

The AXR, SXR, and MXR instructions constitute the entire set of instructions that operate on two extended operands and produce extended-precision results. In each case, the results produced are postnormalized. No facility is provided for division of extended-precision operands.

AXR r1,r2 (*Add Extended*)

Execution of this instruction is analogous to that of the Add Short or Add Long instructions except that, in this case, 28 digits of the operands are involved and adjustments are made on the low-order sign and characteristic, as explained previously.

SXR r1,r2 (*Subtract Extended*)

Execution of this instruction is analogous to execution of the Add Extended instruction except that, in this case, the sign of the second operand is reversed before the addition is performed.

MXR r1,r2 (*Multiply Extended*)

Execution of this instruction is analogous to that of the MER and MDR instructions except that, of course, 28 digits of the operands are involved. The sign and exponent of the low-order part of the result are adjusted as in the case of the AXR and SXR instructions.

The following Multiply instructions operate on two long-precision operands to produce extended-precision results:

MXD r,D(X,B) (*Multiply Long to Extended*)

MXDR r1,r2 (*Multiply Register Long to Extended*)

Execution of either of these instructions causes the normalized product of the long second operand and the long first operand to be generated. This product then replaces the contents of the specified result register and the next-higher addressed register. The sign, characteristic, and high-order 14 digits of the product fraction replace the first operand. The 14 low-order digits of the product fraction replace bit positions 8–63 of the next-higher addressed register. The sign bit of this register is made to match the sign

bit of the result register. The characteristic of the low-order register is adjusted to 14 less than the high-order characteristic if the high-order is at least 14; otherwise, the low-order characteristic is made 128 greater than its correct value. If either or both operand fractions are zero, both parts of the result are made true zero. The condition code is not altered.

The instructions for rounding operands are

```
        LRER      r1,r2          (Load Rounded Short/Long)
and
        LRDR      r1,r2          (Load Rounded Long/Extended)
```

Execution of either of these instructions causes the second operand to be rounded to the short format, and the result replaces the first operand. The second operand is not altered unless the two operands are the same. In the case of the LRER instruction, rounding is accomplished by adding 1 to the contents of bit position 32 of the second operand and propagating the carry to the left. In the case of the LRDR instruction, rounding depends on the contents of bit position 8 of the low-order part of the second operand: If the contents of this bit position is 1, 1 is added to bit position 63 of the result register and the carry is propagated to the left. In either case, rounding could result in a carry out of the high-order digit position of the result fraction. If this occurs, the result fraction is shifted one digit to the right and the characteristic is increased by 1. The condition code is not altered by the execution of these instructions.

## 10.12 FLOATING-POINT ARITHMETIC EXCEPTIONS

Seven types of errors can occur with the use of floating-point instructions. Of these, three should be familiar to and predictable by the reader. These are operation, addressing, and protection exceptions. The four other types of exceptions are peculiar to the floating-point instruction set. These are the exponent overflow, exponent underflow, significance, and floating-point divide exceptions. A brief description of each of these seven exceptions is given in this section. Refer to the IBM 370 *Principles of Operations Manual* for complete details.

- *Operation.* If an attempt to execute a floating-point instruction is made on a system that does not support the floating-point package, this error will occur.

- *Addressing.* If an operand specifies an address that is outside the address range of the particular system, this type of exception will occur.
- *Protection.* This type of exception will occur if an attempt is made to address a storage area that has not been allocated to the program being executed.
- *Exponent Overflow.* This type of exception will occur if the result of a floating-point Add, Subtract, Multiply, or Divide instruction has a characteristic exceeding 127 and if the result fraction is not zero.
- *Exponent Underflow.* This error will occur if the characteristic of the result of a floating-point Add, Subtract, Multiply, Divide, or Halve instruction is less than zero.
- *Significance.* This exception will occur if the result fraction of a floating-point Add or Subtract instruction is zero.
- *Floating-Point Divide.* This exception will occur if division by a floating-point number with a zero fraction is attempted.

## 10.13 THE INPUT AND OUTPUT OF FLOATING-POINT NUMBERS

No instructions are provided for converting floating-point numbers from external format to internal format and vice versa. This lack presents a formidable obstacle to the use of floating-point instructions. Various routines have been developed for doing these conversions; however, a discussion of such routines is beyond the scope of this text.

A simple, if somewhat unusual, technique to facilitate the full use of the floating-point instruction set follows. This technique takes advantage of an IBM ANS COBOL extension that does provide the means for converting between internal and external formats. The COBOL subroutine FLETOI can be used to convert floating-point numbers from external to internal format, and FLITOE can be used to convert from internal to external format. These two routines are listed in Program 10-1.

**Program 10-1**

```
PP 5734-CB2 V4 RELEASE 1.5 10NOV77        IBM OS AMERICAN NATIONAL STANDARD COBOL

  1

00001          IDENTIFICATION DIVISION.
00002          PROGRAM-ID. FLETOI.
00003
00004         * THIS SHORT COBOL SUBROUTINE IS USED TO CONVERT A NUMBER IN
00005         * FLOATING POINT EXTERNAL FORMAT INTO INTERNAL FORMAT.
00006
00007          ENVIRONMENT DIVISION.
00008          CONFIGURATION SECTION.
00009          SOURCE-COMPUTER. IBM-370.
00010          OBJECT-COMPUTER. IBM-370.
00011          DATA DIVISION.
00012          LINKAGE SECTION.
00013
00014          01  EXT-FLOAT  PIC +.9(16)E+99.
00015          01  INT-FLOAT  USAGE IS COMP-2.
00016
00017          PROCEDURE DIVISION USING EXT-FLOAT INT-FLOAT.
00018
00019              MOVE EXT-FLOAT TO INT-FLOAT.
00020              GOBACK.
PP 5734-CB2 V4 RELEASE 1.5 10NOV77        IBM OS AMERICAN NATIONAL STANDARD COBOL

  1

00001          IDENTIFICATION DIVISION.
00002          PROGRAM-ID. FLITOE.
00003
00004         * THIS SHORT COBOL SUBROUTINE IS USED TO CONVERT A NUMBER IN
00005         * FLOATING POINT INTERNAL FORMAT INTO EXTERNAL FORMAT.
00006
00007          ENVIRONMENT DIVISION.
00008          CONFIGURATION SECTION.
00009          SOURCE-COMPUTER. IBM-370.
00010          OBJECT-COMPUTER. IBM-370.
00011          DATA DIVISION.
00012          LINKAGE SECTION.
00013
00014          01  INT-FLOAT  USAGE IS COMP-2.
00015          01  EXT-FLOAT  PIC +.9(16)E+99.
00016
00017          PROCEDURE DIVISION USING INT-FLOAT EXT-FLOAT.
00018
00019              MOVE INT-FLOAT TO EXT-FLOAT.
00020              GOBACK.
```

Program 10-2, FLOATEX, illustrates the use of the double-precision, floating-point instructions, as well as the calls to FLETOI and FLITOE.

To understand how Program 10-2 was prepared for execution, the reader should refer to the discussion in Sections 6.1 and 6.2. The COBOL subroutines were separately compiled into two object modules. Then, the assembler program FLOATEX was assembled, producing a third object module. The three modules were then combined to produce the executable program in memory.

**Program 10-2**

```
FLOATING POINT EXAMPLE                                                                                    PAGE    1

LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                  13 APR 82

                                  2          PRINT NOGEN
                                  3 ******************************************************************
                                  4 *
                                  5 * THIS PROGRAM ILLUSTRATES THE USE OF FLOATING POINT NUMBERS, AS WELL
                                  6 * AS HOW TO INVOKE COBOL SUBROUTINES FROM ASSEMBLER.  IT PERFORMS
                                  7 * THE FOLLOWING STEPS:
                                  8 *
                                  9 *     STEP 1. READ IN A CARD WITH 2 DOUBLE-PRECISION NUMBERS (CALL
                                 10 *             THEM A AND B).  THE NUMBERS ARE IN THE EXTERNAL
                                 11 *             FLOATING POINT FORMAT DESCRIBED IN THE COBOL LANGUAGE
                                 12 *             REFERENCE MANUAL.
                                 13 *
                                 14 *     STEP 2. INVOKE THE COBOL SUBROUTINE 'FLETOI' TO CONVERT THE
                                 15 *             NUMBERS INTO INTERNAL FLOATING POINT FORMAT.  THIS
                                 16 *             REQUIRES
                                 17 *                       A) A CALL TO 'ILBOSTPO' TO INITIALIZE THE
                                 18 *                          COBOL ENVIRONMENT,
                                 19 *
                                 20 *                       B) CALLING 'FLETOI' TWICE (ONCE TO CONVERT
                                 21 *                          A AND ONCE TO CONVERT B)
                                 22 *
                                 23 *     STEP 3. XDUMP OUT A AND B.
                                 24 *
                                 25 *     STEP 4. COMPUTE A+B, A-B, A*B, A/B, AND HALF(A).
                                 26 *
                                 27 *     STEP 5. XDUMP OUT THE VALUES.
                                 28 *
                                 29 *     STEP 6. CALL 'FLITOE' 5 TIMES TO CONVERT THE VALUES TO
                                 30 *             PRINTABLE FORMAT (EXTERNAL FLOATING POINT).
                                 31 *
                                 32 *     STEP 7. PRINT THE RESULT.
                                 33 *
                                 34 *     STEP 8. EXIT.
                                 35 *
                                 36 ******************************************************************
                                 37 *
000000                           38 FLOATEX  CSECT
000000 90EC D00C          0000C  39          STM   R14,R12,12(R13)    SAVE CALLER'S REGISTERS
000004 05C0                      40          BALR  R12,0
                          00006  41          USING BASEPT,R12
000006                           42 BASEPT   DS    0H
                                 43 *
000006 18ED                      44          LR    R14,R13
000008 41D0 C25E          00264  45          LA    R13,SAVEAREA
00000C 50DE 0008          00008  46          ST    R13,8(R14)
000010 50ED 0004          00004  47          ST    R14,4(R13)
                                 48 *
                                 49 ***<STEP 1>    READ THE CARD WITH A AND B.
                                 50 *
000014                           51          XREAD CARD
00003A                           61          XPRNT CARD-1,81          ECHO OUT THE CONTENTS OF THE CARD
                                 71 *
                                 72 ***<STEP 2>    CONVERT A AND B TO INTERNAL FORMAT.
```

**Program 10-2 (continued)**

```
 LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                          13 APR 82

                                   73 *
00005E 58F0 C252            00258  74          L     R15,=V(ILBOSTPO)
000062 05EF                        75          BALR  R14,R15            INITIALIZE COBOL ENVIRONMENT
                                   76 *
000064 4110 C21A            00220  77          LA    R1,=A(EXTA,INTA)
000068 58F0 C256            0025C  78          L     R15,=V(FLETOI)
00006C 05EF                        79          BALR  R14,R15            CONVERT A TO INTERNAL FORMAT
                                   80 *
00006E 4110 C222            00228  81          LA    R1,=A(EXTB,INTB)
000072 58F0 C256            0025C  82          L     R15,=V(FLETOI)
000076 05EF                        83          BALR  R14,R15            CONVERT B TO INTERNAL FORMAT
                                   84 *
                                   85 ***<STEP 3>    XDUMP THE CONVERTED VALUES
                                   86 *
000078                             87          XDUMP INTA,16
                                  104 *
                                  105 ***<STEP 4>    COMPUTE A+B, A-B, A*B, A/B, AND HALF(A)
                                  106 *
0000FA 6800 C2FA            00300 107          LD    FPR0,INTA
0000FE 6A00 C302            00308 108          AD    FPR0,INTB          CALCULATE A + B
000102 6000 C30A            00310 109          STD   FPR0,SUM
                                  110 *
000106 6800 C2FA            00300 111          LD    FPR0,INTA
00010A 6B00 C302            00308 112          SD    FPR0,INTB          CALCULATE A - B
00010E 6000 C312            00318 113          STD   FPR0,DIFF
                                  114 *
000112 6800 C2FA            00300 115          LD    FPR0,INTA
000116 6C00 C302            00308 116          MD    FPR0,INTB          CALCULATE A * B
00011A 6000 C31A            00320 117          STD   FPR0,PRODUCT
                                  118 *
00011E 6800 C2FA            00300 119          LD    FPR0,INTA
000122 6D00 C302            00308 120          DD    FPR0,INTB          CALCULATE A / B
000126 6000 C322            00328 121          STD   FPR0,QUOTIENT
                                  122 *
00012A 6800 C2FA            00300 123          LD    FPR0,INTA
00012E 2400                       124          HDR   FPR0,FPR0          CALCULATE HALF(A)
000130 6000 C32A            00330 125          STD   FPR0,HALFA
                                  126 *
                                  127 ***<STEP 5>    XDUMP RESULTS
                                  128 *
000134                            129          XDUMP SUM,40
                                  146 *
                                  147 ***<STEP 6>    CONVERT TO EXTERNAL FORMATS
                                  148 *
0001B6 4110 C22A            00230 149          LA    R1,=A(SUM,EXTSUM)
0001BA 58F0 C25A            00260 150          L     R15,=V(FLITOE)
0001BE 05EF                       151          BALR  R14,R15
                                  152 *
0001C0 4110 C232            00238 153          LA    R1,=A(DIFF,EXTDIFF)
0001C4 58F0 C25A            00260 154          L     R15,=V(FLITOE)
0001C8 05EF                       155          BALR  R14,R15
                                  156 *
0001CA 4110 C23A            00240 157          LA    R1,=A(PRODUCT,EXTPROD)
```

**Program 10-2 (continued)**

```
         FLOATING POINT EXAMPLE                                                                                    PAGE    3

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                                          13 APR 82

0001CE 58F0 C25A            00260   158          L     R15,=V(FLITOE)
0001D2 05EF                         159          BALR  R14,R15
                                    160 *
0001D4 4110 C242            00248   161          LA    R1,=A(QUOTIENT,EXTQUOT)
0001D8 58F0 C25A            00260   162          L     R15,=V(FLITOE)
0001DC 05EF                         163          BALR  R14,R15
                                    164 *
0001DE 4110 C24A            00250   165          LA    R1,=A(HALFA,EXTHALFA)
0001E2 58F0 C25A            00260   166          L     R15,=V(FLITOE)
0001E6 05EF                         167          BALR  R14,R15
                                    168 *
                                    169 ***<STEP 7>    PRINT THE RESULTS
                                    170 *
0001E8                              171          XPRNT PLINE,133
                                    181 *
                                    182 ***<STEP 8>    EXIT
                                    183 *
00020E 58DD 0004            00004   184          L     R13,4(R13)
000212 98EC D00C            0000C   185          LM    R14,R12,12(R13)
000216 1BFF                         186          SR    R15,R15            SET RETURN CODE TO 0
000218 07FE                         187          BR    R14                RETURN TO THE SYSTEM
                                    188 *
000220                              189          LTORG
000220 000002AD00000300             190                =A(EXTA,INTA)
000228 000002C400000308             191                =A(EXTB,INTB)
000230 0000031000000339             192                =A(SUM,EXTSUM)
000238 0000031800000351             193                =A(DIFF,EXTDIFF)
000240 0000032000000369             194                =A(PRODUCT,EXTPROD)
000248 0000032800000381             195                =A(QUOTIENT,EXTQUOT)
000250 0000033000000399             196                =A(HALFA,EXTHALFA)
000258 00000000                     197                =V(ILBOSTPO)
00025C 00000000                     198                =V(FLETOI)
000260 00000000                     199                =V(FLITOE)
                                    200 *
000264                              201 SAVEAREA DS    18F                REGISTER SAVE AREA
0002AC 40                           202          DC    C' '
0002AD                              203 CARD     DS    CL80               READ INPUT CARD INTO HERE
0002FD                      002AD   204          ORG   CARD
0002AD                              205 EXTA     DS    CL22
0002C3                      002C4   206          ORG   CARD+23
0002C4                              207 EXTB     DS    CL22
0002DA                      002FD   208          ORG
000300                              209 INTA     DS    D                  A IN INTERNAL FORMAT
000308                              210 INTB     DS    D                  B IN INTERNAL FORMAT
                                    211 *
000310                              212 SUM      DS    D                  A + B
000318                              213 DIFF     DS    D                  A - B
000320                              214 PRODUCT  DS    D                  A * B
000328                              215 QUOTIENT DS    D                  A / B
000330                              216 HALFA    DS    D                  HALF(A)
                                    217 *
000338 404040404040404040           218 PLINE    DC    CL133' '
0003BD                      00339   219          ORG   PLINE+1
```

**Program 10-2 (continued)**

```
        FLOATING POINT EXAMPLE

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT

000339                            220 EXTSUM   DS    CL22
00034F                     00351  221          ORG   PLINE+25
000351                            222 EXTDIFF  DS    CL22
000367                     00369  223          ORG   PLINE+49
000369                            224 EXTPROD  DS    CL22
00037F                     00381  225          ORG   PLINE+73
000381                            226 EXTQUOT  DS    CL22
000397                     00399  227          ORG   PLINE+97
000399                            228 EXTHALFA DS    CL22
0003AF                     003BD  229          ORG
                                  230 *
                           00000  231 R0       EQU   0
                           00001  232 R1       EQU   1
                           00002  233 R2       EQU   2
                           00003  234 R3       EQU   3
                           00004  235 R4       EQU   4
                           00005  236 R5       EQU   5
                           00006  237 R6       EQU   6
                           00007  238 R7       EQU   7
                           00008  239 R8       EQU   8
                           00009  240 R9       EQU   9
                           0000A  241 R10      EQU   10
                           0000B  242 R11      EQU   11
                           0000C  243 R12      EQU   12
                           0000D  244 R13      EQU   13
                           0000E  245 R14      EQU   14
                           0000F  246 R15      EQU   15
                                  247 *
                           00000  248 FPR0     EQU   0
                           00002  249 FPR2     EQU   2
                           00004  250 FPR4     EQU   4
                           00006  251 FPR6     EQU   6
000000                            252          END   FLOATEX

+.1234567890123456E+05 -.9876543210654321E-01

BEGIN XSNAP - CALL     1 AT 40316148 USER STORAGE

                          CORE ADDRESSES SPECIFIED-     3163C8 TO 3163D8
3163C0   40404040 40777777 443039AD CC78A7A4    C01948B0 FCDF7720 77777777 77777777   *     ........................*


BEGIN XSNAP - CALL     2 AT 60316204 USER STORAGE

                          CORE ADDRESSES SPECIFIED-     3163D8 TO 316400
3163C0   40404040 40777777 443039AD CC78A7A4    C01948B0 FCDF7720 44303994 83C7AAC4   *     ......................G.D*
3163E0   443039C7 1529A483 C34C3538 923A6A5A    C51E847F FB5A07AC 44181CD6 E63C53D2   *...G....C.......E..........CW..K*

+.1234558013580244E+05  +.1234577766666665E+05  -.1219326311329064E+04  -.1249999988651561E+06  +.6172839450617277E+04
```

# 11

# Debugging a Program

## 11.1 INTRODUCTION

Once a program has been coded, it must still be tested. Any errors (commonly called "bugs") must be detected and corrected. The object is to eventually produce a program that consistently performs as desired. A few simple principles can be used to minimize the effort required to "debug" a program.

*Principle 1.* Before a program is submitted for its first test, it should be listed and carefully deskchecked.

It seems to be extremely difficult for beginners to accept this principle. There is a strong tendency to believe that it is faster to "let the machine find the errors." Understanding that this is categorically wrong is a major step toward good debugging skills.

The reasons for deskchecking a program carefully before submitting it for execution are as follows:

- If the program is very long, several errors are normally detected during the deskcheck. The time spent checking the program is usually much less than the time that would have been spent tracking down the errors individually.
- The time spent reviewing the program can also be used to determine which verifications must be made to ensure the accuracy of the results. This topic will be covered in Section 11.2.

Note that saving machine time is not a major reason for deskchecking: The main reason is to save your time.

It is normally a very good practice to have someone else deskcheck (or "walk through") your code before continuing. In a classroom environment, this will depend on the rules established by your instructor. However, most good, experienced programmers regularly deskcheck each other's code.

## 11.2 VERIFICATION TECHNIQUES

As the program is being deskchecked, it should be examined in light of the following principle:

*Principle 2.* A program should be broken up into sections of code that perform separate functions. (Frequently, these are subroutines, but sometimes a single routine can also be broken into sections.) Determine how to verify that each section is performing its function correctly, and add the required statements.

For example, suppose that SORTTAB is a program to read in a table of integers, sort the table, and print the sorted values. The program can immediately be broken into three major sections:

- the section that reads in a table of integers
- the section that sorts the table
- the section that prints the table

The last two sections might be further subdivided into smaller sections.

To verify that the section to read in the table works correctly, it is necessary to display the contents of the table. Supposing that the number of entries in the table is kept in a register, the contents of that register must be displayed as well.

Assuming that the section to read the table has executed properly, the results of the sort can be verified by again displaying the contents of the table. Finally, the output of the print routine can be checked by examining the values that are actually printed.

Now, before submitting the program for its first debugging run, the extra statements should be added:

```
SORTTAB   CSECT
          read logic
            .
            .
            .
          XDUMP                  ** ADDED **
          XDUMP TAB LE, 100      ** ADDED **
            .
            .
            .
          sort logic
            .
            .
          XDUMP TAB LE, 100      ** ADDED **
```

```
                 .
                 .
                 print logic
                 .
                 .
                 BR R14
TABLE            DS 25F
                 .
                 .
                 .
                 END SORTTAB
```

The addition of these extra statements will make the output of the run much more useful by allowing you to determine which routines executed properly and, normally, to isolate an error to a single routine.

Before continuing, it seems appropriate to discuss the format of the output produced by XDUMPs. Consider the following output, which might have been produced by the first two XDUMPS:

```
BEGIN XSNAP - CALL     1 AT 00000034 USER REGISTERS

 REGS 0-7     F4F4F4F4   00000048   00000013   F4F4F4F4   00000004   0000001B   000000EC   F4F4F4F4
 REGS 8-15    F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4   F4F4F4F4   00000110   FFFE7960   00000000


BEGIN XSNAP - CALL     2 AT 0000003A USER STORAGE

                         CORE ADDRESSES SPECIFIED-     0000AC TO 000110
0000A0   F5F5F5F5 F5F5F5F5 F5F5F5F5 00000006   00000002 00000000 00000013 F5F5F5F5   *555555555555................5555*
0000C0   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5   *5555555555555555555555555555555555*
  LINES    000CE0-0000E0    SAME AS ABOVE
000100   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5   F5F5F5F5 00000000 F5F5F5F5 F5F5F5F5   *5555555555555555555....55555555*
```

Note the following features:

- XDUMP output always begins with a line of the form

  BEGIN XSNAP = CALL  n AT mmaaaaaa USER type

  where n — is an integer that increases by 1 for each XDUMP output

  mmaaaaaa — is the rightmost four bytes of the PSW (i.e., aaaaaa gives the address in the program of the first instruction past the XDUMP that produced the output)

  type — is REGISTERS or STORAGE, depending on which format of the XDUMP produced the output

The aaaaaa is normally the most useful information. It allows you to locate quickly the XDUMP that produced the output. For example, the first XDUMP above has an address of 000034. This means that 34 is the address of the first statement past the XDUMP that displayed the registers.

- The first XDUMP has no operands. This causes the registers to be displayed. Registers 0 through 7 appear on one line, and registers 8 through 15 appear on the next line. Thus, by looking at the output, you should be able to verify that register 4 contained 00000004 at the time of the dump.
- The second XDUMP displays an area in memory. The line

  CORE ADDRESSES SPECIFIED — 0000AC TO 000110

  gives the range of addresses to be displayed. Each line of the display contains the address of the first byte displayed on the line, 32 bytes of memory in hexadecimal format, and finally the same 32 bytes in character format. ("Unprintable" characters are printed as periods.) Thus,

```
Address          Hexadecimal output of 32 bytes                                  Character output
000000  F5F5F5F5 F5F5F5F5 F5F5F5F5 00000006 00000002 00000000 00000013 F5F5F5F5  *5555555555555.............5555*
```

  The reader should now be able to see that the word at that address contains 00000006. Note that the display prints only complete 32-byte lines and that each line begins with an address that is a multiple of 32 ($20_{16}$). This can cause confusion, so the reader should make sure that the format is intelligible. (To test yourself, find the contents of the byte at address BB. The answer is 13.)

Most of the debugging time spent on assignments from this text should be spent deskchecking, inserting XDUMPS to verify results, and carefully checking the produced output.

One more principle relating to verification must be covered:

*Principle 3.* If a program is large enough to contain several routines, test the routines separately.

To illustrate this principle, consider the SORTTAB program. One reasonable way to write such a program is as follows:

1. Write the section that reads in the table of integers. Run this short program, XDUMPing the completed table to verify that everything is working properly.
2. While you are debugging the read routine, code the sort and print routines.
3. Combine the read and sort routines and test them together, XDUMPing the sorted table to verify the sort. At the same time, you can combine the read and print routines (without the sort) to begin debugging the print routine.

There are several benefits to this approach:

- Most errors are easy to locate, since only a small amount of untested code is used in each run.

- Debugging can begin earlier. This makes the process less vulnerable to unforeseen disasters (such as computer breakdown).
- It is easier to make an accurate estimate of progress. If all the program is coded but none of it has been debugged, it is hard to say when the program will be finished. On the other hand, if three-fourths of the routines are coded and half are debugged, there is some basis for projecting the time required to complete the project.

## 11.3 WORKING FROM A DUMP

When a program ends abnormally due to an error, a "dump" is produced. Program 11-1 on page 400 gives an example of an ASSIST dump.

In this section, the basic technique for locating an error from information in a dump will be covered. We have chosen a relatively simple program to illustrate how a dump should be approached. Please read through the source listing before continuing. Note that the line numbers on the left would not normally appear—we have included them for the purpose of this discussion. You may very well have spotted the bug. If so, do not let that distract you from the goal of learning how to extract information from a dump.

A great deal could be said about the art of reading dumps. However, following just a few basic principles will usually make the task of locating bugs quite straightforward.

*Principle 4.* Find out exactly what caused the abnormal termination.

To do this, perform the following tasks:

1. Determine the type of error that caused termination. This is done by examining the first line of the dump (line 97). In this dump

   COMPLETION CODE SYSTEM = 0C7 DATA

   appears. There is a manual that lists the meanings of all completion codes. For the dumps that you encounter with the assignments in this text, however, DATA conveys all the relevant information. Here, a data exception caused termination.
2. Determine the exact instruction that caused the error. In our example, this can also be determined from line 97. The right word of the PSW contains the address of the instruction following the one where the error occurred. Thus, since the address is 00001A, the error occurred while executing the ST instruction shown on line 48. (The left column of the source listing gives the location of the instruction.) ASSIST also provides a convenient instruction trace (lines 98–109). The last ten executed instructions are given, and the instruction that caused the error is labeled.

**Program 11-1**

```
*** ASSIST 4.0/ANIU OF 10/24/75 INS/DFPS/=1111 CHECK/TRP/=221 OPTS/CCKMR/=160012 NORTHERN ILL UNIV 360/67 - OS-MVT ***
$JOB
                                                                                                                    PAGE    1

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
                                     1 * THIS PROGRAM READS IN A SET OF INTEGERS INTO A TABLE AND XDUMPS
                                     2 * IT.  AS THE VALUES ARE READ THEY ARE ACCUMULATED.  AT THE END
                                     3 * THE SUM OF THE TABLE ENTRIES IS PRINTED.  THE LOGIC IS
                                     4 *
                                     5 *   STEP 1.  SET COUNT OF TABLE ENTRIES TO 0, SUM OF TABLE ENTRIES
                                     6 *            TO 0, AND INITIALIZE A POINTER TO POINT TO THE FIRST
                                     7 *            TABLE ENTRY.
                                     8 *
                                     9 *   STEP 2.  READ THE FIRST CARD.
                                    10 *
                                    11 *   STEP 3.  IF EOF HAS OCCURRED, GO TO STEP 6 TO XDUMP THE TABLE
                                    12 *            AND PRINT THE SUM OF THE ENTRIES.
                                    13 *
                                    14 *   STEP 4.  STORE THE NUMBER INTO THE TABLE, INCREMENT THE COUNT OF
                                    15 *            TABLE ENTRIES, AND ADD THE NUMBER TO THE SUM.
                                    16 *
                                    17 *   STEP 5.  READ THE NEXT CARD AND GO TO STEP 3.
                                    18 *
                                    19 *   STEP 6.  XDUMP THE COUNT OF THE TABLE ENTRIES AND THE TABLE.
                                    20 *            THEN PRINT THE SUM OF THE ENTRIES.
                                    21 *
                                    22 *   STEP 7.  EXIT.
                                    23 *
000000                              24 DUMPEX   CSECT
000000                              25          USING DUMPEX,R15
                                    26 *
                                    27 ***<STEP 1>    SET COUNT AND SUM TO 0.  POINT TO 1ST TABLE ENTRY.
                                    28 *
000000 1B44                         29          SR    R4,R4              SET COUNT TO 0
000002 1B55                         30          SR    R5,R5              SET SUM TO 0
000004 4160 F0AC            000AC   31          LA    R6,TABLE           POINT TO 1ST TABLE ENTRY
                                    32 *
                                    33 ***<STEP 2>    READ THE FIRST CARD
                                    34 *
000008 E000 F046 0050 00046         35          XREAD CARD,80
                                    36 *
                                    37 ***<STEP 3>    IF EOF HAS OCCURRED, GO TO STEP 6.
                                    38 *
00000E 4740 F02E            0002E   39 LOOP     BC    B'0100',EOF        BRANCH ON EOF
                                    40 *
                                    41 ***<STEP 4>    ADD ENTRY TO TABLE, INCR COUNT, AND ADD TO SUM
                                    42 *
000012 5320 F046            00046   43          XDECI R2,CARD            R2 HAS NEXT ENTRY
000016 5026 0000            00000   44          ST    R2,0(R6)           STORE INTO THE TABLE
00001A 4166 0004            00004   45          LA    R6,4(R6)           POINT TO NEXT ENTRY
00001E 4144 0001            00001   46          LA    R4,1(R4)           INCR COUNT
000022 1AF2                         47          AR    15,R2              ACCUMULATE THE SUM
                                    48 *
                                    49 ***<STEP 5>    READ THE NEXT CARD AND GO BACK TO STEP 3
                                    50 *
000024 E000 F046 0050 00046         51          XREAD CARD,80
```

## Program 11-1 (continued)

```
                                                                                                                                PAGE    2

   LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT
00002A 47F0 F00E            0000E    52          B     LOOP
                                     53 *
                                     54 ***<STEP 6>    XDUMP THE TABLE AND PRINT THE SUM
                                     55 *
00002E E160 0000 0000 00000          56 EOF      XDUMP
000034 E060 F0AC 0064 000AC          57          XDUMP TABLE,100          R4 HAD THE COUNT IN THE 1ST XDUMP
00003A 5250 F0A0            000A0    58          XDECO R5,SUM
00003E E020 F096 0016 00096          59          XPRNT ANS,22             PRINT THE SUM
000044 07FE                          60          BR    R14                EXIT
                                     61 *
000046                               62 CARD     DS    CL80               CARD IO AREA
000096 F05C5C5C40E2E4D4              63 ANS      DC    C'0*** SUM ='
0000A0                               64 SUM      DS    CL12
0000AC                               65 TABLE    DS    25F
                                     66          LTORG
000000                               67 R0       EQU   0
000001                               68 R1       EQU   1
000002                               69 R2       EQU   2
000003                               70 R3       EQU   3
000004                               71 R4       EQU   4
000005                               72 R5       EQU   5
000006                               73 R6       EQU   6
000007                               74 R7       EQU   7
000008                               75 R8       EQU   8
000009                               76 R9       EQU   9
00000A                               77 R10      EQU   10
00000B                               78 R11      EQU   11
00000C                               79 R12      EQU   12
00000D                               80 R13      EQU   13
00000E                               81 R14      EQU   14
00000F                               82 R15      EQU   15
                                     83          END   DUMPEX

*** NO   STATEMENTS FLAGGED -  NO   WARNINGS,  NO   ERRORS

*** DYNAMIC CORE AREA USED:  LOW:    2468 HIGH:     576 LEAVING:   99356 FREE BYTES. AVERAGE:       36 BYTES/STMT ***

*** ASSEMBLY TIME =    0.049 SECS,     1714 STATEMENTS/SEC ***

*** PROGRAM EXECUTION BEGINNING - ANY OUTPUT BEFORE EXECUTION TIME MESSAGE IS PRODUCED BY USER PROGRAM ***

*** EXECUTION TIME =    0.000 SECS.        13 INSTRUCTIONS EXECUTED -    13000 INSTRUCTIONS/SEC ***

*** FIRST CARD NOT READ: 0

 ASSIST COMPLETION DUMP

PSW AT ABEND FFC50007 C000001A       COMPLETION CODE   SYSTEM = 0C7 DATA

** TRACE OF INSTRUCTIONS JUST BEFORE TERMINATION: PSW BITS SHOWN ARE THOSE BEFORE CORRESPONDING INSTRUCTION DECODED ***

  IM LOCATION    INSTRUCTION :  IM = PSW BITS 32-39(ILC,CC,MASK) BEFORE INSTRUCTION EXECUTED AT PROGRAM LOCATION SHOWN

  00  000008     E000 F046 0050
```

**Program 11-1 (continued)**

```
 C0  00000E     4740 F02E

 80  000012     5320 F046

 A0  000016     5026 0000

 A0  00001A     4166 0004

 A0  00001E     4144 0001

 A0  000022     1AF2

 60  000024     E000 F046 0050

 C0  00002A     47F0 F00E

 80  000014     F046 5026 0000  <-- LAST INSTRUCTION DONE - PROBABLE CAUSE OF TERMINATION


** TRACE OF LAST 10 BRANCH INSTRUCTIONS EXECUTED: PSW BITS SHOWN ARE THOSE BEFORE CORRESPONDING INSTRUCTION DECODED ***

 IM LOCATION    INSTRUCTION :  IM = PSW BITS 32-39(ILC,CC,MASK) BEFORE INSTRUCTION EXECUTED AT PROGRAM LOCATION SHOWN

 00  00002A     47F0 F00E

 REGS 0-7      F4F4F4F4    00000047    00000006    F4F4F4F4    00000001    00000000    000000B0    F4F4F4F4
 REGS 8-15     F4F4F4F4    F4F4F4F4    F4F4F4F4    F4F4F4F4    F4F4F4F4    00000110    FFFE7960    00000006

 FLTR 0-6      F4F4F4F4F4F4F4F4        F4F4F4F4F4F4F4F4        F4F4F4F4F4F4F4F4        F4F4F4F4F4F4F4F4

 USER STORAGE

                                CORE ADDRESSES SPECIFIED-     000000 TO 000258
000000   1B441B55 4160F0AC E000F046 00504740    F02E5320 F0465026 00004166 00044144  *......0...0.... 0...0...........*
000020   00011AF2 E000F046 005047F0 F00EE160    00000000 E060F0AC 00645250 F0A0E020  *...2..0....00.........0.....0...*
000040   F0960016 07FEF640 40404040 F2404040    40404040 40404040 40404040 40404040  *0.....6     2                   *
000060   40404040 40404040 40404040 40404040    40404040 40404040 40404040 40404040  *                                *
000080   40404040 40404040 40404040 40404040    40404040 40404040 40404040 E4D4407E  *                              UM .*
0000A0   F5F5F5F5 F5F5F5F5 F5F5F5F5 00000006    F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5  *555555555555....5555555555555555*
0000C0   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5    F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5  *55555555555555555555555555555555*
  LINES     0000E0-0000E0    SAME AS ABOVE
000100   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5    F5F5F5F5 00000000 F5F5F5F5 F5F5F5F5  *555555555555555555....55555555*
000120   F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5    F5F5F5F5 F5F5F5F5 F5F5F5F5 F5F5F5F5  *55555555555555555555555555555555*
  LINES     000140-000220    SAME AS ABOVE


*** TOTAL RUN TIME UNDER ASSIST =     0.083 SECS***
```

Note the discrepancy! Lines 108 and 109 show that the branch instruction at line 58

```
B        LOOP
```

caused a branch to location 000014 (not to location 00000E, as was intended). All this may seem confusing. Do not let this disturb you—just continue gathering information, always asking: "How could this have happened?" Never assume that it could not have happened, that "the machine broke."

3. Verify that the program has not been altered in memory (by storing values over instructions). At this point, we are mostly concerned with the instructions in the area of 000012-000022. Lines 119 through 129 display the contents of memory at the time of the error. Since the format is the same as that used by an XDUMP, you should be able to compare the contents of 000012-000022 with the source listing. (The object code is shown in the second, third, and fourth columns of the source listing.) Verify that the instructions have not been altered.
4. It is sometimes interesting to look at the contents of data areas. In our example, it might be useful to examine the contents of CARD and TABLE. (Do this as an exercise in locating memory locations.) The registers at the time of the error appear in lines 114–115. (The floating-point registers, which are seldom of interest, appear in line 116.) Registers 2, 4, 5, and 6 all have some bearing on this problem. Check their contents and determine whether they contain "expected" values.

At this point, after analyzing the state of the machine when the error occurred, a new principle must be applied.

*Principle 5.* Isolate the error. Determine which section of code produced unexpected, erroneous results.

The example that we are considering is so short that this principle really does not apply. In a longer program, however, it is extremely important. Too often a student will simply peruse page after page of code, hoping that the error will become apparent. If the verification of output is not adequate to isolate the error, carefully add more verification logic and resubmit the program.

Finally, after isolating the section of code that produced the error, use the following principle:

*Principle 6.* Ask yourself: "What could have caused the error?" Work backward from the error.

This is the "detective" part of debugging. In this example, the procedure might go as follows:

a. We know that

```
B        LOOP
```

caused a branch to location 000014. The actual branch was not altered. This can occur only if the address that was computed resulted in 000014.

b. The address in the branch instruction is F00E (14 bytes past the address in R15). Since this gave the wrong value, R15 must not be set properly.

c. Since R15 was set properly when the program was entered (by assumption), the program must have altered R15. Now we have the bug. The program should not have altered R15, but it did. By looking through the code, you will see in line 51

```
AR       15,R2
```

R15 is altered. (The "15" should be "R5.") The bug was probably caused by a typing error.

With more experience in debugging, the error could have been detected more quickly. Useful rules, such as

*If the PSW (location of the next instruction) does not point at a valid instruction or points at a quite unexpected location, check to see whether the program in memory was altered or a base register was altered*

will eventually become part of your debugging repertoire.

## 11.4 SUMMARY

Being able to debug a program is a skill required of any programmer. A good way to develop the ability to debug a program rapidly is to study the six principles and consistently apply them.

*Principle 1.* Before a program is submitted for its first test, it should be listed and carefully deskchecked.

*Principle 2.* A program should be broken up into sections of code that perform separate functions. (Frequently, these are subroutines, but sometimes a single routine can also be broken into sections.) Determine how to verify that each section is performing its function correctly, and add the required statements.

*Principle 3.* If a program is large enough to contain several routines, test the routines separately.

*Principle 4.* Find out exactly what caused the abnormal termination.

*Principle 5.* Isolate the error. Determine which section of code produced unexpected, erroneous results.

*Principle 6.* Ask yourself: "What could have caused the error?" Work backward from the error.

Finally, after locating each troublesome bug, reevaluate your attack on the error. Determine whether you approached it methodically or wasted time and effort. Try to synthesize your experience into general rules. Learn from your errors so that you can avoid repeating them.

# 12

# Structured Programming

## 12.1 INTRODUCTION

Since the first edition of this text was written, a number of advances have been made in programming methodology. In particular, the advantages of structured programming techniques have become widely recognized. For this reason, most of the examples in the preceding chapters have been replaced with structured programs. In this chapter, the techniques for creating structured programs are presented in detail.

As programming problems become larger and more complex, correct solutions are increasingly difficult to produce. More care is required at the design stage to ensure that the program will produce satisfactory results. All routines and subroutines must be designed so that they will work together correctly and simply.

Each programming task poses a unique set of problems, but the following design criteria apply to every program:

- *Clarity.* The logic of the program should be easy to understand.
- *Modularity.* A program should be broken down functionally into subroutines that interact with each other. It is possible to understand large programs only if they are designed in this way.
- *Ease of modification.* Very few programs survive for long without some changes. Programs should be designed so that modifications can be easily made.
- *Correctness.* An algorithm that has been designed with simplicity as a goal will be easier to verify. In such cases, coding the program should be a routine chore.

Structured programming techniques have been designed and adopted to aid in satisfying these criteria.

The germ of the idea of structured programming came from a paper presented in 1964 to the International Colloquium on Algebraic Linguistics and Automata Theory in Israel. In this paper, Corrado Böhm and Guiseppe Jacopini proved that any programming logic can be expressed using sequential processes and only two control structures.

The first large-scale application of structured programming techniques to a commercial setting took place from 1969 to 1972—the highly publicized "New York Times Project," carried out by the IBM Corporation. The remarkable success of this project and the publicity it received led to general acceptance of structured programming techniques by the mid-1970s.

*Pseudo-code* came into vogue as a notation for presenting program logic, along with the general acceptance of structured programming techniques. In this section and Sections 12.2 and 12.3, pseudo-code is introduced by displaying the logic of some simple constructs and programs in pseudo-code, as well as in flowcharts.

Before considering an example, we shall present a definition of *structured logic*. The meaning and significance of structured logic will become apparent as the examples in the rest of this chapter are examined. A *basic block of code* is a sequence of assembler instructions that is executed from top to bottom. It can contain calls to subroutines, but it cannot include branches. A *structured block of code* can be defined as follows:

1. A basic block of code is a structured block of code.
2. If **block a** and **block b** are both structured blocks of code, then the structure representing **block a** followed by **block b** is a structured block of code. Such a structure is called a *sequence structure*.
3. If **block a** and **block b** are both structured blocks of code and if **cond** is a condition, the structure that causes **cond** to be tested and **block a** or **block b** to be selected on the basis of that test is a structured block of code. Such a structure is called an *if-then-else structure*. Either **block a** or **block b**, but not both, may be vacuous.
4. If **block a** is a structured block of code and if **cond** is a condition, the structure that causes **block a** to be executed repeatedly until **cond** is true is a structured block of code. Such a structure is called a *do-while structure*.

A *structured program* is one that can be formed by repeated application of these four rules. Figure 12-1 and the corresponding pseudo-code illustrate the logic of a structured program.

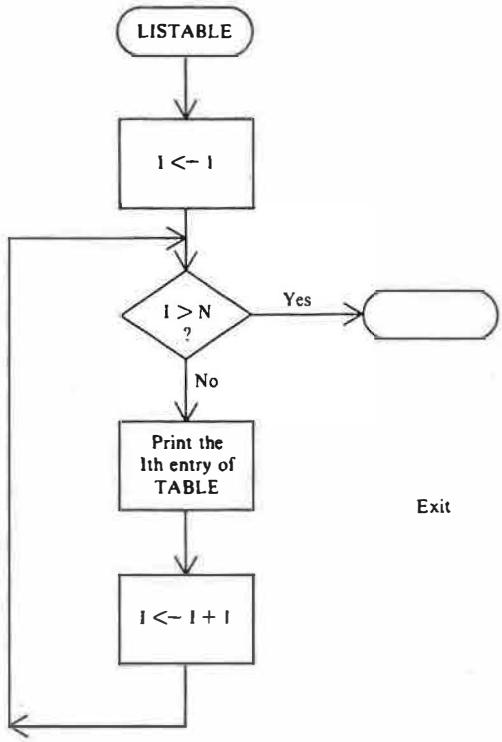



**Figure 12-1**

**PSEUDO-CODE**

```
LISTABLE:   Proc(TABLE,N)
    I ← 1
    Do while (I <= N)
        Print the Ith entry of TABLE
        I ← I + 1
    Enddo
Endproc
```

Study the flowchart to make sure that you understand the logic. The algorithm prints the N entries in TABLE. I is used as a subscript. Now the pseudo-code should be decipherable:

a.
```
LISTABLE: Proc(TABLE,N)
        .
        .
        .
Endproc
```

indicates a module called LISTABLE with two input parameters (TABLE and N). The logic will be described in detail between Proc and Endproc.

b. The individual steps in the pseudo-code correspond to boxes in the flowchart.

c. The loop is presented as

```
Do while (condition)
    .
    .
    .
Enddo
```

which means that the steps between Do and Enddo are to be repeated until the condition is not true. To visually set off the body of the loop, we indent it.

In the following sections of this chapter, the rules for constructing acceptable patterns of logic will be considered. For now, a basic grasp of flowcharts and pseudo-code will suffice.

## 12.2 LOOPS—THE DO-WHILE CONSTRUCT

The structure of the loop in Figure 12-1 can be generalized. Consider the problem of processing the elements of an ordered set, as shown in Figure 12-2 on page 433.

In Figure 12-1, the ordered set was the set of entries in TABLE. Thus, in Figure 12-2,

1. "Set up to access the first element" means "set I to 1."
2. "Has the entire set been processed?" means "check to see whether I is greater than N."
3. "Process one element" means "print the Ith element."
4. "Set up to access the next element" means "add 1 to I."

Now consider the problem of listing a file of records, as shown in Figure 12-3 on page 433. Note that the pattern of logic is identical to that exhibited in Figure 12-2.

Now we will examine the logic of a program to read in a set of test scores (one per record) and calculate the average of the scores. Before continuing, write a flowchart to describe the algorithm.

The pseudo-code (which hopefully matches your flowchart) for the problem is as follows:

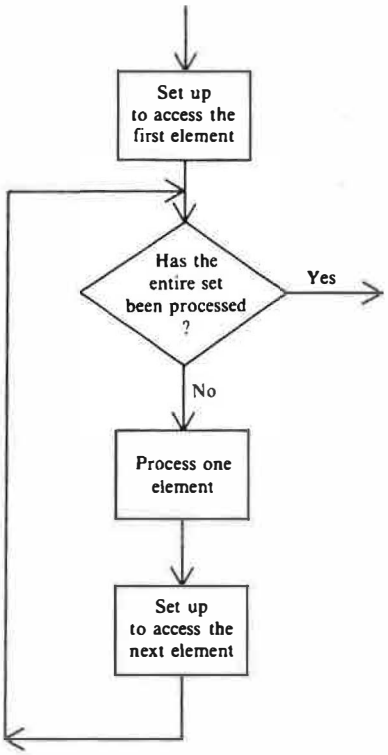



**Figure 12-2**

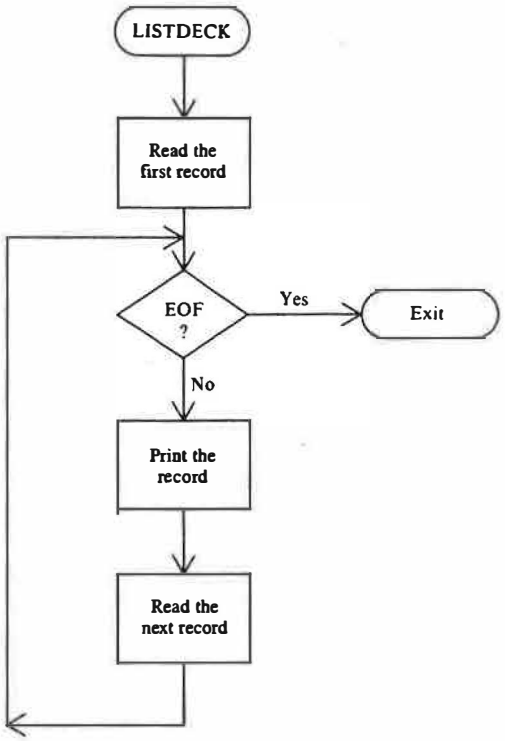



**Figure 12-3**

```
TESTAVG: PROC
    SUM ← 0
    NUM ← 0
    Read the first card
    Do while (EOF has not occurred)
        add the test score to SUM
        NUM ← NUM + 1
        Read the next card
    Enddo
    AVG ← SUM/NUM
    Print AVG
Endproc
```

You might have added a line to print each value or a check to see whether EOF occurred on the first read. What is important is that your loop be similar to the one above. That is, it should have a structure as shown in Figure 12-4.

The pattern of logic that occurs in each of these loops is one of the fundamental patterns of logic. Most loops can be thought of as following this pattern. All loops can be made to conform to the structure of Figure 12-5. This is the pattern represented by the "do-while" construct in pseudo-code. In a structured program, all loops must conform to this pattern.

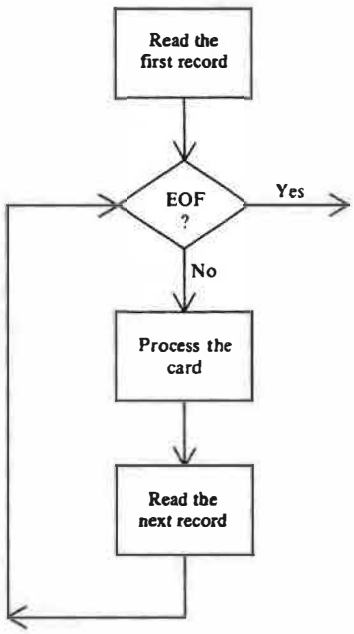



**Figure 12-4**

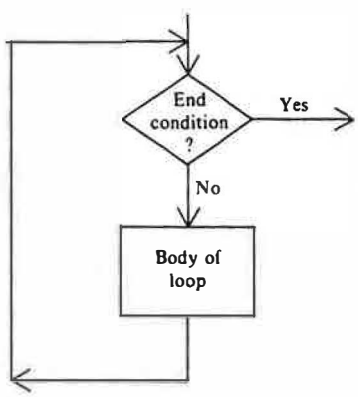



**Figure 12-5**

## 12.3 PROCESSING ALTERNATIVES—THE IF CONSTRUCT

At certain points in an algorithm it is necessary to break the logic into alternatives. In this case, the "if <cond> then <code-1> else <code-2>" construct should be used. (See Figure 12-6.)

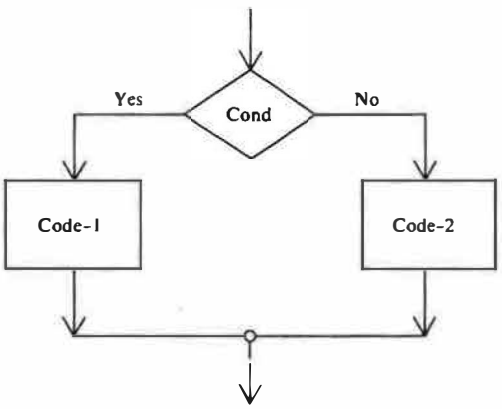



**Figure 12-6**

**PSEUDO-CODE—IF**

```
If (cond)
    code-1
else
    code-2
Endif
```

To illustrate this pattern, consider Figure 12-7, an algorithm to find the largest integer in a table of N numbers.

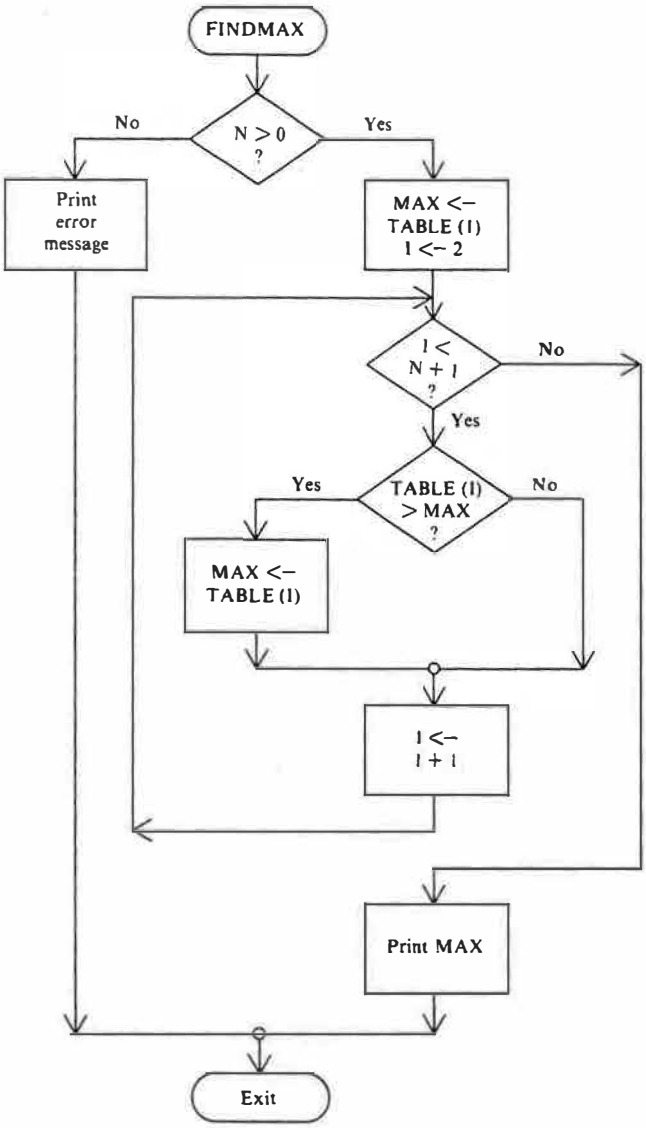

FINDMAX
N > 0 ?
No
Yes
Print error message
MAX <- TABLE (I) I <- 2
I < N + 1 ?
No
Yes
TABLE (I) > MAX ?
Yes
No
MAX <- TABLE (I)
I <- I + 1
Print MAX
Exit

**Figure 12-7**

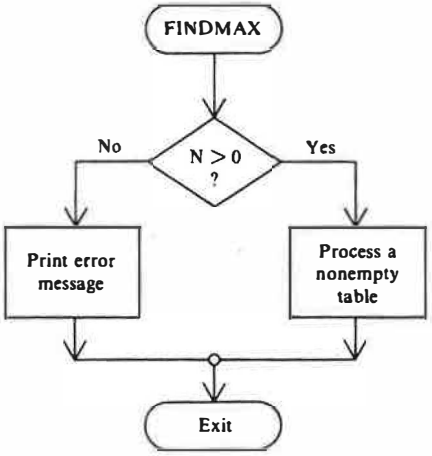



**Figure 12-8**

The structure of FINDMAX can be visualized as in Figure 12-8, where "process a nonempty table" is as in Figure 12-9.

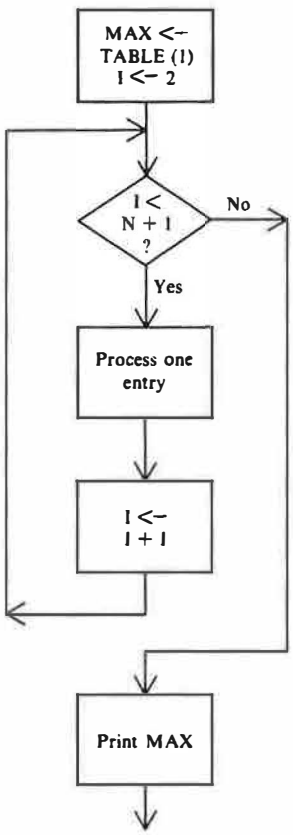



**Figure 12-9**

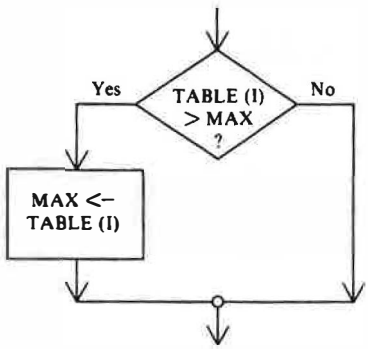



**Figure 12-10**

In Figure 12-10, "process one entry" is valid, even though one alternative contains no code. The pseudo-code for FINDMAX would be as follows:

```
FINDMAX: Proc(TABLE,N)
    If (N <= 0)
        Print error message
    else
        MAX ← TABLE(1)
        I ← 2
        Do while (I < N + 1)
            If (TABLE(I) > MAX)
                MAX ← TABLE(I)
            Endif
            I ← I + 1
        Enddo
        Print MAX
    Endif
Endproc
```

Note the exact correspondence between the flowchart and the pseudo-code.

Occasionally, there will be more than two alternatives. This is called a *case analysis* and is depicted as in Figure 12-11.

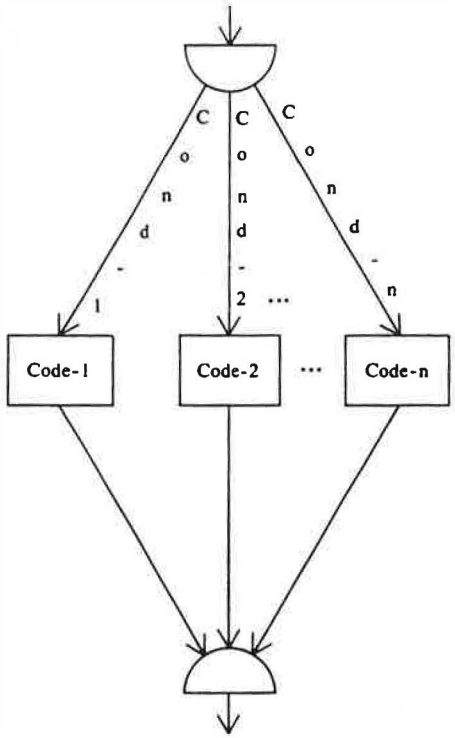



**Figure 12-11**

The pseudo-code for this logic is

```
If
Cond(cond-1)
    code-1

Cond(cond-2)
    code-2
.
.
.
Cond(cond-n)
    code-n

Endif
```

Here it is assumed that at least one of the conditions will be true. For convenience, the last condition may be given as

```
Cond Else
    Code
```

To illustrate this type of structure, suppose that a program to balance a checkbook processes three types of transactions:

- checks
- deposits
- automatic deductions and service charges

Each transaction contains a code (C, D or A) to identify the type of transaction. In this case, the logic might appear as in Figure 12-12.

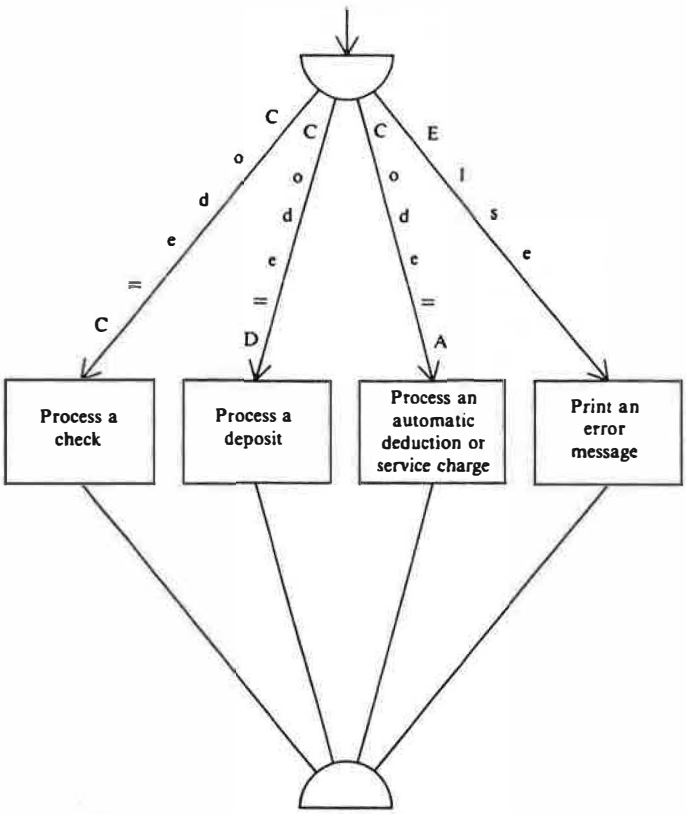



**Figure 12-12**

**PSEUDO-CODE**

```
If
Cond (code = C)
     Process a check
Cond (code = D)
     Process a deposit
```

```
Cond (code = A)
    Process an automatic deduction or service charge
Cond Else
    Print an error message
Endif
```

## 12.4 HOW TO FORMULATE AN ALGORITHM—STEPWISE REFINEMENT

Once the requirements of a program are well understood, the programmer faces the problem of formulating an appropriate algorithm. The technique of stepwise refinement imposes a discipline that allows the programmer to methodically reach a correct, well-structured solution. In this section, we will describe this approach and illustrate its use in a typical program.

The logic of most programs is quite complex. To attack such a problem, it is necessary to break it into subproblems. This is really the key to the design of good logic—the ability to break up a problem into the correct subproblems. The algorithm must be broken up into a few major subfunctions so that, if you think of the subfunctions as subroutines, the algorithm is short and clear. The algorithm should, of course, be constructed using the do-while logic for each loop and the if-then-else logic whenever alternative processing is required.

Once the main routine is properly completed, each subroutine can be attacked using the same approach:

1. Define the subfunctions that allow the task to be broken into a few basic components.
2. Using the defined subfunctions, compose the logic of the algorithm, using the do-while and if-then-else constructs.

To illustrate this technique, we will reconsider a problem presented in Chapter 4: Formulate the logic for a program to produce "class lists" for each class being taught in a given school. The input to the program is assumed to be a set of records that conform to the following format:

| *Position* | *Contents* |
|---|---|
| 1–4 | Department offering the course |
| 5–8 | Course number |
| 9–18 | Last name of student |
| 19–28 | First name of student |
| 29–80 | (Unused) |

It is further assumed that this file has been sorted into ascending order, based on the first 28 columns. The program is to produce a class list for each class, which includes the total number of students registered in the class.

This problem represents a general category of data processing programs called *reports*. Although this program will be relatively simple, the basic logic is typical of most reports.

First, note the function of the report—to produce a set of class lists. It is useful to think of the input as a sequence of groups, each group containing the records for one class. The function of the program is to process a sequence of groups, producing a class list for each group. If a subroutine is used to process a single group (producing one class list), then the rest of the logic will become manageable. (See Figure 12-13.)

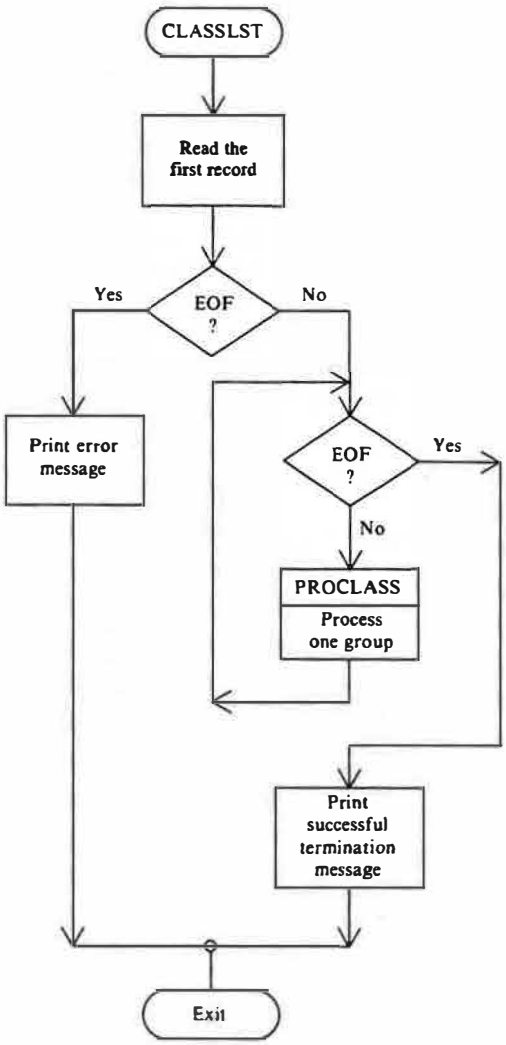



**Figure 12-13**

Note that the logic depicted in Figure 12-13 is essentially the same as that used to list a file of records, with an additional check to ensure that the input file is not empty. The first record must be read before calling PROCLASS, since PROCLASS must always read through the first record of the next group. (This is nontrivial—make sure that you understand.)

The flowchart for CLASSLST is simple and comprehensible. It is properly structured using the if-then-else and do-while patterns. It may be necessary to make some minor modifications later, but at this point it seems correct.

Now the logic for PROCLASS can be considered. If you think about it, there are three basic pieces of logic, as shown in Figure 12-14.

1. Initialization involves
   - saving the department and course number from the first record (which was already read)
   - setting the count of students in the list to zero
   - printing the page headers on the first page of the class list

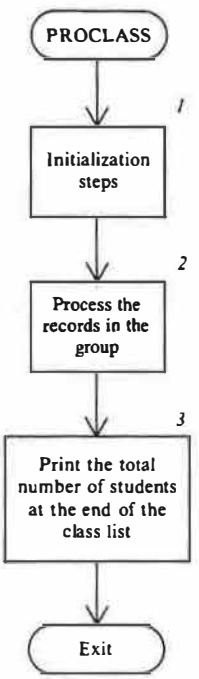



**Figure 12-14**

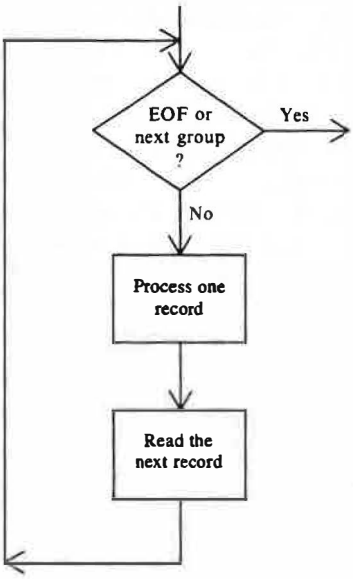



**Figure 12-15**

2. Processing the records involves printing the data from each record in the current group and stopping as soon as the first record from the next group is encountered (or when EOF occurs).
3. The only total in this report is the number of students in the class.

You must admit that the resulting logic is simple! The first block can be expanded to three, one for each initialization step. It is not necessary to implement each block as a separate subroutine. A single block can be replaced by several if doing so does not make the logic overly complex. However, the overall flowchart should always fit on a single page.

The second block processes a sequence of records (those in the group). This logic should be familiar to you by now. (See Figure 12-15.)

"Process one record" simply means

- build a print line
- call PRINTSP1 to print it after single-spacing (unless it is time to skip to the next page)
- increment the count of students

After expanding PROCLASS, the logic shown in Figure 12-16 results.

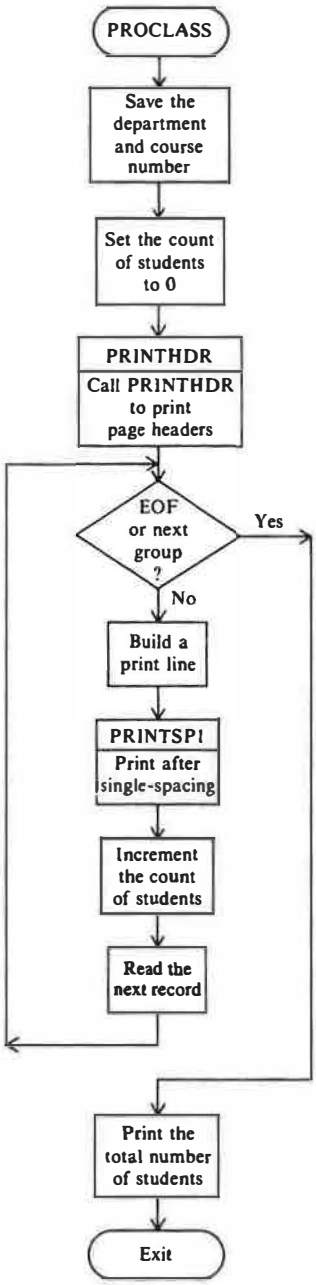

PROCLASS
Save the department and course number
Set the count of students to 0
PRINTHDR
Call PRINTHDR to print page headers
EOF or next group ?
Yes
No
Build a print line
PRINTSPI
Print after single-spacing
Increment the count of students
Read the next record
Print the total number of students
Exit

**Figure 12-16**

PRINTHDR actually contains only trivial logic—print the headers and set the LINECTR to 5. (LINECTR will always contain the line number of the next line on the page.) PRINTSP1 is only slightly more complex. (See Figure 12-17.)

A "rough draft" of the logic for the program is now complete. We achieved this by continually deferring problems, to keep the logic of each routine simple. This is important: It is the only way to consistently compose correct algorithms.

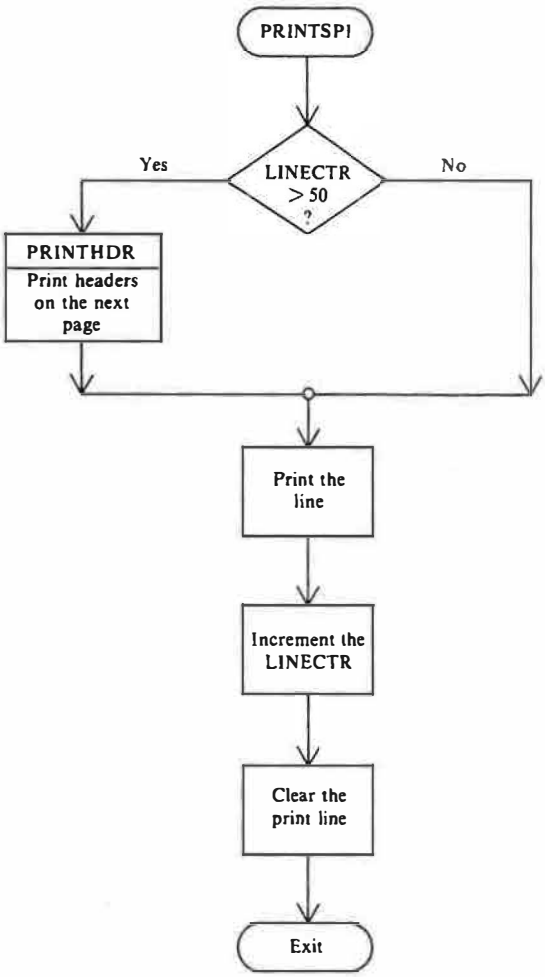



**Figure 12-17**

Our final version of the logic has only two slight modifications:

- A subroutine was created to read records and set an end-of-file flag.
- We decided that the main routine should initially clear the print line. Then the print line will be cleared immediately after each line is printed.

## 12.5 A STRUCTURED PROGRAM WITH PSEUDO-CODE

The documentation of a structured program is more naturally accomplished with pseudo-code than with step algorithms. Programs 12-1 and 12-2 implement the CLASSLST and PROCLASS algorithms from Section 12.4.

**Program 12-1**

```
*****************************************************************
*
* CLASSLST: PROGRAM
*
*  (1) CALL READCARD TO READ THE FIRST CARD AND SET EOFFLAG TO Y
*        IF END-OF-FILE IS DETECTED
*
*      IF (EOF OCCURRED - NO CARDS IN THE INPUT FILE)
*
*  (2)     PRINT AN ERROR MESSAGE (EMPTY INPUT FILE)
*
*      ELSE
*
*  (3)     CLEAR THE PRINT LINE. FROM NOW ON IT IS CLEARED AFTER EACH
*            LINE IS PRINTED.
*
*          DO WHILE (EOF HAS NOT YET OCCURRED)
*
*  (4)         CALL PROCLASS TO PROCESS THE CARDS FOR ONE CLASS LIST
*                (AND TO READ THE 1ST CARD FOR THE NEXT LIST)
*
*          ENDDO
*
*  (5)     PRINT A "SUCCESSFUL TERMINATION" MESSAGE
*
*      ENDIF
*
*    ENDPROG
*
*****************************************************************
*
CLASSLST CSECT
         LR    R12,R15            SET UP R12 AS THE BASE REGISTER
         USING CLASSLST,R12
*
         BAL   R11,READCARD       READ THE 1ST CARD              (1)
*
         CLI   EOFFLAG,C'Y'
         BNE   CLEARLN            BRANCH IF EOF WAS NOT DETECTED
*
         XPRNT =C'1*** NO INPUT ***',17                          (2)
         B     EXIT
*
CLEARLN  MVI   PRNTLINE,C' '      CLEAR THE PRINT LINE           (3)
         MVC   PRNTLINE+1(132),PRNTLINE
```

**Program 12-1 (continued)**

```
*
PROCLOOP CLI   EOFFLAG,C'Y'        CONTINUE LOOPING UNTIL EOF
         BE    PRINTEND
*
         BAL   R11,PROCLASS        PRINT 1 CLASS LIST            (4)
*
         B     PROCLOOP
*
PRINTEND XPRNT =C'1*** SUCCESSFUL TERMINATION ***',31           (5)
*
EXIT     BR    R14                 LEAVE THE PROGRAM
*
```

**Program 12-2**

```
*****************************************************************
*
* PROCLASS PRODUCES 1 CLASS LIST.  WHEN IT COMPLETES, EITHER
* EOF HAS OCCURRED (EOFFLAG WILL BE Y) OR THE FIRST CARD FOR THE
* NEXT CLASS LIST HAS BEEN READ.  THE LOGIC IS AS FOLLOWS:
*
* PROCLASS: PROC
*
*  (1)     SAVE THE DEPARTMENT AND COURSE FOR THIS LIST
*
*  (2)     SET THE COUNT OF THE STUDENTS IN THE LIST TO 0
*
*  (3)     CALL PRINTHDR TO PRINT THE HEADERS FOR THE FIRST PAGE OF
*            THE CLASS LIST
*
*          DO WHILE (EOF HAS NOT OCCURRED AND THE CURRENT CARD IS FOR
*                    THE CLASS LIST THAT WE ARE PRINTING)
*
*  (4)         BUILD A PRINT LINE FROM DATA ON THE CARD
*
*  (5)         CALL PRINTSP1 TO PRINT AFTER SPACING 1 (HEADERS
*                WILL BE PRINTED IF THE NEXT LINE ON THE PAGE
*                IS GREATER THAN 50)
*
*  (6)         ADD 1 TO THE COUNT OF STUDENTS IN THE LIST
*
*  (7)         CALL READCARD TO READ THE NEXT CARD AND SET EOFFLAG
*
*          ENDDO
*
*  (8)     PRINT THE TOTAL NUMBER OF STUDENTS IN THE CLASS LIST
*
*     ENDPROC
*
*
*****************************************************************
*
PROCLASS STM   R14,R12,PRCLSAVE+12 SAVE CALLER'S REGISTERS
*
         MVC   CURRKEY,CARD        SAVE THE KEY (DEPT,COURSE)    (1)
*
         SR    R2,R2               SET COUNT OF STUDENTS IN THE  (2)
*                                  LIST TO 0
*
         BAL   R11,PRINTHDR        PRINT THE PAGE HEADERS        (3)
*
         CLI   EOFFLAG,C'Y'        END LOOP ON EOF OR NEW KEY
         BE    PRINTTOT
         CLC   CURRKEY,CARD
         BNE   PRINTTOT            MISMATCH MEANS NEW KEY
*
```

**Program 12-2 (continued)**

```
         MVC    DEPTOUT,DEPTIN       NOW MOVE DATA FIELDS          (4)
         MVC    COURSOUT,COURSIN     THE PRINT LINE
         MVC    LNAMEOUT,LNAMEIN
         MVC    FNAMEOUT,FNAMEIN
*
         BAL    R11,PRINTSP1         PRINT THE LINE (AND HEADERS,  (5)
*                                    IF NECESSARY)
*
         LA     R2,1(R2)             ADD 1 TO COUNT OF STUDENTS    (6)
*
         BAL    R11,READCARD         TRY TO READ THE NEXT CARD     (7)
*
         B      PROCLOOP
*
PRINTTOT XDECO  R2,PRNTLINE+25       PUT TOTAL INTO PRINT LINE     (8)
         MVC    PRNTLINE+7(18),=C'TOTAL # STUDENTS ='
         MVI    PRNTLINE,C'0'        SET CARRIAGE CONTROL FOR
*                                    DOUBLE-SPACE
         XPRNT  PRNTLINE,133         PRINT LAST LINE FOR LIST
         MVI    PRNTLINE,C' '        CLEAR THE PRINT LINE
         MVC    PRNTLINE+1(132),PRNTLINE
*
         LM     R14,R12,PRCLSAVE+12 RESTORE CALLER'S REGISTERS
         BR     R11
*
PRCLSAVE DS     18F                  REGISTER SAVE AREA
*
```

There are many documentation styles. We feel that the following features are significant:

- The pseudo-code should never contain "go to step n." All loops should follow the do-while pattern, and all alternatives should follow the if-then-else (or case analysis) pattern.
- The instructions that implement the pseudo-code should faithfully implement the described logic. In Programs 12-1 and 12-2, we number the English descriptions in the pseudo-code and use these numbers as comments in the actual code. This usage allows the reader to locate a section of code rapidly.

## 12.6 WRITING STRUCTURED PROGRAMS USING MACROS TO IMPLEMENT THE STRUCTURES

A variety of macro libraries have been developed to support structured programming. Appendix F contains the listings of one such library. These macros were developed by Dave Carpenter, Naiping Lee, and Gene Petrie at Northern Illinois University. They use features that are not supported by ASSIST's macro processor; they are intended for use with any standard assembler supplied by IBM (or any compatible assembler).

An example will help to clarify the use of such macros. The following

```
                IF (LTR,R15,R15,M)
*
                  L       R2,=F'-1'
*
                ELSE
*
                  SR      R2,R2
*
                ENDIF
```

generates code equivalent to

```
                LTR       R15,R15
                BNM       POS
                L         R1,=F'-1'
                B         NEXTINS
POS             SR        R2,R2
NEXTINS         EQU       *
```

Note the clarity that is achieved by using the macros and a few interspersed comment cards.

The IF, ELSE and ENDIF macros generate the testing and branch instructions required to support alternatives. These can be coded as follows:

```
    IF condition
*
        code to execute if the condition is true
*
    ELSE
*
        code to execute if the condition is false
*
    ENDIF
```

or as

```
    IF condition
*
        code to execute if the condition is true
*
    ENDIF
```

The condition can take several forms. A basic condition can be one of the following:

1. *A branch mask.* Thus

```
IF (M)
    LPR  R4,R4
ENDIF
```

is equivalent to

```
         BNM     NEXTINS
         LPR     R4,R4
NEXTINS  EQU     *
```

2. *A comparison.* Here the condition is specified as a list with four components:

(comparison mnemonic,first operand,operator,second operand)

The valid comparison operators are

```
EQ      NE
LT      LE
GT      GE
```

Thus,

```
IF (C,R4,GT,=F'10')
    SR   R4,R4
ENDIF
```

is equivalent to

```
         C       R4,=F'10'
         BNH     NEXTINS
         SR      R4,R4
NEXTINS  EQU     *
```

3. *A noncomparison instruction.* Here the condition is specified as

(instruction mnemonic,first operand,second operand,branch mask)

Thus,

```
IF (SH,R2,=H'1',NM)
    LA R3,80(R3)
ENDIF
```

is equivalent to

```
         SH      R2,=H'1'
         BM      NEXTINS
         LA      R3,80(R3)
NEXTINS  EQU     *
```

A "complex" condition can be formed using the AND and OR parameters. For example,

```
IF (C,R4,GE, =F'90),AND,(C,R4,LE, =F'100')
    code
ENDIF
```

causes the code to be executed if R4 contains a value in the range 90 to 100.

```
IF (CLI,ERRFLAG,EQ,C'T'),OR,(LTR,R6,R6,M)
    code
ENDIF
```

causes the code to be executed if the ERRFLAG is T or if R6 contains a negative value. Similarly,

```
IF (CLC,RC,EQ, =F'0'),AND,(SH,R4, =H'1',NM),AND,(LTR,R7,R7,P)
    code
ENDIF
```

causes the code to be executed only when all three conditions are true.

Since a condition is composed of a list of macro operands, parentheses cannot be used to force a desired grouping. Thus,

```
IF (cond-1,AND,(cond-2,OR,cond-3))
```

is not legal. To force this grouping

```
IF cond-1,ANDIF,cond-2,OR,cond-3
```

would be used. The ANDIF and ORIF parameters are provided to give the effect of enclosing the remaining parameters within parentheses. Although the programmer does not have the freedom to use parentheses arbitrarily, in practice the constraint is seldom noticed.

Finally, if a case analysis is desired, the following pattern can be used:

```
      IF
      COND cond-1
          code to be executed if cond-1 is true
*
      COND cond-2
          code to be executed if cond-2 is true
*
      .
      .
      .
      COND cond-n
          code to be executed if cond-n is true
      ENDIF
```

Here one of the conditions is assumed to be true. (If none is, an abnormal termination results.) For convenience,

```
COND ELSE
```

can be used as the last condition. For example,

```
IF
COND (CLI,TRANCD,EQ,C'A'),OR,(CLI,TRANCD,EQ,C'X')
     code-1
COND (CLI,TRANCD,EQ,C'D')
     code-2
COND (CLI,TRANCD,EQ,C'E')
     code-3
COND ELSE
     code-4
ENDIF
```

selects one of four sections of code, based on the value in TRANCD.

Looping can be achieved by using DO and ENDDO instead of IF and ENDIF. For example,

```
LA       R6,50
DO WHILE,(SH,R6,=H'1',NM)
     code
ENDDO
```

executes the code 50 times. Similarly,

```
DO WHILE,(LTR,R7,R7,P),AND,(CLI,ERRFLAG,EQ,C'F')
     code
ENDDO
```

loops while both basic conditions are true.

The following versions of CLASSLST and PROCLASS in Programs 12-3 and 12-4 illustrate use of the macros.

**Program 12-3**

```
*****************************************************************
*
* CLASSLST: PROGRAM
*
*  (1) CALL READCARD TO READ THE FIRST CARD AND SET EOFFLAG TO Y
*        IF END-OF-FILE IS DETECTED
*
*      IF (EOF OCCURRED - NO CARDS IN THE INPUT FILE)
*
*  (2)     PRINT AN ERROR MESSAGE (EMPTY INPUT FILE)
*
*      ELSE
*
*  (3)     CLEAR THE PRINT LINE. FROM NOW ON IT IS CLEARED AFTER EACH
*            LINE IS PRINTED.
*
*          DO WHILE (EOF HAS NOT YET OCCURRED)
*
*  (4)         CALL PROCLASS TO PROCESS THE CARDS FOR ONE CLASS LIST
*                (AND TO READ THE 1ST CARD FOR THE NEXT LIST)
*
*          ENDDO
*
*  (5)     PRINT A "SUCCESSFUL TERMINATION" MESSAGE
*
*      ENDIF
*
*    ENDPROG
*
*****************************************************************
*
CLASSLST CSECT
         LR    R12,R15            SET UP R12 AS THE BASE REGISTER
         USING CLASSLST,R12
*
         BAL   R11,READCARD       READ THE 1ST CARD              (1)
*
         IF (CLI,EOFFLAG,EQ,C'Y')  IF EOF OCCURRED
*
           XPRNT =C'1*** NO INPUT ***',17                        (2)
*
         ELSE
*
           MVI   PRNTLINE,C' '      CLEAR THE PRINT LINE         (3)
           MVC   PRNTLINE+1(132),PRNTLINE
*
           DO WHILE,(CLI,EOFFLAG,NE,C'Y')  WHILE NOT EOF
*
             BAL   R11,PROCLASS       PRINT 1 CLASS LIST         (4)
*
           ENDDO
*
           XPRNT =C'1*** SUCCESSFUL TERMINATION ***',31          (5)
*
         ENDIF
*
         BR    R14                LEAVE THE PROGRAM
*
```

```
*****************************************************************
*
* PROCLASS PRODUCES 1 CLASS LIST.  WHEN IT COMPLETES, EITHER
* EOF HAS OCCURRED (EOFFLAG WILL BE Y) OR THE FIRST CARD FOR THE
* NEXT CLASS LIST HAS BEEN READ.  THE LOGIC IS AS FOLLOWS:
*
* PROCLASS: PROC
*
*  (1)      SAVE THE DEPARTMENT AND COURSE FOR THIS LIST
*
*  (2)      SET THE COUNT OF THE STUDENTS IN THE LIST TO 0
*
*  (3)      CALL PRINTHDR TO PRINT THE HEADERS FOR THE FIRST PAGE OF
*             THE CLASS LIST
*
*           DO WHILE (EOF HAS NOT OCCURRED AND THE CURRENT CARD IS FOR
*                     THE CLASS LIST THAT WE ARE PRINTING)
*
*  (4)          BUILD A PRINT LINE FROM DATA ON THE CARD
*
*  (5)          CALL PRINTSP1 TO PRINT AFTER SPACING 1 (HEADERS
*                 WILL BE PRINTED IF THE NEXT LINE ON THE PAGE
*                 IS GREATER THAN 50)
*
*  (6)          ADD 1 TO THE COUNT OF STUDENTS IN THE LIST
*
*  (7)          CALL READCARD TO READ THE NEXT CARD AND SET EOFFLAG
*
*           ENDDO
*
*  (8)      PRINT THE TOTAL NUMBER OF STUDENTS IN THE CLASS LIST
*
*     ENDPROC
*
*
*****************************************************************
*
PROCLASS STM   R14,R12,PRCLSAVE+12 SAVE CALLER'S REGISTERS
*
         MVC   CURRKEY,CARD        SAVE THE KEY (DEPT,COURSE)    (1)
*
         SR    R2,R2               SET COUNT OF STUDENTS IN THE  (2)
*                                  LIST TO 0
*
         BAL   R11,PRINTHDR        PRINT THE PAGE HEADERS        (3)
*
         DO WHILE,(CLI,EOFFLAG,NE,C'Y'),AND,(CLC,CURRKEY,EQ,CARD)
*
           MVC   DEPTOUT,DEPTIN      NOW MOVE DATA FIELDS        (4)
           MVC   COURSOUT,COURSIN    THE PRINT LINE
           MVC   LNAMEOUT,LNAMEIN
           MVC   FNAMEOUT,FNAMEIN
*
           BAL   R11,PRINTSP1        PRINT THE LINE (AND HEADERS, (5)
*                                    IF NECESSARY)
*
           LA    R2,1(R2)            ADD 1 TO COUNT OF STUDENTS   (6)
*
           BAL   R11,READCARD        TRY TO READ THE NEXT CARD    (7)
*
         ENDDO
*
         XDECO R2,PRNTLINE+25      PUT TOTAL INTO PRINT LINE     (8)
         MVC   PRNTLINE+7(18),=C'TOTAL # STUDENTS ='
         MVI   PRNTLINE,C'0'       SET CARRIAGE CONTROL FOR
*                                  DOUBLE-SPACE
         XPRNT PRNTLINE,133        PRINT LAST LINE FOR LIST
         MVI   PRNTLINE,C' '       CLEAR THE PRINT LINE
         MVC   PRNTLINE+1(132),PRNTLINE
*
         LM    R14,R12,PRCLSAVE+12 RESTORE CALLER'S REGISTERS
         BR    R11
*
PRCLSAVE DS    18F                 REGISTER SAVE AREA
*
```

# 13

# A Cursory Tour of ASSIST/I

## 13.1 INTRODUCTION

This chapter provides a very brief introduction to some of the basic functions of ASSIST/I and to the text editor that is an integral part of this package. Chapter 14 expands upon this material to provide enough information for the reader to work effectively with ASSIST/I. Chapter 15 is a users' guide to use as a quick reference when working with this software. Your comprehension of the material in Chapters 13 and 14 depends heavily upon your knowledge of the content of the first 25 pages of Chapter 2. If you do not feel comfortable with that content, it would be well worth your while to reread it before proceeding.

In these final three chapters, several notational conventions that do not appear elsewhere in the text are used. These are

- User responses to ASSIST/I are shown in capital letters.
- The symbol <*cr*> is used to indicate that the Return key is to be depressed.
- Editor commands require use of the Control key. The symbol ^ indicates that the Control (or Ctrl) key is to be held down while the letter immediately following this symbol is typed. For example, ^*K* may be thought of as a single keystroke that requires two keys to be depressed, much as the Shift key on a standard typewriter is used with a letter key to produce uppercase. The instruction ^*K* is pronounced *control K*, and ^*QX* is pronounced *control Q X*.

## 13.2 GETTING STARTED WITH ASSIST/I

ASSIST/I may be invoked by typing

```
CAS<cr>
```

and waiting a few moments while the software is being loaded into memory. Once this has been accomplished, the screen shown in Figure 13-1 should

appear on your console. This is the main ASSIST/I menu; its presence indicates that the system is ready for use. Take a careful look at the options offered in this menu, but do not be overly concerned about them. Only the E and R options are introduced in this chapter.

Our object here is to create a simple program, save it on disk, assemble the program, and then execute it one instruction at a time. The text editor must be used to create the program, so choose the Edit option from the main menu by typing:

```
E
```

When you enter the editor mode, the prompt *Enter name of file to edit:* asks you for the name of the file to edit. Respond to this prompt by typing:

```
B:TEST.ASM<cr>
```

The filename entered must be valid; its validity depends upon the operating system under which ASSIST/I is running. In this case, B: designates the B drive. If no drive is specified, the program defaults to the current logged drive.

After the editor has initialized this new file, you can begin typing in a program. So long as you make no errors, you can just type in the text of your program, using <cr> to end each line. We cover the editor commands in the next section. (If you do inadvertently introduce an error, you should skip ahead to Section 13.3 to learn how to correct it.) For now we assume that you can type in the following program ADD2 without making any errors:

```
        ADD2    CSECT
                L       1,16(15)        LOAD 1ST NUMBER INTO R1
                L       2,20(15)        LOAD 2ND NUMBER INTO R2
                AR      1,2             ADD THE TWO NUMBERS
                ST      1,24(15)        STORE RESULT INTO 7TH
*                                         WORD IN PROGRAM
                BCR     B'1111',14       EXIT FROM PROGRAM
                DC      F'4'
                DC      F'6'
                DS      F
                END     ADD2
        $ENTRY
```

Now save a copy of this program to the disk in drive B, by typing:

```
^KX
```

Remember to hold down the Control key while typing K, then type X. The editor saves the program and returns to the ASSIST/I menu.

To run the program, select the *Run a program* option from the menu by typing

```
R
```

```
                                        IIIIIIII
                                           II
A  S  S  I  S  T   /                       II
                                           II
                                        IIIIIIII

 E  ===>  Edit a program
 R  ===>  Run a program
 F  ===>  Execute a program Final Run
 P  ===>  Print a program or listing
 A  ===>  Alter ASSIST/I options
 Q  ===>  Quit

 Enter desired function:


ASSIST/I   Version  1.12                          Serial #:  AIS000127
Copyright (C) 1984                                       BDM  Software
```

**Figure 13-1**

This option calls the ASSIST/I interpreter. The screen indicates when the first pass of the interpreter is complete and indicates the start of the second pass. In the second pass, the program is actually assembled, and the program listing appears on the screen as each instruction is assembled. If, for some reason, your program does not assemble, the editor can be recalled and the necessary corrections made to the program. The basic editor commands are covered in Section 13.3. Here we assume, for simplicity, that the assembly was successful. After assembly of the program is successfully completed, the debugger is automatically called and the screen shown in Figure 13-2 is displayed.

```
PSW AT BREAK   FFC50000 0F000000

R0-7 :  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000020 00000068 00000000

000000       581F0010   582F0014   1A12501F   001807FE       *..........&.....*
000010       00000004   00000006   F5F5F5F5   F5F5F5F5       *........55555555*
000020       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000030       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000040       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000050       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000060       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000070       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000080       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
000090       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000A0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000B0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000C0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000D0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000E0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*
0000F0       F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5       *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 13-2**

This screen, which displays a snapshot of the current status of the program, should be studied in some detail. A number of observations need to be made:

- The first line of the display shows the current contents of the Program Status Word. Note that the rightmost three bytes of the PSW contain 000000. This is the Location Counter, which always contains the address of the next instruction to be executed. By convention, ASSIST/I always indicates the address of the first instruction as location 0. This is a handy aid in calculating the relative addresses of other memory locations in the program's memory area.
- The second and third lines show the contents of the 16 registers. Note that only registers 13, 14, and 15 contain anything other than a sequence of F4s. These three registers are special registers that are used by the IBM operating system. Their contents must never be changed by a programmer unless extreme caution is exercised. By an ASSIST/I convention, the F4s in the other registers indicate that these registers have not been altered by the program. This convention makes it easy for the programmer to identify such registers.
- The next block of printed lines shows the current status of the program's memory space. The first column of each of these lines contains the hexadecimal address of the first byte displayed to its right in the second column. The next four columns each show the contents of a four-byte fullword of memory. Finally, the lines in the rightmost column, enclosed between asterisks, show the printed representation of all printable characters in the respective memory locations; the periods indicate nonprintable characters. Examine the contents of the first four fullwords of this memory display, and observe that the executable instructions of the program have been loaded into these words. You should take the time to disassemble these instructions and convince yourself that they have been correctly assembled. Note also that the fifth fullword of memory contains the number corresponding to the first DC instruction in the program and that the sixth fullword contains the second number. The remainder of the memory locations in this display are all filled with F5s, which is the conventional way ASSIST/I displays unused memory locations. This convention allows such locations to be readily identified.
- The last line of the display shows the options offered by ASSIST/I. Only the S(tep) option is used in this section; the other options are covered in Chapter 14.

It has been verified that the program ADD2 has been correctly assembled and loaded into memory. This program is now ready for execution. To observe the execution of the program in detail, we can execute the program instructions one at a time, observing the effect of executing each of these instruc-

```
PSW AT BREAK   FFC50000 8F000004

R0-7 :  F4F4F4F4 00000004 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000020 00000068 00000000

000000        581F0010   582F0014   1A12501F   001807FE        *..........&......*
000010        00000004   00000006   F5F5F5F5   F5F5F5F5        *........55555555*
000020        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000030        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000040        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000050        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000060        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000070        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000080        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000090        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000A0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 13-3**

tions. This can be accomplished through use of the S option. To execute the first instruction, type:

```
S
```

After execution of the first instruction, the screen depicted in Figure 13-3 should be displayed on your console. Study this screen for a moment, and verify the following observations:

- The PSW has been updated, and the Location Counter now contains the address (000004) of the next instruction to be executed, the second Load instruction.
- A copy of the first number, which is in memory location 10, has replaced the contents of Register 1.

Execute the second Load instruction by typing:

```
S
```

Look at the displayed screen, and note that the Location Counter now contains the address (000008) of the Add instruction. Also note that the contents of R2 have been replaced by a copy of the second number, which is located in the sixth fullword of memory.

Execute the Add instruction by typing:

```
S
```

You should now be looking at the screen depicted in Figure 13-4. Note that R1 now contains 0000000A. Recall that this is the hexadecimal equivalent of decimal 10. This indicates that the Add instruction has been successfully executed. Note also that execution of the instructions thus far has not altered

```
PSW AT BREAK   FFC50000 6F00000A

R0-7 :  F4F4F4F4 0000000A 00000006 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000020 00000068 00000000

000000        581F0010   582F0014   1A12501F   001807FE        *..........&.....*
000010        00000004   00000006   F5F5F5F5   F5F5F5F5        *........55555555*
000020        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000030        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000040        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000050        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000060        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000070        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000080        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000090        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000A0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 13-4**

the contents of the memory locations. One more step will change this pattern.

The Location Counter now contains the address of the Store instruction, which may be executed in one more step. Type:

```
S
```

The screen shown in Figure 13-5 should appear on your console.

Note the contents of the seventh fullword of memory, and verify that a copy of the contents of R1 has been stored there. You have now observed execution of the entire program, and all that remains is to return control to the system.

```
PSW AT BREAK   FFC50000 AF00000E

R0-7 :  F4F4F4F4 0000000A 00000006 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000020 00000068 00000000

000000        581F0010   582F0014   1A12501F   001807FE        *..........&.....*
000010        00000004   00000006   0000000A   F5F5F5F5        *............5555*
000020        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000030        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000040        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000050        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000060        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000070        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000080        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
000090        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000A0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 13-5**

Perform one final S. Information will be flashed on your console, indicating that execution of the program has been completed and that no warnings were issued or errors detected. No output is displayed, since there were no instructions in the program that would produce output. The ASSIST/I menu is again displayed.

ASSIST/I supports the pseudo-instructions XREAD, XDECI, XDECO, and XPRNT, which allow the input and output functions to be easily performed. These instructions are discussed in Chapter 14. However, ASSIST/I does *not* support the XDUMP pseudo-instruction. Together with the Trace functions presented in the next chapter, the simple demonstration covered in this section should convince you that support of the XDUMP instruction was unnecessary in ASSIST/I.

## 13.3 BASIC FUNCTIONS OF THE TEXT EDITOR

In the preceding section, it was assumed that no mistakes were made in typing the program into a file, using the ASSIST/I text editor. That is a risky assumption, even in the case of such a simple program. Such a feat would be remarkable if a much longer and more complex program were involved. Fortunately, ASSIST/I provides editor commands to correct any errors in a file.

The ASSIST/I text editor is very similar in operation to MicroPro International's WordStar when WordStar is used to edit a nondocument file. If you are familiar with WordStar, this editor will be very easy for you to use. If not, you should take time to master a few basic editor commands.

Now call ASSIST/I, and choose the E option from the menu. When you enter the Editor mode, you are automatically prompted for the name of a file to edit. This filename must conform to the naming conventions of your host operating system. After typing the file name, enter <cr>. One of these two possibilities will occur:

- If the filename already exists, the file will be brought into memory for editing, and its first full screen of lines will be displayed.
- If the filename does not exist, a new file by this name will be created.

Assume that the file already exists or has been typed in and that the file contains errors that must be corrected. To make the corrections, you must be able to move the cursor around the screen to any position, insert and replace characters, delete characters, and save the corrected file. The edit commands that provide these facilities may be viewed by typing:

```
^U
```

This causes the Main Edit Menu to be displayed. This menu is shown in Figure 13-6.

```
NAME=TEST.RAO          LINE=1      COL=1      ^U for HELP     INSERT= ON

        <<<<<<   M A I N   E D I T   M E N U   >>>>>>

   --Cursor Movement--      | -Delete- |   -Miscellaneous-   | -Other  Menus-
^S char left ^D char right  |^G  char  | ^V INSERT ON/OFF    | ^KU Block & File
^A word left ^F word right  |DEL chr lf| ^I (or TAB key) Tab| ^QU Quick
^E line up   ^X line down   |^T word rt| RETURN to end line |
   --Scrolling--            |^Y line   | ^N Insert a RETURN  |
^Z line up    ^W line down  |          | ^L Repeat Find/Repl|
^C screen up  ^R screen down|          |                    |


Enter any key to continue:
```

**Figure 13-6**

Take a little time to study this menu. In all probability, at first, you will display it often as a reminder, when a basic editor command does not readily come to mind.

The four most basic and perhaps most often used of the commands for moving the cursor are those that cause the cursor to move one character to the right, one character to the left, up one line, or down one line. These four commands are

- *^D. Char Right* moves the cursor one character to the right.
- *^S. Char Left* moves the cursor one character to the left.
- *^E. Line Up* moves the cursor up one line.
- *^X. Line Down* moves the cursor down one line.

Note the location of these four letter keys on your keyboard. The four together form a diamond, and their relative positions in this diamond indicate the direction of the cursor movement they effect. See Figure 13-7. Make an effort to remember this diamond, for you will frequently need these keys when using the text editor.

The other two commands for moving the cursor move it one word to the left or right. These commands are

- *^A. Word Left* moves the cursor one word to the left.
- *^F. Word Right* moves the cursor one word to the right.

These commands are often used to move the cursor through a line more efficiently than can be done with ^S and ^D. Check the relative positions of these two command keys on your keyboard, and note that these keys and the four command keys above still form a diamond, as shown in Figure 13-8. The key to the left of the key that moves the cursor one *character* to the left moves the cursor one *word* to the left. A similar rule holds for movement of the cursor to the right.

When text of any kind is entered, it should be checked on the screen to determine whether errors have been made. Errors such as the omission of

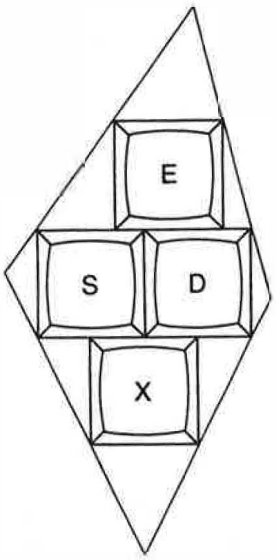



**Figure 13-7**

words or the misentry of a single character occur quite frequently and may easily be corrected using the facilities provided by the text editor.

The editor functions in one of two modes when it is active. These modes are Insert = On and Insert = Off (or Replace, if you prefer). An editor command allows the user to toggle between these two modes. This command is

- *^V. Insert On/Off* toggles between Insert = On and Insert = Off modes. When this command is issued, a message is displayed at the top right of

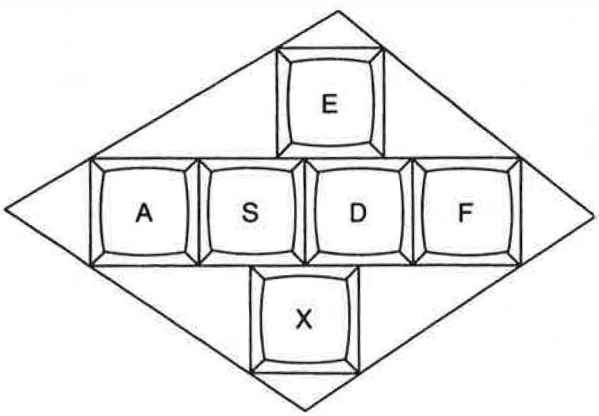



**Figure 13-8**

the screen, indicating the current mode. The toggle action of this command reverses the input mode. That is, if ^V is issued when Insert is on, then Insert is turned off, and vice versa.

When Insert is on, each character typed is inserted at the cursor position, and the characters to the right of the cursor move one position to the right to make room for what is inserted. If the cursor line fills during an insertion, the terminal bell sounds, indicating that the line is full.

When Insert is off, a text character typed replaces the character at the cursor.

You can delete an unwanted character from the text, with the following text editor command:

- *^G. Character at Cursor* deletes the character at the current cursor position.

Occasionally, you may also find it convenient to delete an entire line, using ^Y, or to delete a single word, using ^T.

The set of editor commands introduced above is sufficient for correcting any errors that occur on a single screen of text. However, most nontrivial files contain more lines than can be displayed on a single screen. To deal with longer files, it is necessary to scroll the screen through the text, so that any portion of the file may be viewed. This facility is provided by the following two commands:

- *^C. Screen Down* scrolls the screen down (forward in the file) approximately one full screen.
- *^R. Screen Up* scrolls the screen up (backward in the file) approximately one full screen.

The only way to become proficient with any text editor is through practice. The reader is strongly urged to enter some files and use the editor commands. The ASSIST/I editor is not restricted to the entry of programs or program data; it may be used to create *any* type of data file. Call the editor, create a file, and experiment with correcting errors and changing the contents of the file. You will probably be surprised how little practice is required to master the basic editor commands in this section. Remember that the help menu may be displayed at any time when using the editor, by simply typing ^U.

Files that have been created or edited usually should be saved. When an existing file has been edited, the Save command causes the edited version of the file to replace the existing, unedited file. There are occasions, however, when it is not desirable to replace an existing file with an edited version. The following two commands accommodate both of these contingencies:

- *^KX. Save & Exit* saves the file being edited and returns control to the ASSIST/I driver.

- *^KQ. Quit No Save* ends the editing session and returns control to the ASSIST/I driver. Any changes made to the edited file are lost.

Only the basic editor commands have been covered in this section. Some of the more sophisticated commands are introduced in Chapter 14. The reader is advised to consult the help menu or the users' guide in Chapter 15 when questions arise.

# 14

# Effective Use of ASSIST/I

## 14.1 INTRODUCTION

The last chapter introduced the basic features of ASSIST/I. In this chapter, we discuss the features of ASSIST/I that make it a truly convenient tool for learning IBM assembler language. The basic topics that will be covered are

- How to utilize XREAD and XPRNT to perform input/output operations
- How to produce a disk file containing the program listing and output
- How to debug a program interactively
- How to use some of the more advanced editing commands

It is assumed that the reader has covered the material in both Chapters 2 and 13. The examples we use to illustrate features of ASSIST/I are versions of the short programs discussed in Chapter 2.

Much of the time spent writing and debugging a program would be better spent in first gaining a clear understanding of the task and only then carefully writing the program. Use of an interactive environment such as that provided by ASSIST/I cannot reduce the effort expended in the creation of this original program. However, once you have written a program, the time and effort required to verify that it works properly (or, more likely, to correct it and produce the desired program) can be substantially reduced by the use of ASSIST/I. The time spent mastering the techniques in this chapter will be repaid many times over, as you address more complex programming assignments.

## 14.2 USE OF XREAD AND XPRNT UNDER ASSIST/I

In the last chapter, you learned how to edit and run a simple program in the interactive environment. However, no attempt was made to read input data or to produce output. To verify that the program worked properly, you

simply observed changes to memory and to the registers as the instructions were executed. How would you go about running a program that required input and output, such as the program to add pairs of numbers that was displayed in Program 2.6?

There is very little more that must be said about the use of XPRNT. It behaves just as described in Chapter 2, with the output lines displayed on the console. Some comments are required to describe the use of XREAD. When using XREAD, you must indicate where the input lines are to be found. You have three options:

1. The most commonly used method is to include the input lines immediately following the $ENTRY line, which must immediately follow the last line of your program. This allows you to edit your program and input data in a single file. In this case, however, you must reedit the file every time you wish to change the input data.
2. A second method is to type in the input lines interactively. That is, as the program is executing, it prompts you to enter input lines, whenever an XREAD instruction is executed. The prompt looks like

   ```
   ENTER XREAD DATA NOW (ENTER CONTROL Z FOR EOF)
   ```

   When this prompt is displayed, you can type in any desired input line, terminated by a <cr>. You indicate an end-of-file condition by typing in ^z. To request this option, you should use the following form of the $ENTRY line:

   ```
   $ENTRY CONSOLE
   ```

   This method allows you to rapidly retest your program using a variety of different sets of input data.
3. You can request that your input lines be read from a separate disk file. This makes it convenient to create a common file of test data that can be shared by multiple users by simply copying the data file. To invoke this option, you simply specify the filename on the $ENTRY statement. For example,

   ```
   $ENTRY B:PROG1.DAT
   ```

   specifies that the input data is to be read from the file PROG1.DAT (located on disk drive B).

As we stated, the first option is the most commonly used. To illustrate its use, suppose that you have created the file shown in Figure 14-1, which we will assume is called B:SUMUP. Then, to run the program, you simply use the R (Run) command, specifying B:SUMUP as the file to be assembled and executed. As we pointed out in the last chapter, ASSIST/I pauses after assembling the program. If you were to respond with G (Go), the output shown in Figure 14-2 would be produced.

```
*****************************************************************
*
* THIS PROGRAM READS DATA CARDS, EACH OF WHICH CONTAINS TWO
* NUMBERS.  THE SUM OF THE TWO NUMBERS IS PRINTED
*
*****************************************************************
*
SUMUP    CSECT
         USING   SUMUP,15
*
         XPRNT HEADING,28        PRINT A PAGE HEADING
*
         XREAD CARD,80   READ THE FIRST CARD
*
CHECKEOF         BC      B'0100',EXIT    BRANCH ON EOF
*
         XDECI   2,CARD  WE ASSUME THAT BOTH NUMBERS
         XDECI   3,0(1)  ARE VALID
*
         AR      2,3     CALCULATE THE SUM
*
         XDECO   2,OUTPUT        PUT PRINTABLE FORM INTO PRINT LINE
*
         XPRNT   CRG,13  PRINT THE SUM (SINGLE SPACED)
*
         XREAD   CARD,80 TRY TO READ THE NEXT CARD
         BC      B'1111',CHECKEOF        GO CHECK FOR EOF
*
EXIT     BCR     B'1111',14      LEAVE THE PROGRAM
*
CARD     DS      CL80    CARD INPUT AREA
*
CRG      DC      C' '    SINGLE SPACE CARRIAGE CONTROL
OUTPUT   DS      CL12    OUTPUT THE SUM HERE
*
HEADING  DC      C'1THIS IS THE OUTPUT OF SUMUP'
         END     SUMUP
$ENTRY
1 2
2 3
```

**Figure 14-1**

## 14.3 GETTING PRINTED OUTPUT

In the last section, we displayed the output of a short program. If you were to run the program interactively, the output on your screen would include only the leftmost 80 characters of each line. You will frequently wish to get a printed copy of an entire listing. To do so, set the ASSIST/I options to cause a copy to be written to a disk file. The copy on the disk will include all of the characters in each line and can easily be written to your printer.

To set options for ASSIST/I, you should respond to the main ASSIST/I menu with A (Alter options). This causes the menu displayed in Figure 14-3 to appear on your console. By responding with a 1, you can toggle the option to cause a disk file to be created whenever you assemble and execute a program. Thus, if the option is already set to Y, you can just use <cr> to go back to the main menu; otherwise, typing 1 will change the setting from N to Y (and then a <cr> can be used to go back to the main menu). The default options for ASSIST/I are set so that this first option is usually the only one that you alter.

```
ASSIST/I Version 1.11, Copyright 1984, BDM Software.


PAGE 1
  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT

                                    1 ***********************************************************
                                    2 *
                                    3 * THIS PROGRAM READS DATA CARDS, EACH OF WHICH CONTAINS TWO
                                    4 * NUMBERS.  THE SUM OF THE TWO NUMBERS IS PRINTED
                                    5 *
                                    6 ***********************************************************
                                    7 *
000000                              8 SUMUP   CSECT
000000                              9         USING SUMUP,15
                                   10 *
000000 E020 F080 001C 00080        11         XPRNT HEADING,28        PRINT A PAGE HEADING
                                   12 *
000006 E000 F030 0050 00030        13         XREAD CARD,80           READ THE FIRST CARD
                                   14 *
00000C 4740 F02E          0002E    15 CHECKEOF BC   B'0100',EXIT     BRANCH ON EOF
                                   16 *
000010 5320 F030          00030    17         XDECI 2,CARD            WE ASSUME THAT BOTH NUMBERS
000014 5331 0000          00000    18         XDECI 3,0(1)            ARE VALID
                                   19 *
000018 1A23                        20         AR    2,3               CALCULATE THE SUM
                                   21 *
00001A 5220 F081          00081    22         XDECO 2,OUTPUT          PUT PRINTABLE FORM INTO PRINT LINE
                                   23 *
00001E E020 F080 0000 00080        24         XPRNT CRG,13            PRINT THE SUM (SINGLE SPACED)
                                   25 *
000024 E000 F030 0050 00030        26         XREAD CARD,80           TRY TO READ THE NEXT CARD
00002A 47F0 F00C          0000C    27         BC    B'1111',CHECKEOF  GO CHECK FOR EOF
                                   28 *
00002E 07FE                        29 EXIT    BCR   B'1111',14        LEAVE THE PROGRAM
                                   30 *
000030                             31 CARD    DS    CL80              CARD INPUT AREA
                                   32 *
000080 40                          33 CRG     DC    C' '              SINGLE SPACE CARRIAGE CONTROL
00008B1                            34 OUTPUT  DS    CL12              OUTPUT THE SUM HERE
                                   35 *
000080 F1E3C8C9E240C9E2            36 HEADING DC    C'1THIS IS THE OUTPUT OF SUMUP'
                                   37         END   SUMUP

***   0 STATEMENTS FLAGGED - 0 WARNINGS, 0 ERRORS

*** PROGRAM EXECUTION BEGINNING -
ANY OUTPUT BEFORE EXECUTION COMPLETE MESSAGE IS PRODUCED BY USER PROGRAM ***

        3
        5

*** EXECUTION COMPLETED ***
```

**Figure 14-2**

Assuming that the option is set to cause a disk file to be created, a disk file will be produced whenever you assemble and execute a program. The disk file will be given a name based on the name of the file containing the program that was assembled and executed. The name of the disk file is formed from the original file name by altering the filetype to PRT. That is, if the program file is named B:SUMUP, the disk file will be named B:SUMUP.PRT. If the program file is named B:SUMUP.ASM, then the disk file will be named B:SUMUP.PRT. Because of this specialized use of the

```
A S S I S T / I   Options


1)  Save output listing      -  y
2)  Maximum # lines          -  500
3)  Maximum # instructions   -  5000
4)  Maximum # pages          -  100
5)  Maximum size (in bytes)  -  2700


Enter option number to alter (RETURN to quit): _
```

**Figure 14-3**

filetype PRT, you should never use a filetype of PRT for any of the files you create with the editor.

Once a file has been created on disk (either by using the editor or by assembling and executing a program), it can easily be printed by using the P (Print) option available in the main menu. This option prompts you for the name of the file you want printed and causes the contents of that file to be printed.

Before leaving this section, it is worth noting the use of F (Final listing) command in response to the main menu. This command is identical to the R command, except for the following two features:

1. It causes the file to be assembled and executed, without pausing before execution. That is, you are not offered any opportunities for interactive debugging.
2. You are prompted for an identifier, which is displayed in the title line for each page.

This option is provided for making a final listing of each program, with a header giving the designated identifier.

## 14.4 INTERACTIVE DEBUGGING WITH ASSIST/I

You have already seen the most basic technique for interactive debugging—single-stepping through instructions to verify that they produce the expected results. In this section, we discuss the use of:

- Breakpoints
- Interactive alteration of memory, registers, and the PSW
- Instruction traces

To illustrate these techniques, we utilize a slightly modified version of the program displayed in Figures 14-1 and 14-2. Consider a version of the pro-

gram in which line 20 of the program listing has an error—rather than adding registers 2 and 3 together, it causes register 4 to be added to register 2. Thus, in the example we are considering, line 20 appears as:

```
000018 1A24                20        AR    2,4          CALCULATE THE SUM
```

This fairly trivial bug is sufficient to illustrate the features of ASSIST/I that can be employed to isolate such errors rapidly.

Before continuing, type in the program displayed in Figure 14-1, introducing the minor error discussed in the previous paragraph. Then make sure the ASSIST/I options are set to produce a copy of the listing and output in a disk file. Finally, use the Final listing option to produce a disk copy of the listing and its erroneous output, and use the Print command to get a printed listing of the program. These steps will reinforce your knowledge of the editor, while verifying that you completely understand the topics discussed earlier in this chapter. Our presentation of interactive debugging depends heavily on your ability to actually invoke the debugger to operate on this program, so these preliminary steps are indeed necessary if you are to follow the material in the remainder of this section.

Once you have created the modified file containing the source program, use the Run command to begin debugging it. When the program containing the error is run, ASSIST/I will not detect any syntax errors—that is, the program will assemble, and ASSIST/I will pause before initiating execution of the program. It will print the contents of memory and wait for you to select an item from the following menu:

```
=> B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race)
```

With this program, because it is so short, it makes sense to single-step through the execution to verify that every instruction produces the expected results. However, in longer programs, it would be too tedious to have to type S repeatedly for each instruction. Instead, it is a good idea to locate critical spots in the program, points where execution could logically be halted to allow you to verify that an entire sequence of instructions has produced an expected result. In this case, the programmer can set breakpoints. A *breakpoint* designates a specific instruction and causes execution to pause immediately before that instruction is executed. That is, whenever ASSIST/I reaches the point where the designated instruction is the next to be executed, it pauses and allows the programmer to examine the state of memory and the registers. In our short example, it would make sense to set a breakpoint at the instruction on line 22 of the program listing (see Figure 14-2). When execution has reached this instruction, one input record has been read, and the desired result has been calculated. A breakpoint on this instruction allows you to verify that the input had been read correctly and converted into registers correctly and that the computed result was indeed the desired sum. In this program, it really does not make sense to set more than one

breakpoint. However, in longer programs, you will frequently set a number of breakpoints before initiating execution.
To set a breakpoint, simply answer B for the above menu. This causes the following submenu to be displayed:

```
BREAKPOINT:  S(et), C(lear), D(isplay)
```

At this point, you can establish a breakpoint, remove an existing breakpoint, or display the addresses of instructions for which breakpoints are currently established. A <cr> here simply returns you to the previous menu. The first time this menu appears, there are no established breakpoints. You can set one by typing S. This causes you to be prompted for the hexadecimal address of the instruction on which you wish to set the breakpoint. In our example, you would type in:

```
1a<cr>
```

to set the breakpoint on address 00001A. (Note that leading zeroes need not be typed in, and lowercase letters are quite acceptable.) If you then respond with G to cause the program to begin execution, it will execute instructions until it either terminates or reaches the instruction at address 00001A. At this point, you should Run the program, Set the breakpoint, and use Go to cause the program to execute until the breakpoint is detected during execution.

When we run the program, it reaches address 00001A and then pauses. The exact contents on your terminal screen should be as depicted in Figure 14-4. Now you again have the same menu that you had before execution was initiated.

By examining the contents of memory, starting at address 000030, you can determine that the program successfully read the input line containing the numbers 1 and 2. You would expect register 3 to contain the value 1 and register 2 to contain the sum of the two input values. Register 2, however, contains F4F4F4F5. By examining the short section of code, it should be easy to detect that it was actually the instruction in line 20 that caused the erroneous results. (If it were not clear, you could always rerun the program, single-stepping through the section of code to check the effects of each instruction.) At this point, you could type Q to quit executing instructions, use the editor to correct the program, and reinitiate execution. However, as you become more proficient at interactive debugging, you will find it convenient to attempt to locate multiple bugs during a single execution of the program. For the sake of exploring the facilities offered by ASSIST/I, let us take this approach.

You can avoid actually going back to the editor to reassemble your program by "fixing" the error in the actual memory and registers of the machine and then reinitiating execution. This practice should be performed very carefully, and you must certainly keep track of the changes that are eventually

```
PSW AT BREAK   FFC50000 5F00001A

R0-7 :  F4F4F4F4 00000033 F4F4F4F5 00000002 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

000000        E020F08D   001CE000   F0300050   4740F02E        *\.0...\.0..&. 0.*
000010        5320F030   53310000   1A245220   F081E020        *..0.........0a\.*
000020        F080000D   E000F030   005047F0   F00C07FE        *0...\.0..&.00...*
000030        F140F240   40404040   40404040   40404040        *1 2             *
000040        40404040   40404040   40404040   40404040        *                *
000050        40404040   40404040   40404040   40404040        *                *
000060        40404040   40404040   40404040   40404040        *                *
000070        40404040   40404040   40404040   40404040        *                *
000080        40F5F5F5   F5F5F5F5   F5F5F5F5   F5F1E3C8        * 5555555555551TH*
000090        C9E240C9   E240E3C8   C540D6E4   E3D7E4E3        *IS IS THE OUTPUT*
0000A0        40D6C640   E2E4D4E4   D7F5F5F5   F5F5F5F5        * OF SUMUP5555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 14-4**

to be made to the file containing the program. To fix this error before reinitiating execution, you can:

1. Alter the contents of register 2 back to 00000001
2. Alter the instruction encoded at location 000018 (i.e., alter the memory at location 000018 from 1A24 to 1A23)
3. Alter the address of the next instruction to be executed (in the PSW) to 000018

Then, when execution is reinitiated, the AR instruction is executed again (in this case, adding the contents of register 3 to register 2).

To alter the contents of register 2, you simply respond to the prompt with R. When you are prompted for the register to be altered, a response of 2 will cause the cursor to be positioned over the contents of register 2. By typing in the desired contents (00000001) followed by <cr>, you alter the actual contents of register 2. Make this alteration, which should return you to the menu:

```
=>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race)
```

The next step is to alter the encoded version of the instruction:

```
AR        2,4
```

to its correct form, representing:

```
AR        2,3
```

By reexamining the material in Chapter 2, you should be able to verify that the encoding of the erroneous instruction is 1A24, while the corrected version should be 1A23. Note that the erroneous encoding is located at address

000018 on your screen. To alter the contents of memory, the M option of the menu must be specified. This causes the following submenu to be displayed:

```
MEMORY: <RET> for this screen, N(ext scr.), P(rev. scr.), (hex address)
```

By responding with <cr>, you request the option to alter the section of memory displayed on the current screen. The other options allow you either to scroll forward and backward through memory, which would be useful with large programs in which the entire relevant memory could not be displayed on a single screen, or to move the cursor directly to a specified address in memory, by typing the actual hexadecimal address. Suppose that you respond with a <cr>. Then, you must move the cursor directly over the 4 at location 000019 (which contains the right hexadecimal digit of the byte). This can be achieved by using the same cursor-movement commands that you would normally use while typing in a file with the editor. Once the cursor is over the 4, make the correction by typing 3 followed by <cr>. With these actions, the erroneous encoded version of:

```
AR      2,4
```

is changed to:

```
AR      2,3
```

Make this alteration before continuing.

Finally, we are going to alter the address of the next instruction to be executed, to cause

```
AR      2,3
```

to be reexecuted. The address of the next instruction to be executed is kept in the rightmost three bytes of the PSW. To change this address in the PSW, you simply use the P option to position the cursor over the right three bytes of the PSW, where the address of the next instruction to be executed is maintained. Move the cursor over the rightmost character, and change A to 8. Then use <cr> to return to the menu. By altering the address from 00001A back to 000018, you have "fixed" the error and can reinitiate execution of the program. At this point, your screen should look exactly as shown in Figure 14-5.

Now reinitiate execution of your program by specifying G, which causes the single instruction at 000018 to be executed. The breakpoint at 00001A again causes execution to be suspended. If you examine the display on your screen this time, it should match the screen depicted in Figure 14-6 with register 2 containing the desired value sum.

By typing G again, you cause execution to proceed until the breakpoint is reached again. This time your screen should look like the screen shown in Figure 14-7. Note that a new record has been read. (Examine the memory, starting at location 000030, which corresponds to CARD in the program

```
PSW AT BREAK   FFC50000 5F000018

R0-7 :  F4F4F4F4 00000033 00000001 00000002 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

000000        E020F08D   001CE000   F0300050   4740F02E        *\.0...\.0..&. 0.*
000010        5320F030   53310000   1A235220   F081E020        *..0.........0a\.*
000020        F080000D   E000F030   005047F0   F00C07FE        *0...\.0..&.00...*
000030        F140F240   40404040   40404040   40404040        *1 2             *
000040        40404040   40404040   40404040   40404040        *                *
000050        40404040   40404040   40404040   40404040        *                *
000060        40404040   40404040   40404040   40404040        *                *
000070        40404040   40404040   40404040   40404040        *                *
000080        40F5F5F5   F5F5F5F5   F5F5F5F5   F5F1E3C8        * 5555555555551TH*
000090        C9E240C9   E240E3C8   C540D6E4   E3D7E4E3        *IS IS THE OUTPUT*
0000A0        40D6C640   E2E4D4E4   D7F5F5F5   F5F5F5F5        * OF SUMUP5555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 14-5**

listing.) The input values were 2 and 3, and register 2 actually contains the correct sum.

At this point, if you type G, your program will complete execution. Instead, set a breakpoint on

```
BCR      B'1111',14
```

which is used to exit your program. Then reinitiate execution, which should cause the program to pause just before exiting.

Now, before terminating this exercise, you should examine the information available to you through the Trace command. This command can be used to display either the last 10 instructions executed or just the last 10 branch

```
PSW AT BREAK   FFC50000 6F00001A

R0-7 :  F4F4F4F4 00000033 00000003 00000002 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

000000        E020F08D   001CE000   F0300050   4740F02E        *\.0...\.0..&. 0.*
000010        5320F030   53310000   1A235220   F081E020        *..0.........0a\.*
000020        F080000D   E000F030   005047F0   F00C07FE        *0...\.0..&.00...*
000030        F140F240   40404040   40404040   40404040        *1 2             *
000040        40404040   40404040   40404040   40404040        *                *
000050        40404040   40404040   40404040   40404040        *                *
000060        40404040   40404040   40404040   40404040        *                *
000070        40404040   40404040   40404040   40404040        *                *
000080        40F5F5F5   F5F5F5F5   F5F5F5F5   F5F1E3C8        * 5555555555551TH*
000090        C9E240C9   E240E3C8   C540D6E4   E3D7E4E3        *IS IS THE OUTPUT*
0000A0        40D6C640   E2E4D4E4   D7F5F5F5   F5F5F5F5        * OF SUMUP5555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 14-6**

```
PSW AT BREAK   FFC50000 6F00001A

R0-7 :  F4F4F4F4 00000033 00000005 00000003 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

000000        E020F08D   001CE000   F0300050   4740F02E        *\.0...\.0..&. 0.*
000010        5320F030   53310000   1A235220   F081E020        *..0.........0a\.*
000020        F0B0000D   E000F030   005047F0   F00C07FE        *0...\.0..&.00...*
000030        F240F340   40404040   40404040   40404040        *2 3             *
000040        40404040   40404040   40404040   40404040        *                *
000050        40404040   40404040   40404040   40404040        *                *
000060        40404040   40404040   40404040   40404040        *                *
000070        40404040   40404040   40404040   40404040        *                *
000080        40404040   40404040   40404040   F3F1E3C8        *            31TB*
000090        C9E240C9   E240E3C8   C540D6E4   E3D7E4E3        *IS IS THE OUTPUT*
0000A0        40D6C640   E2E4D4E4   D7F5F5F5   F5F5F5F5        * OF SUMUP5555555*
0000B0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000C0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000D0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000E0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*
0000F0        F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5        *5555555555555555*

===>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race):
```

**Figure 14-7**

instructions executed. Type T, followed by I, to produce the trace of the last 10 instructions executed. Your screen should now be identical to the screen displayed in Figure 14-8. Now type T, followed by B, to get a trace of just the last branch instructions. Your screen should now match the screen displayed in Figure 14-9. Note that every branch instruction executed is displayed—even those branches that "failed." That is, the first two instances of the instruction:

```
CF          00000C   4740 F02E
```

correspond to instances of the source instruction

```
CHECKEOF BC        B'0100',EXIT
```

which did not result in a branch to EXIT.

Once you have studied the trace information, use the Go command to complete execution of your program. Then make sure that you actually go back and correct the original program in the source file. Always remember that changes made temporarily during interactive debugging are *not* reflected in your actual program unless you use the editor to make them after the debugging run has been completed.

## 14.5 ADVANCED FEATURES OF THE EDITOR—THE QUICK COMMANDS

In Chapter 13, all the basic commands required to edit files were introduced. However, there are a number of advanced commands that prove quite convenient, once you master them. We recommend that you become completely

```
PSW AT BREAK   FFC50000 9F00002E

R0-7 :  F4F4F4F4 00000033 00000005 00000003 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

            ** TRACE OF INSTRUCTIONS JUST BEFORE TERMINATION **
        IM = PSW bits 32-39 (ILC,CC,MASK) before instruction decoded


            IM    LOCATION    INSTRUCTION
            ==    ========    ===========
            CF     00002A     47F0 F00C
            8F     00000C     4740 F02E
            8F     000010     5320 F030
            AF     000014     5331 0000
            AF     000018     1A23
            6F     00001A     5220 F081
            AF     00001E     E020 F080 000D
            EF     000024     E000 F030 0050
            DF     00002A     47F0 F00C
            9F     00000C     4740 F02E    <-- Last instruction executed

 RETURN to continue:
:Trace:  Instruction Trace
```

**Figure 14-8**

familiar with the basic commands before attempting to use these more advanced commands.

First, there is a set of commands referred to as the Quick commands. These all involve typing two characters: ^Q followed by a second character designating a specific operation. To see the menu displaying the available quick commands, simply type ^QU. This causes the menu in Figure 14-10 to appear.

The most commonly used Quick commands are those for cursor movement. You have already used the basic cursor-control commands: ^S, ^D, ^E, ^X,

```
PSW AT BREAK   FFC50000 9F00002E

R0-7 :  F4F4F4F4 00000033 00000005 00000003 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
R8-15:  F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 000000B0 000000F8 00000000

            ** TRACE OF LAST 10 BRANCH INSTRUCTIONS EXECUTED **
        IM = PSW bits 32-39 (ILC,CC,MASK) before instruction decoded


            IM    LOCATION    INSTRUCTION
            ==    ========    ===========
            CF     00000C     4740 F02E
            CF     00002A     47F0 F00C
            8F     00000C     4740 F02E
            DF     00002A     47F0 F00C
            9F     00000C     4740 F02E



 RETURN to continue:
:Trace:  Branch Trace
```

**Figure 14-9**

```
<<<<<<   Q U I C K   M E N U   >>>>>>

                 ----- CURSOR  MOVEMENT -----
Line LEFT (col 1)   ==>  S        Line RIGHT (end of line)  ==>  D
TOP of screen       ==>  E        BOTTOM of screen          ==>  X
TOP of file         ==>  R        BOTTOM of file            ==>  C

                 --------- DELETES ----------
RIGHT (to end line) ==>  Y        LEFT (to begin of line)   ==> DEL

                 ------ MISCELLANEOUS -------
FIND text in file   ==>  F        FIND & REPLACE text       ==>  A
```

**Figure 14-10**

^C, and ^R. The Quick versions of these commands can be used to replace sequences of these basic commands. Their effects may be summarized as follows:

- *^QS*. Moves the cursor to the first character in the current line
- *^QD*. Moves the cursor to the last character of the current line
- *^QE*. Positions the cursor to the first character in the first line on the screen
- *^QX*. Moves the cursor to the first character of the last line on the screen
- *^QR*. Moves the cursor to the first character in the file
- *^QC*. Moves the cursor past the last character in the file

As you edit increasingly larger files, you will find these commands for rapid movement of the cursor quite convenient.

Two Quick commands are provided for deleting portions of the current line:

- *^QY*. Deletes all characters from the one over which the cursor is positioned through the end of the line
- *^QDel*. Deletes all characters in the current line to the left of the cursor (Here *^QDel* means holding down the control key and typing Q then depressing the Delete key on your terminal.)

These two commands can save time in deleting portions of sentences, removing the necessity of manually deleting a sequence of individual characters or words.

Occasionally, you will wish to scan a file for a particular string of characters. For example, you might wish to locate the string " * " to find a comment that began in column 2, rather than in column 1. In this case, you can use the following command:

- *^QF*. Finds the first occurrence of a string, starting from the current position of the cursor. You are prompted for the string to be located and for whether to search forward or backward from the position of the cursor. (By specifying the option B, you can cause the scan to proceed backward from the position of the cursor; the default is to move forward.)

```
<<<<<<   B L O C K   &   F I L E   O P E R A T I O N S   >>>>>>

                          BLOCK  OPERATIONS
=================================================================
 Set BEGIN block marker  ==>  B        Move block to cursor  ==>  V
 Set END block marker    ==>  K        Copy block to cursor  ==>  C
 Hide/Display marker(s)  ==>  H        Delete marked block   ==>  Y

                          FILE   OPERATIONS
=================================================================
 Write a block to a file ==>  W        Read a file to cursor ==>  R
 SAVE & EXIT             ==>  X        Quit NOSAVE           ==>  Q
```

**Figure 14-11**

To search the entire text for the string, it is frequently a good idea to use ^QR first, to position the cursor at the start of the text. Once you have located one occurrence, you may wish to continue the search by scanning for the next occurrence of the string. Do this by typing ^L.

The last Quick command can be used to replace one or more occurrences of a string by a replacement string. This command requires you to indicate whether you wish to be prompted to verify the replacement.

- *^QA*. Finds the next occurrence of a string and replaces it with a specified replacement string. You are prompted for the search string, for the replacement string, and for options. The replacement options are as follows:
  - *<cr>* Replace the next occurrence (A prompt asks whether or not you really wish the replacement to occur.)
  - *N* Make the replacement without prompting for permission
  - *G* Replace all remaining occurrences of the string
  - *GN* Replace all remaining occurrences, without prompting for permission

  In addition, you can specify the option B to cause the search to proceed backward from the current cursor position.

Just as with ^QF, ^L can be issued to repeat the last find-and-replace command.

## 14.6 MORE ON THE EDITOR—BLOCK AND FILE COMMANDS

Another useful set of editor commands allows you to manipulate entire blocks of text. That is, you can move, copy, or delete entire sequences of lines in a single operation. To see the menu of available block and file commands, simply type ^KU, which should cause the menu shown in Figure 14-11 to appear at the top of your screen. To manipulate a block of text, you must first *mark* the first and last character in the block of text. The following commands are provided for this purpose:

- *^KB*. Sets a Begin block marker to mark the beginning of a text block. To mark a block, place the cursor at the first character of that block, and type

^KB. The *display* of the text character is replaced by > to indicate the location of the beginning marker; the *actual* text character is not changed. There can be only one Begin marker in a file. If a Begin marker was active somewhere else in the file, it is moved when ^KB is issued.

- *^KK*. Sets an End block marker to mark the end of a text block, replacing the displayed character with <. The actual text character is not changed. If the last character of a line (the linefeed) is to be marked, the cursor must be positioned at that character. (^QD is helpful for positioning the cursor at the end of a line.) There can be only one End marker in a file. If an End marker was active somewhere else in the file, it is moved when ^KK is issued.
- *^KH*. Hide/Display marker(s) is a toggle used to hide and to redisplay markers. Any attempt to perform a copy-, move-, or delete-block operation when markers are hidden results in an error message.

Markers can be repositioned to any point without being hidden first. The normal procedure is to mark the block, perform the block operation, and then hide the markers. The following rules apply to all the block operations:

1. Both markers must have been set and must not be hidden.
2. The End marker must occur after the Begin marker.
3. The cursor cannot be positioned on or between the markers.

Once a block of text has been marked, it can be moved, copied, deleted, or written to a disk file by using the following commands:

- *^KV*. Moves a marked block to the location of the cursor.
- *^KC*. Copies a marked block to the cursor position.
- *^KY*. Deletes all characters in the marked block.
- *^KW*. Writes the marked block of text to a disk file. You will be prompted for the name of the file to be created. This command creates a new file or, if the name of an existing file is given, overwrites the contents of the existing file. It does *not* append the block to the end of an existing file.

This last command can be quite useful when you wish to include the same sequence of lines in several files. To retrieve the text from a disk file and insert it into the current text, you can use the following command:

- *^KR*. Reads the contents of a disk file, inserting the lines into the current text at the position of the cursor.

As we stated before, you will probably find it difficult to master all of the material covered in this chapter before actually using ASSIST/I extensively. You may well find yourself frequently referring back to the material in this chapter, as well as to the ASSIST/I users' manual provided in the next chapter.

# 15

# ASSIST/I Users' Manual

This chapter is a users' reference manual for ASSIST/I. Each section presents guidance for the use of a facility that appears on the main menu when ASSIST/I is invoked.

## 15.1 Editing Programs

The ASSIST/I text editor is used to create new datasets and to change existing ones (programs, program data, documentation, etc.). It is a full-screen text editor modeled after MicroPro International's WordStar word processor, as used in nondocument mode. The WordStar format was chosen because of its popularity and its adaptability to most terminals.

The editor comes with preset tab stops for easy writing of assembler programs. The student is encouraged to use tabbing, for storage savings as well as convenience. The editor will not allow more than 79 characters (including the spaces taken up by expanded tabs) on a line.

### *Starting the Editor*

The following four steps should be followed in all normal editing sessions:

1. Choose the *Edit a program* option in the ASSIST/I menu.
2. To the prompt *Enter name of file to edit:*, type in the name of the file to be edited. A filename is a unique identifier assigned to a dataset. It can be any combination of characters that conforms to the host operating system's naming conventions.

   If a file by that name exists, it is brought into memory for editing, and its first full screen of lines is displayed.

   If no file by that name exists, a new file is created.

   The validity of a filename depends on the operating system under which

ASSIST/I is running. Most systems accept filenames following these conventions:

a. You can use from 1 to 8 alphanumeric characters, with the first character being alphabetic.
b. This 1-to-8-character name can be followed by an optional 1-to-3-character alphanumeric suffix (extension), which is preceded by a period.
c. Special characters (punctuation, $, %, @, etc.) differ from system to system and should be avoided.

An example that follows the conventions is

```
ASSGT1.ASM
```

3. Type in the program, data, text, or whatever. View and modify the file, using the editor commands described in the Editor Commands section.
4. Finally, to save the file and exit the editor, type ^KX. See the paragraph under Entering Editor Commands for an explanation of ^ . See also the Block & File Operations menu, below, for other file operations.

## *Editor Commands*

Commands tell the editor what to do. Single-keystroke commands, located in the Main Edit Menu, Figure 15-1, are the most commonly used. The less frequently used commands, located in the Quick Menu and the Block & File Operations menu, require two keystrokes. The following pages cover the menus and describe their associated commands.

## *Entering Editor Commands*

Editor commands are entered by holding down the Control key. The symbol ^ indicates that the Control (or Ctrl) key is to be held down while the letter immediately following the symbol ^ is typed. ^K can be thought of as one

```
NAME=TEST.RAO          LINE=1       COL=1      ^U for HELP     INSERT= ON

          <<<<<<   M A I N   E D I T   M E N U   >>>>>>

   --Cursor Movement--      | -Delete- |   -Mi scellaneous- |  -Other  Menus-
^S char left ^D char right  |^G  char  | ^V INSERT ON/OFF   | ^KU Block & File
^A word left ^F word right  |DEL chr lf| ^I (or TAB key) Tab| ^QU Quick
^E line up   ^X line down   |^T word rt| RETURN to end line |
   --Scrolling--            |^Y line   | ^N Insert a RETURN |
^Z line up    ^W line down  |          | ^L Repeat Find/Repl|
^C screen up  ^R screen down|          |                    |


Enter any key to continue:
```

Figure 15-1

keystroke that requires two keys to be depressed. The Control key is used much the same as a Shift key, which works with a letter to create its uppercase. In English, ^K is pronounced *Control K*, and ^QX is pronounced *Control Q X*.

### Cursor Movement

- *^S. Char Left* Moves the cursor one character to the left. If the cursor is on the first character of a line when ^S is issued, the cursor wraps to the last character of the previous line. ^S has no effect when the cursor is on the first character of the file.
- *^D. Char Right* Moves the cursor one character to the right. If the cursor is on the last character of a line, the cursor is moved to the first column of the next line. ^D has no effect when the cursor is at the end of the file.
- *^A. Word Left* Moves the cursor one word to the left, unless the cursor is at the beginning of the file.
- *^F. Word Right* Moves the cursor one word to the right, unless the cursor is at the end of the file.
- *^E. Line Up* Moves the cursor to the previous line. When the cursor is on the top line of the file, ^E has no effect.
- *^X. Line down* Moves the cursor to the next line. When the cursor is on the last line of the file, ^X has no effect.

### Scrolling

- *^C. Screen down* Scrolls the screen down (forward in the file) approximately one full screen. (Not quite a full screen is scrolled, so the user has a point of reference between ^Cs.)

  ^C has no effect when the cursor is at the end of the file.

  Successive ^Cs can be issued without waiting for the screen to be rewritten.
- *^R. Screen Up* Scrolls the screen up (backward in the file) approximately one full screen in the same manner that ^C scrolls forward.

  ^R has no effect when the cursor is at the beginning of the file.

  Successive ^Rs can be issued without waiting for the screen to be rewritten.

### Deletes

- *^G. Character at Cursor* Deletes the character the cursor is on.

  If the character is past the last text character on a line, the next line is wrapped up to the cursor position. However, if there is not enough room on the current line to fit the characters of the next line (since the ASSIST/I editor limits lines to 79 characters), the terminal bell beeps, and ^G does nothing.

- *Del. Character before Cursor* The Del (Delete) key deletes the character to the left of the cursor.

  When the cursor is in column 1 and the Del key is pressed, the current line is wrapped up to the end of the previous line if the length of both lines is not greater than 79 characters. If the lines cannot fit together, the terminal bell sounds, and Del does nothing.
- *^T. Del Word* Deletes all characters over to the next word boundary.

  If ^T is issued when the cursor is past the last text character of a line, the effect is the same as that of ^G under the same circumstances.
- *^Y. Del Line* Deletes the entire cursor line.

### Miscellaneous

- *^V. Insert On/Off* Toggles between Insert On and Insert Off modes, as indicated by the INSERT= portion of the editor's status line. The toggle action of this command reverses the Insert status. That is, if ^V is issued when Insert is on, then Insert is turned off, and vice versa.

  Editor commands work the same way, regardless of the Insert status, with the exceptions of ^I (Tab) and Return, which will be described shortly.

  When Insert is on, each character typed is inserted at the cursor. If the cursor line fills during insertions, the terminal bell is sounded to indicate that the line is full.

  When Insert is off, each text character typed replaces the character at the cursor. (See ^I for the exception.)
- *^I. (or Tab key). Tab* Moves the cursor to the next tab stop, according to the following rules:
  1. If Insert is on, all characters at the cursor and to its right are moved to the next tab stop. A Tab causes the terminal to beep if there is no room for the insertion.
  2. If Insert is off, the cursor is moved to the next tab stop without moving or disrupting any text characters.

  Tab stops are preset to the following column positions:

  ```
  10, 16, 35, 40, 45, 50, 55, 60, 65, 70, and 75.
  ```

  Most terminals have a Tab key, which can be used interchangeably with ^I.
- *Return.* The Return key moves the cursor to column 1 of the next line, according to the following rules:
  1. When Insert is on, any characters at the cursor and to the right of it are forced down to create a new line.
  2. When Insert is off, the cursor line is kept intact, and the cursor is moved to column 1 of the next line.

- *^N. Insert Return* Inserts a Carriage Return (or, more accurately, a Linefeed) at the cursor. The cursor remains in the same position as it was when ^N was typed, and the cursor character and all characters to its right (if any) are forced down to create a new line.

  ^N has the same effect as typing Return except that the cursor does not move.
- *^L. Next Find & Replace* Performs the next Find or Find & Replace, according to the same criteria supplied in the last Find (^QF) or Find & Replace (^QA) command. This single-keystroke command saves having to retype the ^QF or ^QA commands (two-keystroke commands) and respond to the prompts when the criteria are the same. See the ^QA and ^QF descriptions in the QUICK MENU.

### Other Menus

- *^KU. Block/File* Displays the Block & File Operations menu, described shortly. The ^K-prefixed commands in this menu allow copying, deleting, and moving text blocks and exiting the editor.
- *^QU. Quick* Displays the menu of the ^Q-prefixed Quick commands. These commands allow fast cursor movement within the file and fast deleting within a line. They also provide global Find and Find & Replace of text strings.

The Block & File Operations menu is displayed when ^KU is issued. The desired menu option may be entered when this menu is displayed, or the space bar may be used to exit the menu without performing any operation.

Block & File Operations commands do *not* have to go through this menu. The desired option may be selected after ^K has been entered.

## *Block Operations*

Blocks are designated areas of text that can be moved, copied, or deleted. The editor must be told where the first (Begin) and last (End) characters

```
<<<<<<   B L O C K   &   F I L E   O P E R A T I O N S   >>>>>>

                         BLOCK  OPERATIONS
=================================================================

Set BEGIN block marker  ==>  B        Move block to cursor  ==>  V
Set END block marker    ==>  K        Copy block to cursor  ==>  C
Hide/Display marker(s)  ==>  H        Delete marked block   ==>  Y

                         FILE   OPERATIONS
=================================================================

Write a block to a file ==>  W        Read a file to cursor ==>  R
SAVE & EXIT             ==>  X        Quit NOSAVE           ==>  Q
```

**Figure 15-2**

are located, by marking a block. It is logical that the End-block marker comes after the Begin-block marker and that both markers must be set correctly before the editor can perform any block commands. The following ^K-prefixed commands are used to mark and unmark blocks. Markers are not saved when a file is saved.

- *^KB. Set Begin Block Marker* Marks the beginning of a text block. To mark a block, put the cursor at the first character of that block, and type ^KB. The *display* of the text character is replaced by > to indicate the location of the beginning marker. The *actual* text character is not changed.

  There can be only one Begin marker in a file. If a Begin marker was active somewhere else in the file, it is moved when ^KB is issued.
- *^KK. Set End Block Marker* Marks the end of a text block, replacing the displayed character with <. The actual text character is not changed. If the last character of a line (the linefeed) is to be marked, the cursor must be positioned at that character. (^QD is helpful for positioning the cursor at the end of a line.)

  There can be only one End marker in a file. If an End marker was active somewhere else in the file, it is moved when ^KK is issued.

  If, for some reason, the same character is marked for begin and end, the replacement display character is * .
- *^KH. Hide/Display Marker(s)* Is a toggle used to hide and to redisplay markers. Any attempt to perform a copy-, move-, or delete-block operation when markers are hidden results in an error message.

  Markers can be repositioned to any point without being hidden first.

Rules for the following block operations:

1. Both markers must have been set and may not be hidden.
2. The End marker must occur after the Begin marker.
3. The cursor cannot be positioned on or between the markers.

- *^KV. Move Block to Cursor* Moves a marked block to the location of the cursor. The markers are moved with the block.
- *^KC. Copy Block to Cursor* Copies a marked block to the cursor location. The markers come with the copied text.
- *^KY. Delete Marked Block* Deletes all characters in a marked block. The markers become unset after a ^KY; that is, they are deleted along with the block of text.

### File Operations

- *^KW. Write a Block to a File* Writes the currently marked block to a file. If a file by the name you give already exists, you are given the option of overwriting the existing file.

```
<<<<<<   Q U I C K   M E N U   >>>>>>

                ----- CURSOR  MOVEMENT -----
Line LEFT (col 1)   ==>  S        Line RIGHT (end of line)  ==>  D
TOP of screen       ==>  E        BOTTOM of screen          ==>  X
TOP of file         ==>  R        BOTTOM of file            ==>  C

                --------- DELETES ----------
RIGHT (to end line) ==>  Y        LEFT (to begin of line)   ==> DEL

                ------ MISCELLANEOUS -------
FIND text in file   ==>  F        FIND & REPLACE text       ==>  A
```

**Figure 15-3**

- *^KR. Read a File* Reads an existing file into the current working file, at the location of the cursor. The file being read is truncated if there is not enough available space in memory.
- *^KX. Save & Exit* Saves the file being edited and returns control to the ASSIST/I driver.
- *^KQ. Quit with No Save* Aborts the editing session and returns control to the ASSIST/I driver. Any changes to the edited file are lost.

The Quick menu is displayed when ^QU is issued. The desired menu option can be entered when this menu is displayed, or the space bar can be used to exit the menu without performing any operation.

Quick commands do not have to go through this menu. The desired option may be selected after the ^Q has been entered.

### Cursor Movement

- *^QS. Line Left* (Column 1) Moves the cursor to column 1 of the cursor line.
- *^QD. Line Right* (End of Line) Moves the cursor to the last character of the cursor line.
- *^QE. Top of Screen* Positions the cursor at column 1 of the top line on the screen.
- *^QX. Bottom of Screen* Places the cursor at the first character of the last line on the screen.
- *^QR. Top of File* Moves the cursor to the first character in the file.
- *^QC. Bottom of File* Positions the cursor past the last character in the file.

### Deletes

- *^QY. Right* (to End of Line) Deletes the cursor character and all characters to its right on the cursor line except the linefeed.
- *^QDel. Left* (to Beginning of Line) Deletes all characters to the left of the cursor on that line.

### Miscellaneous

The Find command is used to position the cursor at the next occurrence of a text string, according to the search direction.

The Find & Replace command is used to find the next occurrence of a text string and optionally replace it with another string.

- *^QF. Find Text in File* This text pattern matcher finds the first occurrence of a string past the current cursor position (or before, depending on the search direction given—forward or back).

  Prompts are issued for the search string and search direction.

  To cause the search to proceed backwards, specify B in response to the options prompt.

  A message is displayed if no occurrence of the string is found in the direction of the search. The cursor is positioned at the file's end or at its beginning, depending on the search direction.

  The easiest way to search the entire text is to issue a ^QR before ^QF.

  ^L (Main Edit menu) repeats the last Find or Find & Replace operation.
- *^QA. Find & Replace Text* Finds the next occurrence of a string and optionally replaces it with a replacement string.

  Prompts are issued for the search and replacement strings, the search direction, and the replacement options. The replacement options are:

<cr> To replace the next occurrence.
N To make replacements without asking.
G To replace all remaining occurrences.
GN To replace all remaining occurrences without asking. (NG works the same as GN.)

^L (Main Edit menu) is used to repeat the last Find or Find & Replace operation.

## 15.2 ASSIST/I PSEUDO-INSTRUCTIONS

ASSIST/I supports the following four pseudo-instructions for performing basic I/O and for processing numeric data. All pseudo-instructions can have a statement label, as noted in the instruction formats. After the instructions PACK, UNPK, CVB, and CVD have been learned, there should be no need to continue using XDECI and XDECO.

### XREAD

The XREAD statement is used to read data from the source defined on the $ENTRY line. Data can be read from:

1. The console
2. Lines immediately following $ENTRY
3. A disk file

See the section covering $ENTRY for the details of how to specify the input data source.

The format of the XREAD statement is

```
label      XREAD    addr, length
```

where `addr` is the address of the area where the data line should be placed. This address is of the form D(X,B).

`length` is the number (in decimal) of input characters to be read by the statement. The maximum length is 79 but may be less. If the specified length is less than 79, the remaining characters on the line are ignored.

XREAD treats each input line as if it contained 79 characters. Each XREAD statement reads exactly one line of input data. The data obtained by XREAD is stored in character format at the D(X,B) location.

XREAD sets the condition code in the following manner:

| *Condition Code* | *Meaning* |
|---|---|
| 0 | Successful read. |
| 1 | No data line could be read. This is termed an end-of-file or EOF condition. |
| 2 | CC of 2 will not occur. |
| 3 | CC of 3 will not occur. |

Execution of an XREAD statement after the end-of-file condition has occurred results in a Read Past End of File program exception.

The encoded form of XREAD resides in 3 halfwords.

- *Example.* XREAD CARD,40 will read 40 characters from the next input record and place the first character at Card + 0, the second at Card + 1, and so on.

## XPRNT

The XPRNT statement provides an easy way to print program output lines. XPRNT lines appear in the program listing (filetype = .PRT) just after the assembly listing.

The format of the XPRNT statement is

```
label    XPRNT addr, length
```

where `addr` is the D(X,B) address of the line in storage to be printed.
`length` is the number of bytes to be sent to the printer. The length should be 133 or fewer characters, including the carriage-control character.

The first character of the line at the D(X,B) address is used by XPRNT for the printer carriage control. The carriage-control character determines the positioning of the line on the page.

Valid carriage controls are

| | |
|---|---|
| blank | Single space before printing. |
| 0 | Double space before printing. |
| - | Triple space before printing. |
| + | Suppress spacing—overprint. |
| 1 | Skip to the top of the next page before printing. |

Carriage-control bytes containing nonprintable values are treated as if they were blanks. XPRNT does not alter the condition code. The encoded form of XPRNT resides in 3 halfwords.

Examples:

- XPRNT = C'1THIS IS A PAGE HEADER',22 will print the line THIS IS A PAGE HEADER
  at the top of the next page
- XPNT CARD–1,80 will print a line beginng with the byte before CARD for a length of 80 bytes. The carriage control byte would be at CARD–1.

## XDECI

The XDECI pseudo-instruction converts a number from its character format into its corresponding binary equivalent and places the conversion into a register.

The format of the XDECI instruction is

```
label    XDECI reg,addr
```

where `reg` is the number of the general-purpose register in which to place the result.
`addr` is the D(X,B) address of the number in character format to be converted.

Beginning at addr, memory is scanned for the first nonblank character. If the first nonblank character is not a decimal digit, a plus sign, or a minus sign, register 1 is set to the address of that character, the condition code is set to 3, and reg remains unchanged.

If the character is a decimal digit, a plus sign, or a minus sign, up to 9 decimal digits are scanned, converted to binary, and placed in reg. Register 1 is set to the first nondigit after the string of decimal digits. Thus the user can convert multiple values that are separated by blanks from one input line.

If ten or more digits are found in succession, register 1 is set to the address of the first nondecimal digit, the condition code is set to 3, and reg remains unchanged.

XDECI sets the condition code as follows:

| *Condition Code* | *Meaning* |
|---|---|
| 0 | Number converted was 0. |
| 1 | Number converted was < 0. |
| 2 | Number converted was > 0. |
| 3 | Attempt to convert an invalid number. |

Note: XDECI may alter register 1. Therefore, reg should usually not be 1.

To prevent XDECI from scanning beyond the desired area, the byte immediately following the area can be set as a marker. Example:

```
CARD      DS      CL79          INPUT CARD AREA
          DC      C'*'          XDECI STOPPER
```

The encoded form of XDECI resides in 2 halfwords.

Assuming that the input cards contained one or more numbers and that the above marker technique was used, the following code segment can serve as an example:

```
        SR     R3,R3
        XDECI  R5,CARD            GET 1st NUMBER
LOOP    BC     B'0001',EXITLUP    EXIT NONE LEFT
        ST     R5,TABLE(R3)       SAVE THE NUMBER
        LA     R3,4(R3)           INCRMENT INDEX
        XDECI  R5,0(R1)           GET NEXT NUMBER
        BC     B'1111',LOOP
```

## XDECO

XDECO is used to convert a binary number in a register to its printable decimal equivalent. Once converted, the number can be printed with XPRNT.

The format of the XDECO statement is

```
label    XDECO reg,addr
```

where `reg` is the register number that contains the binary number to be converted. This register number is not altered by XDECO.

`addr` is the address in which to place the 12-byte character representation of the number.

XDECO does not alter the condition code. The encoded form of XDECO resides in 2 halfwords.

- *Example.* XDECO R4,ANSWER converts the number in register 4 to its printable character representation. The result requires 12 bytes. In this case, the 12-byte character representation is placed at the location ANSWER.

## XDUMP

The XDUMP pseudo-instruction was intentionally left out of ASSIST/I because of the interactive debugger. With the capability of single-stepping and setting breakpoints, the student should have no need to take memory snapshots.

## XSAVE

The XSAVE pseudo-instruction can be used to generate the instructions to set up a base register and establish a register save area. The only form of the XSAVE instruction supported by ASSIST/I is

```
XSAVE BR=reg[,SA=NO]
```

where reg must be a number in the range 3–12. The SA = NO option, which should be specified for lowest-level subroutines, suppresses the generation of a save area for the routine. Thus,

```
XSAVE BR=12
```

can be used to establish register 12 as a base register and to establish a save area, while

```
XSAVE BR=12,SA=NO
```

establishes register 12 as a base register but does not generate a save area for the routine.

### XRETURN

The XRETURN instruction can be used to generate the code to exit from a routine. It supports a single optional operand, to indicate whether or not a save area was established for the routine. Thus,

```
XRETURN
```

could be used to exit from a routine for which a register save area was established, while

```
XRETURN SA=NO
```

would be used for a lowest-level routine in which no save area was needed.

## 15.3 THE $ENTRY

$ENTRY tells ASSIST/I where to look for a program's input (XREAD) data. Depending on the $ENTRY parameter, input data can be read from:

1. The lines immediately following $ENTRY
2. The console
3. A disk file

$ENTRY is coded immediately following the program's End statement. It must conform to one of the following formats:

### $ENTRY

$ENTRY with no parameters is used for programs that will read in-stream data (data coded on the lines following $ENTRY) or for those programs not requiring data.

### $ENTRY CONSOLE

The CONSOLE parameter causes XREAD data to be obtained from the console. ^Z is used to indicate end-of-file from the console. ASSIST/I issues the prompt:

```
ENTER XREAD DATA NOW (ENTER CONTROL Z FOR EOF)
```

### $ENTRY CONSOLE NOPROMPT

This format works the same as the $ENTRY CONSOLE, except that the prompt to enter data from ASSIST/I is not issued.

Care should be taken when using the NOPROMPT option. The programmer should XPRNT a prompt from the program before executing XREAD, so the program user knows what is expected by the program.

**$ENTRY filename**

XREADs data from the named file. If the file does not exist, a message is issued, and any XREAD data are obtained as if $ENTRY CONSOLE had been coded.

Notes:

A program that does not have $ENTRY will assemble but not execute.

An attempt to read data past the end of file results in abnormal program termination.

## 15.4 RUNNING PROGRAMS

There are two options in the ASSIST/I main menu that can be used to run programs: the R (Run) option and the F (Final Run) option. The F option is discussed under Making Final Runs.

Providing the Save Output Listing option is on (see the section Altering ASSIST/I Options), both the R and F options create a print file with the same name as the program being run, but with a .PRT filetype. If a file with the same name exists, it will be overwritten. For this reason, source programs should *never* be given a name with the format filename.PRT.

The R option is used for program debugging. It invokes the ASSIST/I two-pass assembler to assemble the source code and generate the object code. If a program does not assemble correctly, control is returned to the ASSIST/I main menu. When a program does assemble correctly and a valid $ENTRY was included, execution control is passed to the program.

With the R option, an automatic breakpoint is set on the program's first instruction, to invoke the ASSIST/I debugger before any instructions have executed. The user can then decide whether to execute multiple statements via the debugger's Go option or to execute one instruction at a time with the debugger's Step option.

## 15.5 MAKING FINAL RUNS

ASSIST/I provides a facility for making final program runs through the selection of the F option of the ASSIST/I main menu. The option assembles and executes programs but does not provide access to the debugger. For user convenience, the F option prompts for the user's name. The name is printed with the ASSIST/I output-page header.

## 15.6 PRINTING PROGRAMS AND LISTINGS

The Print a Program (P) option in the ASSIST/I main menu can be used to print programs created by the editor and assembly/program-output listings (listings with .PRT filetypes). Tab characters are expanded to the same positions as the editor expands them. (See ^I under the Main Edit Menu in the Entering and Editing Programs section.)

The print option writes to the operating system's assigned list device.

## 15.7 USING THE ASSIST/I DEBUGGER

The ASSIST/I debugger allows the user to view a program's status during the execution phase. The debugger is invoked at execution time only under one of the following four conditions:

1. When control is initially passed to the student's program
2. Upon encountering a user-defined breakpoint (set by the B(rkpt.) facility described shortly)
3. On most implementations, when a key is struck during program execution
4. When a program exception (abnormal termination) is encountered

Figure 15-4 is an example of a screen display by the debugger when it is first invoked (i.e., the automatic break before control is passed to the program for execution).

```
------------------------------ begin screen ------------------------------
PSW AT BREAK:  FF000000 0F000000

0-7 : F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4
8-15: F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 F4F4F4F4 00000398 000083E0 00000000

000000     90ECD00C   45EF0050   F5F5F5F5   F5F5F5F5     *..}....&55555555*
000010     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
000020     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
000030     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
000040     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
000050     50DE0004   50ED0008   18DE4120   F0B045E0     *&...&.......0..\*
000060     F1505030   F0A845E0   F21C4120   F0D845E0     *1&&.0y.\2...00.\*
000070     F1505030   F0AC45E0   F21C4120   F0B04130     *1&&.0..\2...0...*
000080     F0D84140   F1005850   F0A85860   F0AC45E0     *00. 1..&0y.-0..\*
000090     F2D44120   F1001837   45E0F21C   58DD0004     *2M..1....\2.....*
0000A0     98ECD00C   07FEF5F5   F5F5F5F5   F5F5F5F5     *q.}...5555555555*
0000B0     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
0000C0     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
000000     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
0000E0     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*
0000F0     F5F5F5F5   F5F5F5F5   F5F5F5F5   F5F5F5F5     *5555555555555555*

==>  B(rkpt.), D(ump), G(o), M(emory), P(SW), Q(uit), R(eg.), S(tep), T(race)
:
---------------------- end screen ----------------------
```

**Figure 15-4**

At the bottom of the screen, the line with the arrow at the left lists the primary debugger options available to the user. These options are explained as follows:

### B(reakpoint)

The B(rkpt.) option provides a way to dynamically set, clear, and display program breakpoints (addresses where the debugger will automatically be called). The following prompt will be issued:

`BREAKPOINT: S(et), C(lear), D(isplay)` where

| | |
|---|---|
| `S(et)` | Prompts for the hex address at which to set a breakpoint. Leading zeroes of an address need not be entered.<br>A breakpoint is executed only when it is set at an instruction's beginning address (the op-code byte). |
| `C(lear)` | Clears an individual breakpoint or all breakpoints, depending on the response to the following prompt: |

`Breakpoint CLEAR: I(ndividual), A(ll)` where

| | |
|---|---|
| `I(ndividual)` | prompts for the address of the breakpoint to clear. |
| `A(ll)` | clears all the program breakpoints currently set. |
| `D(isplay)` | Displays the first 140 program breakpoint addresses.<br>Return exits the breakpoint display. |

### D(ump)

The D option is selected to write an ASSIST/I dump to the user's output-listing file. The dump is representative of the PSW, registers, and memory at the time the D option was selected. The following confirmation prompt is issued:

```
DUMP user memory to disk and QUIT DeBugger? (Y/N):
```

Note: Responding with Y stops program execution, exits the debugger, writes the dump to disk, and returns control to the ASSIST/I menu.

### G(o)

The G option simply causes the debugger to exit and return control to program execution. Execution is resumed at the instruction address located in the PSW.

### M(emory)

The M option allows the user to display and alter the contents of any memory location within the user area. This allows the user to make most program changes without having to reassemble the program. After the program area is modified, the PSW can optionally be reset with the P(SW) option, and execution can be resumed via the G or S option.

The following prompt is issued for the M option:

```
MEMORY: <RET> for this screen, N(ext scr.), P(rev. scr.), (hex address)
```

| | |
|---|---|
| where <Ret> | (depressing the Return key) moves the cursor to the first byte of the current screen. The cursor may then be positioned via the Modify Memory Commands, described later, and the valid hex digits may be entered at any location. |
| N(ext screen) | displays the next full screen of memory-dump lines, beginning with the line that follows the bottom line displayed on the current screen, and positions the cursor on the first byte. See Modify Memory Commands. |
| P(revious screen) | displays the screenful of memory-dump lines located before the current screen's top memory-dump line, and positions the cursor at its first byte. See Modify Memory Commands, below. |
| (Hex Address) | allows an address to be entered by simply entering a valid hex address. It is assumed that a hex address is being entered when a valid hex digit (0–F) is typed at this prompt level. The screen dump is then updated if necessary, and the cursor is positioned at the specified address. See Modify Memory Commands, below. |

### *Modify Memory Commands*

In memory modification, any valid hexadecimal digit may be typed to replace the hex digit at the cursor location. As new hex digits are typed, the EBCDIC display at the right of the screen is updated to reflect the correct translated character.

The cursor can be positioned within the hexadecimal memory-display portion via the following sequences:

- *Backspace or ^S* Moves the cursor left to the previous hex digit.
- *Space Bar or ^D* Moves the cursor right to the next hex digit.
- *^A* Moves the cursor left to the previous fullword boundary.
- *^F* Moves the cursor right to the next fullword boundary.
- *^E* Positions the cursor up one line.
- *^X* Positions the cursor down one line.

Return is used to exit memory modification.

Note:

The M option can be used to display memory by requesting the location to modify and then immediately exiting via Return.

### P(SW)

The P(SW) option allows the PSW to be modified. It positions the cursor at the second byte of the address portion of the PSW's instruction address. The cursor may then be positioned anywhere within the last four bytes of the PSW. ^S is used to position left, and ^D is used to position right.

Only hex digits are accepted as replacement data. Return is used to exit the P(SW) modification.

### Q(uit)

The Q(uit) option causes the following prompt to be issued:

```
Quit ASSIST Debugger & return to main menu? (Y/N):
```

Answering Y causes the debugger to exit to the ASSIST/I main menu. Program execution is terminated.

### R(eg)

The R option provides the capability of altering the contents of any of the general-purpose registers. A prompt asks you to enter the register number. Register numbers 0 through 15 are accepted, and the cursor is positioned at the register's leftmost byte.

Only hex digits are accepted as replacement data. Return is used to exit the R modification.

**S(tep)**

The S option causes the next instruction to be executed, without leaving the debugger. Single-step has the same effect as setting a temporary breakpoint at the next instruction.

**T(race)**

The T option is selected to display the ASSIST/I branch trace or instruction trace. The following second-level prompt is issued:

```
TRACE:  B(ranch Trace), I(nstruction Trace)
```

| | |
|---|---|
| where B(ranch Trace) | This selection displays a trace of the last branch instructions that were executed before the interrupt that invoked the debugger.<br>As many as 10 branches can be displayed with the PSW bits 32–39 (the instruction-length code, condition code, and instruction mask), the location of the branch instruction, and the encoded form of the instruction. Return exits the branch trace and refreshes the screen dump. |
| I(nstruction Trace) | This selection displays a trace of the last 10 instructions that were executed before the interrupt that caused the editor to be invoked.<br>The instructions are displayed with the PSW bits 32–39 (the instruction-length code, condition code, and instruction mask), the instruction location, and the encoded form of the instruction.<br>Return exits the instruction trace and refreshes the screen dump. |

```
** TRACE OF LAST 10 INSTRUCTIONS EXECUTED **

===> IM = PSW bits 32-39 (ILC,CC,MASK) before instruction executed at LOCATION.

IM  LOCATION  INSTRUCTION
==  ========  ==============
20  0000D4    4570 F1BA
A0  0001BA    F3F7 F1E1 F1F1
E0  0001C0    96F8 F1F0
90  0001C4    E020 F1CC 0025
D0  0001CA    07F7
50  0000D8    F3F7 F1C0 F201
D0  0000DE    96F0 F10C
90  0000E2    47F0 F11E
90  00011E    47F0 F12E
90  00012E    FC87 F122 F201   <-- Last instruction executed.
```

**Figure 15-5**

Figure 15-5 is an example of the instruction trace display.

The last instruction in the list was executed just before the debugger was called. The cause of termination is probably either this instruction or the fact that a breakpoint had been set on the instruction following it.

## 15.8 ALTERING ASSIST/I OPTIONS

ASSIST/I provides the facility to alter program execution options by selecting the "A" option in the ASSIST/I main menu. The example screen display in Figure 15-6 lists the items that are alterable.

| *Option* | *Description* |
|---|---|
| 1 | Is a toggle to determine whether or not the output listing (source code listing and program-generated output) are to be written to an output disk file. If the option is n, no listing is generated; y |

```
---------------------- begin screen ---------------------------

                A S S I S T / I   Options


          1)  Save output listing      -  y
          2)  Maximum # lines          -  500
          3)  Maximum # instructions   -  5000
          4)  Maximum # pages          -  100
          5)  Maximum size (in bytes)  -  2700


          Enter option number to alter (RETURN to quit): _

---------------------- end screen -----------------------------
```

**Figure 15-6**

insures that an output listing is generated, with a filename the same as the source code file, but with a filetype .PRT.

2 Indicates the maximum number of lines a program output listing is allowed to contain. The output listing includes source-code lines and program-generated lines (lines generated with the XPRNT statement).

3 Indicates the maximum number of instructions ASSIST/I can execute. A program that tries to execute more instructions is terminated. (This is handy for dealing with endless loops.)

4 Indicates the maximum number of pages an output listing may contain. Since this number includes the source listing and XPRNT-generated pages, it must be set high enough to accommodate both.

5 Reserves storage for the program's object code. This value may need adjustment, depending on the system ASSIST/I is running under.

# Appendix A

# Illustration of Subroutines

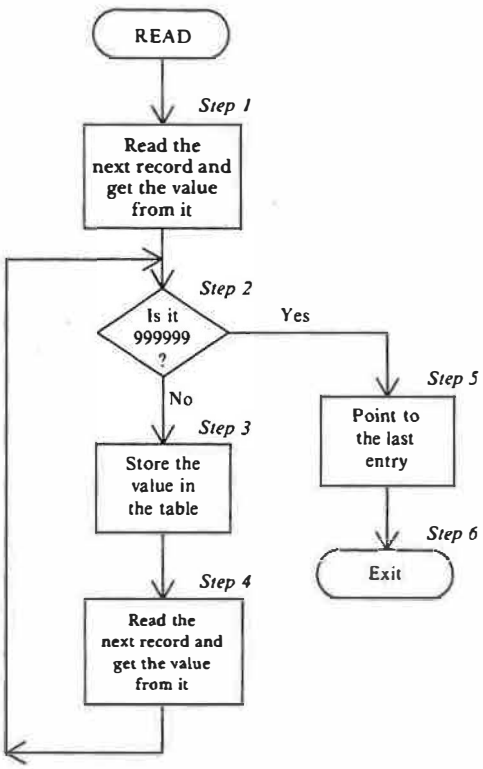



**Figure A-1**

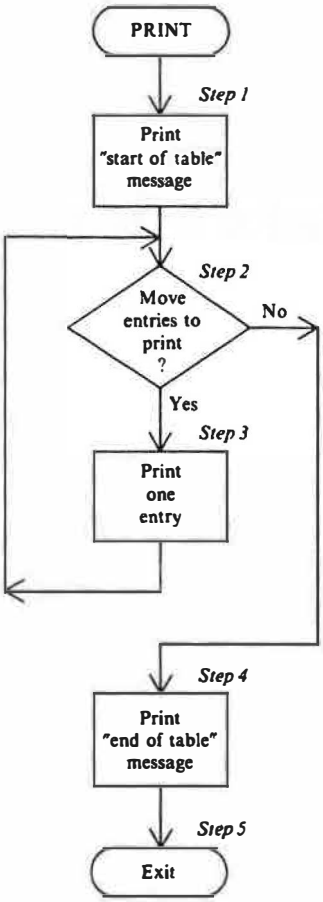

PRINT
Step 1
Print "start of table" message
Step 2
Move entries to print ?
No
Yes
Step 3
Print one entry
Step 4
Print "end of table" message
Step 5
Exit

**Figure A-2**

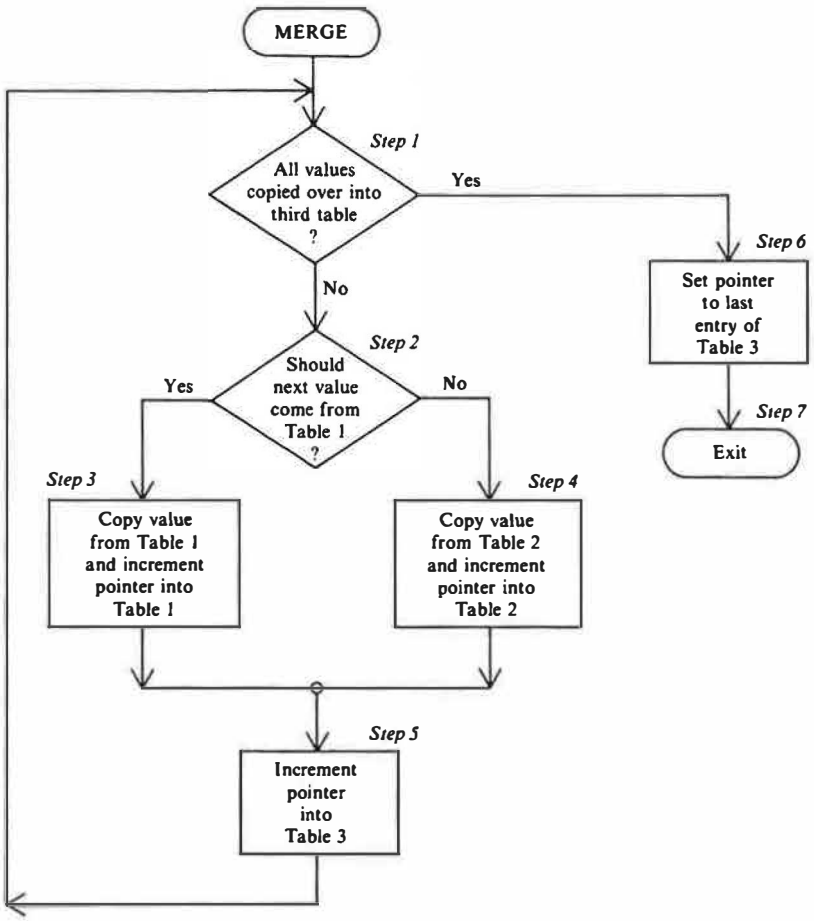

MERGE
Step 1
All values copied over into third table ?
Yes
No
Step 6
Set pointer to last entry of Table 3
Step 7
Exit
Step 2
Should next value come from Table 1 ?
Yes
No
Step 3
Copy value from Table 1 and increment pointer into Table 1
Step 4
Copy value from Table 2 and increment pointer into Table 2
Step 5
Increment pointer into Table 3

**Figure A-3**

**Program A-1**

```
*****************************************************************
*
* THIS PROGRAM ILLUSTRATES THE USE OF SUBROUTINES.  THE PROGRAM
*
*        1) READS A SET OF NUMBERS INTO 'TABLE1'.  IT IS
*           ASSUMED THAT THE INPUT VALUES HAVE BEEN SORTED INTO
*           ASCENDING ORDER.
*
*        2) PRINTS OUT THE NUMBERS IN 'TABLE1'.
*
*        3) READS IN A SECOND SET OF NUMBERS INTO 'TABLE2'.
*
*        4) PRINTS OUT THE NUMBERS IN 'TABLE2'.
*
*        5) MERGES THE NUMBERS IN THE TWO TABLES INTO 'TABLE3'.
*
*        6) PRINTS OUT THE NUMBERS IN 'TABLE3'.
*
* THE LOGIC OF THE PROGRAM IS AS FOLLOWS:
*
*        STEP 1.  CALL 'READ' TO READ IN THE FIRST TABLE.  THIS WILL
*                 REQUIRE PASSING TO 'READ' THE ADDRESS OF THE TABLE
*                 TO FILL.  THE 'READ' ROUTINE WILL RETURN THE ADDRESS
*                 OF THE LAST ENTRY, WHICH IS STORED IN 'ENDT1'.
*
*        STEP 2.  CALL 'PRINT' TO PRINT OUT THE VALUES IN 'TABLE1'.
*
*        STEP 3.  CALL 'READ' TO READ IN THE VALUES FOR 'TABLE2', AND
*                 SAVE THE ADDRESS OF THE LAST ENTRY IN 'ENDT2'.
*
*        STEP 4.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE2'.
*
*        STEP 5.  CALL 'MERGE' TO MERGE THE VALUES IN 'TABLE1' AND
*                 'TABLE2' INTO 'TABLE3'.
*
*        STEP 6.  CALL 'PRINT' TO DISPLAY THE VALUES IN 'TABLE3'.
*
*        STEP 7.  EXIT.
*
*****************************************************************
*
MAINPROG CSECT
         USING MAINPROG,R15
*
***<STEP 1>    READ IN THE VALUES FOR 'TABLE1'.
*
         LA    R2,TABLE1          R2 IS USED TO PASS THE ADDRESS OF
*                                 WHERE THE VALUES ARE TO BE STORED
         BAL   R10,READ           READ IN 'TABLE1'
         ST    R3,ENDT1           SAVE THE ADDRESS OF THE LAST VALUE
*
***<STEP 2>    PRINT OUT THE VALUES IN 'TABLE1'.
*
         BAL   R10,PRINT          R2 MUST HAVE ADDRESS OF 'TABLE1' AND
*                                 R3 MUST HAVE ADDRESS OF LAST ENTRY
```

**Program A-1 (continued)**

```
*
***<STEP 3>     READ IN THE VALUES FOR 'TABLE2'.
*
         LA     R2,TABLE2          POINT TO THE SECOND TABLE
         BAL    R10,READ           READ IN THE VALUES
         ST     R3,ENDT2           SAVE ADDRESS OF LAST ENTRY
*
***<STEP 4>     PRINT OUT THE VALUES IN 'TABLE2'.
*
         BAL    R10,PRINT
*
***<STEP 5>     NOW MERGE THE TWO TABLES INTO 'TABLE3'.
*
         LA     R2,TABLE1          R2 <- ADDRESS OF FIRST TABLE
         LA     R3,TABLE2          R3 <- ADDRESS OF SECOND TABLE
         LA     R4,TABLE3          R4 <- ADDRESS OF TABLE TO BUILD
*
         L      R5,ENDT1           R5 <- ADDRESS OF LAST ENTRY IN TABLE1
         L      R6,ENDT2           R6 <- ADDRESS OF LAST ENTRY IN TABLE2
*
         BAL    R10,MERGE          NOW MERGE THE TWO TABLES
*
***<STEP 6>     PRINT OUT THE CONTENTS OF 'TABLE3'.
*
         LA     R2,TABLE3
         LR     R3,R7              'MERGE' PUT ADDRESS OF LAST ENTRY
*                                  INTO R7
         BAL    R10,PRINT          NOW PRINT THE MERGED TABLE
*
***<STEP 7>     EXIT.
*
         BR     R14
*
*****************************************************************
*
*                STORAGE AREAS FOR THE MAIN ROUTINE
*
*****************************************************************
*
         LTORG
ENDT1    DS     F                  ADDRESS OF LAST ENTRY IN TABLE1
ENDT2    DS     F                  ADDRESS OF LAST ENTRY IN TABLE2
TABLE1   DS     50F                BUILD THE FIRST TABLE HERE
TABLE2   DS     50F                AND THE SECOND TABLE HERE
TABLE3   DS     100F               AND THE MERGED TABLE HERE
*
*****************************************************************
*
*                        READ ROUTINE
*
* THIS IS THE READ ROUTINE.  WHEN IT IS ENTERED, R2 CONTAINS THE
* ADDRESS OF THE TABLE TO BE FILLED.  EACH DATA CARD CONTAINS ONE
* NUMBER. END OF THE TABLE IS DESIGNATED BY A CARD CONTAINING
* 999999.  UPON EXITING, R3 CONTAINS THE ADDRESS OF THE LAST ENTRY
* OF THE TABLE.  NO OTHER REGISTERS ARE ALTERED.  R10 IS THE LINK
* REGISTER.
*
```

**Program A-1 (continued)**

```
*
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  READ THE NEXT CARD AND GET THE VALUE OFF IT.
*
*        STEP 2.  IF THE VALUE ON THE CARD IS 999999, GO TO STEP 5.
*
*        STEP 3.  STORE THE VALUE INTO THE TABLE BEING BUILT.
*                 INCREMENT THE POINTER TO WHERE THE NEXT VALUE GOES.
*
*        STEP 4.  READ THE NEXT CARD, GET THE VALUE OFF IT, AND GO
*                 BACK TO STEP 2.
*
*        STEP 5.  SET R3 TO POINT TO THE LAST ENTRY.
*
*        STEP 6.  EXIT.
*
*************************************************************************
*
READ     STM   R4,R2,READSAVE     SAVE ALL REGS EXCEPT R3
*
***<STEP 1>    READ THE NEXT CARD AND GET THE VALUE OFF IT.
*
         XREAD CARD,80            IT IS ASSUMED THAT THERE IS A CARD
         XDECI R4,CARD            AND THAT THE NUMBER IS VALID
*
***<STEP 2>    TEST FOR END OF LOOP (VALUE OF 999999).
*
READLOOP C     R4,=F'999999'
         BE    SETLAST            BRANCH IF END OF INPUT VALUES
*
***<STEP 3>    STORE VALUE INTO TABLE AND INCREMENT NEXT ENTRY POINTER.
*
         ST    R4,0(R2)           STORE ENTRY
         LA    R2,4(R2)           POINT TO NEXT ENTRY
*
***<STEP 4>    READ THE NEXT CARD, GET VALUE, AND GO TO STEP 2.
*
         XREAD CARD,80            READ THE CARD
         XDECI 4,CARD             AND GET THE VALUE
         B     READLOOP
*
***<STEP 5>    SET POINTER TO LAST ENTRY.
*
SETLAST  LR    R3,R2              R2 HAS ADDRESS OF "NEXT ENTRY"
         S     R3,=F'4'           R3 NOW POINTS TO LAST ENTRY
*
***<STEP 6>    RETURN TO CALLER.
*
         LM    R4,R2,READSAVE     RESTORE ALL REGISTERS BUT R3
         BR    R10                AND RETURN
*
         LTORG
*
CARD     DS    CL80               CARD INPUT AREA
*
READSAVE DS    15F                ROOM FOR ALL REGISTERS, EXCEPT R3
```

**Program A-1 (continued)**

```
*
*
*****************************************************************
*
*                        PRINT ROUTINE
*
* THIS ROUTINE PRINTS OUT THE VALUES IN THE TABLE POINTED TO BY
* R2.  R3 MUST CONTAIN THE ADDRESS OF THE LAST ENTRY IN THE TABLE.
* R10 IS THE LINK REGISTER.  ENTRIES ARE PRINTED OUT 1 PER LINE.
* NO REGISTERS ARE ALTERED BY A CALL TO THIS ROUTINE.
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  PRINT A HEADING.
*
*        STEP 2.  IF ALL OF THE ENTRIES HAVE BEEN PRINTED, GO
*                 TO STEP 4.
*
*        STEP 3.  PRINT ONE ENTRY, INCREMENT POINTER TO NEXT ENTRY,
*                 AND GO BACK TO STEP 2.
*
*        STEP 4.  PRINT "END OF TABLE" MESSAGE.
*
*        STEP 5.  EXIT.
*
*****************************************************************
*
PRINT    STM   R0,R15,PRINTSAV     SAVE ALL OF THE REGISTERS
*
***<STEP 1>    PRINT A HEADING.
*
         XPRNT =C'0*** START OF TABLE ***',23
*
***<STEP 2>    CHECK FOR END OF TABLE.
*
PRINTLP  CR    R2,R3               COMPARE CURRENT AGAINST LAST
         BH    PRINTEND            BRANCH IF PAST LAST ENTRY
*
***<STEP 3>    PRINT ONE ENTRY AND GO BACK TO STEP 2.
*
         L     R4,0(R2)            GET A VALUE FROM THE TABLE
         XDECO R4,OUTVAL           CONVERT TO PRINTABLE FORMAT
         XPRNT PRNTLINE,13         PRINT IT
*
         LA    R2,4(R2)            INCREMENT POINTER TO NEXT ENTRY
         B     PRINTLP
*
***<STEP 4>    PRINT "END OF TABLE" MESSAGE.
*
PRINTEND XPRNT =C'0*** END OF TABLE ***',21
*
***<STEP 5>    EXIT.
*
         LM    R0,R15,PRINTSAV     RESTORE ALL REGISTERS
         BR    R10                 EXIT
```

**Program A-1 (continued)**

```
*
        LTORG
*
PRNTLINE DC    C' '                CARRIAGE CONTROL
OUTVAL   DS    CL12                OUTPUT THE VALUES HERE
*
PRINTSAV DS    16F                 SAVE REGISTERS HERE
*
*************************************************************************
*
*                        MERGE ROUTINE
*
* THIS ROUTINE MERGES THE TWO SORTED TABLES INTO A THIRD TABLE.  UPON
* ENTRANCE
*
*        R2 = ADDRESS OF FIRST TABLE
*        R3 = ADDRESS OF SECOND TABLE
*        R4 = ADDRESS OF THIRD TABLE
*        R5 = ADDRESS OF LAST ENTRY IN FIRST TABLE
*        R6 = ADDRESS OF LAST ENTRY IN SECOND TABLE
*
* THE ROUTINE WILL SET R7 TO THE ADDRESS OF THE LAST ENTRY IN THE
* THIRD TABLE, WHICH IS PRODUCED BY MERGING THE FIRST TWO TABLES.
* R10 IS THE LINK REGISTER.  ONLY R7 IS ALTERED BY A CALL TO THIS
* ROUTINE.
*
* THE LOGIC IS AS FOLLOWS:
*
*        STEP 1.  IF ALL VALUES FROM BOTH TABLES ARE IN THE THIRD
*                 TABLE, GO TO STEP 6.
*
*        STEP 2.  IF (ALL VALUES IN TABLE2 ARE ALREADY IN TABLE3 OR
*                    (SOME VALUES IN TABLE1 HAVE NOT YET BEEN
*                     MOVED AND THE NEXT ONE FROM TABLE1 IS LESS
*                     THAN THE NEXT ONE FROM TABLE2)), GO TO STEP 3.
*                     ELSE, GO TO STEP 4.
*
*        STEP 3.  MOVE A VALUE FROM TABLE1 TO TABLE3, UPDATING THE
*                 POINTER TO THE NEXT ENTRY IN TABLE1.  GO TO STEP 5.
*
*        STEP 4.  MOVE A VALUE FROM TABLE2 TO TABLE3, UPDATING THE
*                 POINTER TO THE NEXT ENTRY IN TABLE2.
*
*        STEP 5.  UPDATE THE POINTER TO THE NEXT ENTRY IN TABLE3 AND
*                 GO BACK TO STEP 1.
*
*        STEP 6.  SET R7 TO POINT TO THE LAST ENTRY IN TABLE3.
*
*        STEP 7.  EXIT.
*
*************************************************************************
*
MERGE    STM   R8,R6,MERGESAV      SAVE ALL REGS, EXCEPT R7
*
***<STEP 1>    BRANCH TO STEP 6, IF ALL ENTRIES HAVE BEEN MOVED.
*
MERGELP  CR    R2,R5
         BNH   SOMELEFT           BRANCH IF NOT ALL OF TABLE1 HAS
*                                 BEEN MOVED
         CR    R3,R6
         BH    POINTR7            BRANCH IF ALL ENTRIES HAVE BEEN
*                                 MOVED TO TABLE3
```

**Program A-1 (continued)**

```
*
***<STEP 2>     FIGURE OUT WHICH TABLE THE NEXT ENTRY COMES FROM.
*
SOMELEFT CR     R3,R6
         BH     FROMT1              BRANCH IF TABLE2 EXHAUSTED
*
         CR     R2,R5
         BH     FROMT2              BRANCH IF TABLE1 EXHAUSTED
*
         L      R8,0(R2)            R8 <- NEXT ENTRY FROM TABLE1
         C      R8,0(R3)
         BH     FROMT2              BRANCH IF T1'S ENTRY IS HIGH
*
***<STEP 3>     MOVE ENTRY FROM TABLE1 TO TABLE3.
*
FROMT1   L      R8,0(R2)            LOAD ENTRY FROM TABLE1
         ST     R8,0(R4)            STORE INTO TABLE3
         LA     R2,4(R2)            INCREMENT POINTER INTO TABLE1
         B      INCRT3              GO INCREMENT TABLE3'S POINTER
*
***<STEP 4>     MOVE ENTRY FROM TABLE2 TO TABLE3.
*
FROMT2   L      R8,0(R3)            LOAD ENTRY FROM TABLE2
         ST     R8,0(R4)            AND PUT IT INTO TABLE3
         LA     R3,4(R3)            INCREMENT POINTER INTO TABLE2
*
***<STEP 5>     INCREMENT TABLE3'S POINTER AND GO BACK TO STEP 1.
*
INCRT3   LA     R4,4(R4)            INCREMENT POINTER TO NEXT ENTRY
*                                   FOR TABLE3
         B      MERGELP
*
***<STEP 6>     POINT R7 AT LAST ENTRY IN TABLE3.
*
POINTR7  LR     R7,R4               R4 POINTS JUST PAST LAST ENTRY
         S      R7,=F'4'            NOW R7 POINTS AT LAST ENTRY
*
***<STEP 7>     EXIT.
*
         LM     R8,R6,MERGESAV      RESTORE ALL REGISTERS BUT R7
         BR     R10                 AND RETURN
*
MERGESAV DS     15F                 REGISTER SAVEAREA
         LTORG

R0       EQU    0
R1       EQU    1
R2       EQU    2
R3       EQU    3
R4       EQU    4
R5       EQU    5
R6       EQU    6
R7       EQU    7
R8       EQU    8
R9       EQU    9
R10      EQU    10
R11      EQU    11
R12      EQU    12
R13      EQU    13
R14      EQU    14
R15      EQU    15
         END    MAINPROG
```

# Appendix B

# Table of Extended Mnemonics

| *Extended Mnemonic* | | *Meaning* | *Corresponding BC or BCR Instruction* | |
|---|---|---|---|---|
| B | address | Branch Unconditional | BC | B'1111',address |
| BR | r | Branch Unconditional | BCR | B'1111',r |
| NOP | address | No Operation | BC | B'0000',address |
| NOPR | r | No Operation | BCR | B'0000',r |
| | | **Used after Comparison Instructions** | | |
| BH | address | Branch on High | BC | B'0010',address |
| BL | address | Branch on Low | BC | B'0100',address |
| BE | address | Branch on Equal | BC | B'1000',address |
| BNH | address | Branch on Not High | BC | B'1101',address |
| BNL | address | Branch on Not Low | BC | B'1011',address |
| BNE | address | Branch on Not Equal | BC | B'0111',address |
| | | **Used after Arithmetic Instructions** | | |
| BO | address | Branch on Overflow | BC | B'0001',address |
| BP | address | Branch on Plus | BC | B'0010',address |
| BM | address | Branch on Minus | BC | B'0100',address |
| BZ | address | Branch on Zero | BC | B'1000',address |
| BNO | address | Branch on Not Overflow | BC | B'1110',address |
| BNP | address | Branch on Not Plus | BC | B'1101',address |
| BNM | address | Branch on Not Minus | BC | B'1011',address |
| BNZ | address | Branch on Not Zero | BC | B'0111',address |
| | | **Used after Test under Mask Instructions** | | |
| BO | address | Branch If Ones | BC | B'0001',address |
| BM | address | Branch If Mixed | BC | B'0100',address |
| BZ | address | Branch If Zeros | BC | B'1000',address |
| BNO | address | Branch If Not All Ones | BC | B'1110',address |
| BNM | address | Branch If Not Mixed | BC | B'1011',address |
| BNZ | address | Branch If Not All Zeros | BC | B'0111',address |

# Appendix C

# Converting Hexadecimal to Punched Card Codes

You will find the following tables particularly useful. However, all this information and much more is contained in the System/370 Reference Summary, published by IBM.

## CHARACTER-TO-HEXADECIMAL CONVERSIONS

| *Hexa-decimal* | *Character* | *Punched Card Code* | *Hexa-decimal* | *Character* | *Punched Card Code* |
|---|---|---|---|---|---|
| 00 | | 12-0-1-8-9 | 15 | | 11-5-9 |
| 01 | | 12-1-9 | 16 | | 11-6-9 |
| 02 | | 12-2-9 | 17 | | 11-7-9 |
| 03 | | 12-3-9 | 18 | | 11-8-9 |
| 04 | | 12-4-9 | 19 | | 11-1-8-9 |
| 05 | | 12-5-9 | 1A | | 11-2-8-9 |
| 06 | | 12-6-9 | 1B | | 11-3-8-9 |
| 07 | | 12-7-9 | 1C | | 11-4-8-9 |
| 08 | | 12-8-9 | 1D | | 11-5-8-9 |
| 09 | | 12-1-8-9 | 1E | | 11-6-8-9 |
| 0A | | 12-2-8-9 | 1F | | 11-7-8-9 |
| 0B | | 12-3-8-9 | 20 | | 11-0-1-8-9 |
| OC | | 12-4-8-9 | 21 | | 0-1-9 |
| 0D | | 12-5-8-9 | 22 | | 0-2-9 |
| 0E | | 12-6-8-9 | 23 | | 0-3-9 |
| 0F | | 12-7-8-9 | 24 | | 0-4-9 |
| 10 | | 12-11-1-8-9 | 25 | | 0-5-9 |
| 11 | | 11-1-9 | 26 | | 0-6-9 |
| 12 | | 11-2-9 | 27 | | 0-7-9 |
| 13 | | 11-3-9 | 28 | | 0-8-9 |
| 14 | | 11-4-9 | 29 | | 0-1-8-9 |

| *Hexa-decimal* | *Character* | *Punched Card Code* | *Hexa-decimal* | *Character* | *Punched Card Code* |
|---|---|---|---|---|---|
| 2A | | 0-2-8-9 | 58 | | 12-11-8-9 |
| 2B | | 0-3-8-9 | 59 | | 11-1-8 |
| 2C | | 0-4-8-9 | 5A | ! | 11-2-8 |
| 2D | | 0-5-8-9 | 5B | $ | 11-3-8 |
| 2E | | 0-6-8-9 | 5C | * | 11-4-8 |
| 2F | | 0-7-8-9 | 5D | ) | 11-5-8 |
| 30 | | 12-11-0-1-8-9 | 5E | ; | 11-6-8 |
| 31 | | 1-9 | 5F | ¬ | 11-7-8 |
| 32 | | 2-9 | 60 | - | 11 |
| 33 | | 3-9 | 61 | / | 0-1 |
| 34 | | 4-9 | 62 | | 11-0-2-9 |
| 35 | | 5-9 | 63 | | 11-0-3-9 |
| 36 | | 6-9 | 64 | | 11-0-4-9 |
| 37 | | 7-9 | 65 | | 11-0-5-9 |
| 38 | | 8-9 | 66 | | 11-0-6-9 |
| 39 | | 1-8-9 | 67 | | 11-0-7-9 |
| 3A | | 2-8-9 | 68 | | 11-0-8-9 |
| 3B | | 3-8-9 | 69 | | 0-1-8 |
| 3C | | 4-8-9 | 6A | ¦ | 12-11 |
| 3D | | 5-8-9 | 6B | , | 0-3-8 |
| 3E | | 6-8-9 | 6C | % | 0-4-8 |
| 3F | | 7-8-9 | 6D | — | 0-5-8 |
| 40 | | no punches | 6E | > | 0-6-8 |
| 41 | | 12-0-1-9 | 6F | ? | 0-7-8 |
| 42 | | 12-0-2-9 | 70 | | 12-11-0 |
| 43 | | 12-0-3-9 | 71 | | 12-11-0-1-9 |
| 44 | | 12-0-4-9 | 72 | | 12-11-0-2-9 |
| 45 | | 12-0-5-9 | 73 | | 12-11-0-3-9 |
| 46 | | 12-0-6-9 | 74 | | 12-11-0-4-9 |
| 47 | | 12-0-7-9 | 75 | | 12-11-0-5-9 |
| 48 | | 12-0-8-9 | 76 | | 12-11-0-6-9 |
| 49 | | 12-1-8 | 77 | | 12-11-0-7-9 |
| 4A | ¢ | 12-2-8 | 78 | | 12-11-0-8-9 |
| 4B | • | 12-3-8 | 79 | | 1-8 |
| 4C | < | 12-4-8 | 7A | : | 2-8 |
| 4D | ( | 12-5-8 | 7B | # | 3-8 |
| 4E | + | 12-6-8 | 7C | @ | 4-8 |
| 4F | \| | 12-7-8 | 7D | ' | 5-8 |
| 50 | & | 12 | 7E | = | 6-8 |
| 51 | | 12-11-1-9 | 7F | " | 7-8 |
| 52 | | 12-11-2-9 | 80 | | 12-0-1-8 |
| 53 | | 12-11-3-9 | 81 | a | 12-0-1 |
| 54 | | 12-11-4-9 | 82 | b | 12-0-2 |
| 55 | | 12-11-5-9 | 83 | c | 12-0-3 |
| 56 | | 12-11-6-9 | 84 | d | 12-0-4 |
| 57 | | 12-11-7-9 | 85 | e | 12-0-5 |

| *Hexa-decimal* | *Character* | *Punched Card Code* | *Hexa-decimal* | *Character* | *Punched Card Code* |
|---|---|---|---|---|---|
| 86 | f | 12-0-6 | B4 | | 12-11-0-4 |
| 87 | g | 12-0-7 | B5 | | 12-11-0-5 |
| 88 | h | 12-0-8 | B6 | | 12-11-0-6 |
| 89 | i | 12-0-9 | B7 | | 12-11-0-7 |
| 8A | | 12-0-2-8 | B8 | | 12-11-0-8 |
| 8B | | 12-0-3-8 | B9 | | 12-11-0-9 |
| 8C | | 12-0-4-8 | BA | | 12-11-0-2-8 |
| 8D | | 12-0-5-8 | BB | | 12-11-0-3-8 |
| 8E | | 12-0-6-8 | BC | | 12-11-0-4-8 |
| 8F | | 12-0-7-8 | BD | | 12-11-0-5-8 |
| 90 | | 12-11-1-8 | BE | | 12-11-0-6-8 |
| 91 | j | 12-11-1 | BF | | 12-11-0-7-8 |
| 92 | k | 12-11-2 | C0 | { | 12-0 |
| 93 | l | 12-11-3 | C1 | A | 12-1 |
| 94 | m | 12-11-4 | C2 | B | 12-2 |
| 95 | n | 12-11-5 | C3 | C | 12-3 |
| 96 | o | 12-11-6 | C4 | D | 12-4 |
| 97 | p | 12-11-7 | C5 | E | 12-5 |
| 98 | q | 12-11-8 | C6 | F | 12-6 |
| 99 | r | 12-11-9 | C7 | G | 12-7 |
| 9A | | 12-11-2-8 | C8 | H | 12-8 |
| 9B | | 12-11-3-8 | C9 | I | 12-9 |
| 9C | | 12-11-4-8 | CA | | 12-0-2-8-9 |
| 9D | | 12-11-5-8 | CB | | 12-0-3-8-9 |
| 9E | | 12-11-6-8 | CC | ∽ | 12-0-4-8-9 |
| 9F | | 12-11-7-8 | CD | | 12-0-5-8-9 |
| A0 | | 11-0-1-8 | CE | ⅄ | 12-0-6-8-9 |
| A1 | ~ | 11-0-1 | CF | | 12-0-7-8-9 |
| A2 | s | 11-0-2 | D0 | } | 11-0 |
| A3 | t | 11-0-3 | D1 | J | 11-1 |
| A4 | u | 11-0-4 | D2 | K | 11-2 |
| A5 | v | 11-0-5 | D3 | L | 11-3 |
| A6 | w | 11-0-6 | D4 | M | 11-4 |
| A7 | x | 11-0-7 | D5 | N | 11-5 |
| A8 | y | 11-0-8 | D6 | O | 11-6 |
| A9 | z | 11-0-9 | D7 | P | 11-7 |
| AA | | 11-0-2-8 | D8 | Q | 11-8 |
| AB | | 11-0-3-8 | D9 | R | 11-9 |
| AC | | 11-0-4-8 | DA | | 12-11-2-8-9 |
| AD | | 11-0-5-8 | DB | | 12-11-3-8-9 |
| AE | | 11-0-6-8 | DC | | 12-11-4-8-9 |
| AF | | 11-0-7-8 | DD | | 12-11-5-8-9 |
| B0 | | 12-11-0-1-8 | DE | | 12-11-6-8-9 |
| B1 | | 12-11-0-1 | DF | | 12-11-7-8-9 |
| B2 | | 12-11-0-2 | E0 | | 0-2-8 |
| B3 | | 12-11-0-3 | E1 | | 11-0-1-9 |

| *Hexa-decimal* | *Character* | *Punched Card Code* |
|---|---|---|
| E2 | S | 0-2 |
| E3 | T | 0-3 |
| E4 | U | 0-4 |
| E5 | V | 0-5 |
| E6 | W | 0-6 |
| E7 | X | 0-7 |
| E8 | Y | 0-8 |
| E9 | Z | 0-9 |
| EA | | 11-0-2-8-9 |
| EB | | 11-0-3-8-9 |
| EC | ┘ | 11-0-4-8-9 |
| ED | | 11-0-5-8-9 |
| EE | | 11-0-6-8-9 |
| EF | | 11-0-7-8-9 |
| F0 | 0 | 0 |
| F1 | 1 | 1 |
| F2 | 2 | 2 |
| F3 | 3 | 3 |
| F4 | 4 | 4 |
| F5 | 5 | 5 |
| F6 | 6 | 6 |
| F7 | 7 | 7 |
| F8 | 8 | 8 |
| F9 | 9 | 9 |
| FA | \| | 12-11-0-2-8-9 |
| FB | | 12-11-0-3-8-9 |
| FC | | 12-11-0-4-8-9 |
| FD | | 12-11-0-5-8-9 |
| FE | | 12-11-0-6-8-9 |
| FF | | 12-11-0-7-8-9 |

## OP CODES OF COMMONLY USED INSTRUCTIONS

| *Name* | *Mnemonic* | *OP Code* |
|---|---|---|
| Add | AR | 1A |
| Add | A | 5A |
| Add Decimal | AP | FA |
| Add Halfword | AH | 4A |
| Add Logical | ALR | 1E |
| Add Logical | AL | 5E |
| AND | NR | 14 |
| AND | N | 54 |
| AND | NI | 94 |
| AND | NC | D4 |
| Branch and Link | BALR | 05 |
| Branch and Link | BAL | 45 |
| Branch on Condition | BCR | 07 |
| Branch on Condition | BC | 47 |
| Branch on Count | BCTR | 06 |
| Branch on Count | BCT | 46 |
| Branch on Index High | BXH | 86 |
| Branch on Index Low or Equal | BXLE | 87 |
| Compare | CR | 19 |
| Compare | C | 59 |
| Compare Decimal | CP | F9 |
| Compare Halfword | CH | 49 |
| Compare Logical | CLR | 15 |
| Compare Logical | CL | 55 |
| Compare Logical | CLC | D5 |
| Compare Logical | CLI | 95 |
| Compare Logical Characters under Mask | CLM | BD |
| Compare Logical Long | CLCL | 0F |
| Convert to Binary | CVB | 4F |
| Convert to Decimal | CVD | 4E |
| Divide | DR | 1D |
| Divide | D | 5D |
| Divide Decimal | DP | FD |
| Edit | ED | DE |
| Edit and Mark | EDMK | DF |
| Exclusive OR | XR | 17 |
| Exclusive OR | X | 57 |
| Exclusive OR | XI | 97 |
| Exclusive OR | XC | D7 |

| *Name* | *Mnemonic* | *OP Code* |
|---|---|---|
| Execute | EX | 44 |
| Insert Character | IC | 43 |
| Insert Characters under Mask | ICM | BF |
| Load | LR | 18 |
| Load | L | 58 |
| Load Address | LA | 41 |
| Load and Test | LTR | 12 |
| Load Complement | LCR | 13 |
| Load Halfword | LH | 48 |
| Load Multiple | LM | 98 |
| Load Negative | LNR | 11 |
| Load Positive | LPR | 10 |
| Load PSW | LPSW | 82 |
| Move | MVI | 92 |
| Move | MVC | D2 |
| Move Long | MVCL | 0E |
| Move Numerics | MVN | D1 |
| Move with Offset | MVO | F1 |
| Move Zones | MVZ | D3 |
| Multiply | MR | 1C |
| Multiply | M | 5C |
| Multiply Decimal | MP | FC |
| Multiply Halfword | MH | 4C |
| OR | OR | 16 |
| OR | O | 56 |
| OR | OI | 96 |
| OR | OC | D6 |
| Pack | PACK | F2 |
| Set Program Mask | SPM | 04 |
| Shift and Round Decimal | SRP | F0 |
| Shift Left Double | SLDA | 8F |
| Shift Left Double Logical | SLDL | 8D |
| Shift Left Single | SLA | 8B |
| Shift Left Single Logical | SLL | 89 |
| Shift Right Double | SRDA | 8E |
| Shift Right Double Logical | SRDL | 8C |
| Shift Right Single | SRA | 8A |
| Shift Right Single Logical | SRL | 88 |
| Store | ST | 50 |
| Store Character | STC | 42 |
| Store Characters under Mask | STCM | BE |
| Store Halfword | STH | 40 |
| Store Multiple | STM | 90 |

| *Name* | *Mnemonic* | *OP Code* |
|---|---|---|
| Subtract | SR | 1B |
| Subtract | S | 5B |
| Subtract Decimal | SP | FB |
| Subtract Halfword | SH | 4B |
| Subtract Logical | SLR | 1F |
| Subtract Logical | SL | 5F |
| Supervisor Call | SVC | 0A |
| Test under Mask | TM | 91 |
| Translate | TR | DC |
| Translate and Test | TRT | DD |
| Unpack | UNPK | F3 |
| Zero and Add Decimal | ZAP | F8 |

## POWERS OF 16

| $16^n$ | $n$ |
|---|---|
| 1 | 0 |
| 16 | 1 |
| 256 | 2 |
| 4 096 | 3 |
| 65 536 | 4 |
| 1 048 576 | 5 |
| 16 777 216 | 6 |
| 268 435 456 | 7 |
| 4 294 967 296 | 8 |
| 68 719 476 736 | 9 |
| 1 099 511 627 776 | 10 |
| 17 592 186 044 416 | 11 |
| 281 474 976 710 656 | 12 |
| 4 503 599 627 370 496 | 13 |
| 72 057 594 037 927 936 | 14 |
| 1 152 921 504 606 846 976 | 15 |

## POWERS OF 2

| $2^n$ | $n$ |
|---|---|
| 512 | 9 |
| 1 024 | 10 |
| 2 048 | 11 |
| 4 096 | 12 |
| 8 192 | 13 |
| 16 384 | 14 |
| 32 768 | 15 |
| 65 536 | 16 |
| 131 072 | 17 |
| 262 144 | 18 |
| 524 288 | 19 |
| 1 048 576 | 20 |
| 2 097 152 | 21 |
| 4 194 304 | 22 |
| 8 388 608 | 23 |
| 16 777 216 | 24 |

## FORMAT OF THE PROGRAM STATUS WORD (PSW)

The PSW is composed of 64 bits, which are used as follows:

| *Bits* | *Use* |
|---|---|
| 0–7 | System mask (used to mask interrupts) |
| 8–11 | Memory protection key |
| 12–15 | Status bits. The most significant for our purposes are:<br>14 indicates whether or not the machine is in the wait state<br>15 indicates whether the machine is in supervisor or problem state |
| 16–31 | Interruption code. Information concerning the cause of an interrupt is stored here when the old PSW is stored. |
| 32–33 | Instruction length code. Normally, this is set to the number of halfwords in the last instruction decoded. |
| 34–35 | Condition code |
| 36–39 | Program mask<br>36 A value of 1 will cause an interrupt on fixed-point overflow.<br>37 A value of 1 will cause an interrupt on decimal overflow.<br>38 A value of 1 will cause an interrupt on exponent underflow.<br>39 A value of 1 will cause an interrupt on a significance exception. |
| 40–63 | Address of next instruction |

# Appendix D

# Errors and Their Causes

This appendix contains a short discussion of the common causes of the following types of errors:

- Addressing exception
- Data exception
- Decimal-overflow exception
- Decimal-divide exception
- Fixed-point overflow exception
- Fixed-point divide exception
- Operation exception
- Protection exception
- Specification exception

The comments here on each type of error are not comprehensive. The reader should consult the IBM *Principles of Operation Manual* for more details. A table summarizing the errors that can occur during the execution of each type of instruction is included at the end of this appendix.

1. *Addressing exception.* This error results when an attempt is made to reference an address outside the limits of the actual memory. For example, if R1 contained 00A2FC04 and the highest address of an actual word of memory were 07FFFC, then

```
L       2,0(1)
```

would cause an addressing exception. The usual cause of this error is inadvertent destruction of the contents of a base or index register (or failure to initialize a base or index register properly). For example, if the following routine were used to initialize all entries in a table to the value 100000, an addressing exception might occur.

```
         LA      2,TABLE
         SR      3,3
         L       4,=F'100000'
         L       5,NUMENT
*
LOOP     ST      4,0(4,2)
         LA      3,4(3)
         BCT     5,LOOP
         .
         .
         .
NUMENT   DC      F'100'          # OF ENTRIES
```

In this case, a typing error was probably responsible for

```
LOOP     ST      4,0(4,2)
```

which should have been

```
LOOP     ST      4,0(3,2)
```

Since the address of TABLE would be offset by 100000, the result might well be an address beyond the limits of the memory of the machine.

2. *Data exception.* This error is normally caused by an attempt to manipulate a field that is expected to contain a valid packed-decimal number but actually contains something else. For example, if

   01*23

   were the first five characters on a record, then

```
XREAD   CARD,80
PACK    INVAL(4),CARD(5)
AP      TOTAL, INVAL(4)
```

   would result in a data exception. In this case, the PACK would leave 0001C23F in INVAL. Since this is not a valid packed-decimal value, the attempt to add it to TOTAL will result in an error.

3. *Decimal-overflow exception.* A decimal overflow is usually the result of performing a decimal arithmetic instruction when the result cannot be represented in the receiving field. For example, if an input record contained

   996

   in the first three positions, then

```
        XREAD  CARD,80
        PACK   TESTAVG(2),CARD(3)
        AP     TESTAVG(2),=P'5'
        MVO    RESULT,TESTAVG(1)
* THE LAST 2 INST. ARE DESIGNED
* TO ROUND THE SCORE TO THE NEAREST
* VALUE IN THE RANGE 0-99
        .
        .
        .
TESTAVG DS     PL2
RESULT  DC     PL2'0'
```

would result in an overflow (since 996 + 5 = 1001, which cannot be represented in a two-byte field).

4. *Decimal-divide exception.* This error occurs on a DP when the quotient is too large to be represented in the allotted space or when an attempt is made to divide by zero. For example, if NUMIND contained 002C and TOTAL contained 00200C, then

```
        DP     TOTAL,NUMIND
```

would cause a decimal-divide exception (since 100 cannot be represented in one byte—the length of the quotient).

5. *Fixed-point overflow exception.* This error occurs when the result of an arithmetic operation cannot be represented in a 32-bit word. For example, if R1 contained 80000000, then

```
        LPR    2,1
```

would cause an error. (The machine cannot complement the smallest negative value.) Similarly,

```
        S      1,=F'10'
```

will cause an error, since the result is less than the smallest number that can be represented in one word.

6. *Fixed-point divide exception.* This error is most often caused by an attempt to divide by 0. However, it can also result when the quotient cannot be represented in 32 bits; normally, this would be caused by failure to clear the even register of the pair. For example,

```
        L      3,TOTAL
        D      2,NUM
```

could cause an error. (R2 should be zeroed first to assure the correct

result.) Another cause of a fixed-point divide exception is an attempt to convert a large decimal number to binary with a CVB. For example, if NUM contained 123456789012345F, then

```
        CVB     0,NUM
```

would result in an error (since the result cannot be represented in one word).

7. *Operation exception.* This error results from an attempt to execute a value in memory that does not represent a valid instruction. There are several common causes:

   a. If a constant is included in the middle of a routine, an operation error normally results. For example,

```
        L       0,RESULT
        A       0,=F'1'
        ST      0,RESULT
RESULT  DS      F
        B       RETURN
```

   will probably cause an operation exception, since the left byte of the result will probably be 00, which is an invalid operation code.

   b. If a section of a program is altered during execution, an operation exception can result. For example, if the following code were executed, an operation exception would result:

```
* INITIALIZE TABLE
        LM      0,3,=A(0, TABLE,4, TABLE+400)
ZEROIT  ST      0,0(1)
        BXLE    1,2,ZEROIT
        B       GO
TABLE   DS      100F
*
GO      LA      1,TABLE
          .
          .
          .
```

   Here, the instruction at GO would be altered to 00000000 before being executed.

   c. If a branch address is incorrect, an operation exception often results. Thus, if

```
        BC      B'1111',14
```

   were used rather than

```
        BCR     B'1111',14
```

an operation exception might result (if the value at location 14 were not a valid instruction).

8. *Protection exception.* This error is caused by the execution of an instruction that accesses or alters an area in memory outside the limits of the program. Normally, such an error results from an unexpected value in either an index or a base register. If such an error occurs, do the following:

   - Look in memory to make sure that the instruction causing the error matches the generated code in the assembler listing. (The instruction might have been altered during execution.)
   - Look at the generated base and index registers. (If you failed to drop a register, these registers might not be what you expected.)

   These two steps should at least allow you to detect rapidly which register contains the incorrect value.

9. *Specification exception.* By far the most common cause of a specification exception is a failure to observe a boundary alignment. This can result from a simple error such as:

```
        L       1, STARTVAL
        .
        .
        .
WORD1   DS      F
HEADER  DC      C'0***PAGE HEADER***'
*
STARTVAL DS     CL4
```

   Here STARTVAL is not on a fullword boundary, so a specification error will result. More frequently, however, specification exceptions are caused by an unexpected value in an index register. In this case, as with protection and addressing exceptions, you can determine which register is invalid by examining the instruction in memory and the contents of the appropriate registers.

## ERRORS OCCURRING DURING EXECUTION OF SPECIFIC INSTRUCTIONS

The meanings of the column headers are as follows:

| | | | |
|---|---|---|---|
| A | Addressing exception | FD | Fixed-point divide exception |
| D | Data exception | FO | Fixed-point overflow exception |
| DO | Decimal-overflow exception | P | Protection exception |
| DD | Decimal-divide exception | S | Specification exception |

| *Mnemonic* | *A* | *D* | *DO* | *DD* | *FD* | *FO* | *P* | *S* |
|---|---|---|---|---|---|---|---|---|
| A | X | | | | X | | X | X |
| AH | X | | | | X | | X | X |
| AL | X | | | | | | X | X |
| ALR | | | | | | | | |
| AP | X | X | X | | | | X | |
| AR | | | | | X | | | |
| BAL | | | | | | | | |
| BALR | | | | | | | | |
| BC | | | | | | | | |
| BCR | | | | | | | | |
| BCT | | | | | | | | |
| BCTR | | | | | | | | |
| BXH | | | | | | | | |
| BXLE | | | | | | | | |
| C | X | | | | | | X | X |
| CH | X | | | | | | X | X |
| CL | X | | | | | | X | X |
| CLC | X | | | | | | X | |
| CLCL | X | | | | | | X | X |
| CLI | X | | | | | | X | |
| CLM | X | | | | | | X | |
| CLR | | | | | | | | |
| CP | X | X | | | | | X | |
| CR | | | | | | | | |
| CVB | X | X | | | | X | X | X |
| CVD | X | | | | | | X | X |
| D | X | | | | | X | X | X |
| DP | X | X | | X | | | X | X |
| DR | | | | | | X | | X |
| ED | X | X | | | | | X | |
| EDMK | X | X | | | | | X | |
| EX | X | | | | | | X | X |
| IC | X | | | | | | X | |

| *Mnemonic* | *A* | *D* | *DO* | *DD* | *FD* | *FO* | *P* | *S* |
|---|---|---|---|---|---|---|---|---|
| ICM | X | | | | | | X | |
| L | X | | | | | | X | X |
| LA | | | | | | | | |
| LCR | | | | | X | | | |
| LH | X | | | | | | X | X |
| LM | X | | | | | | X | X |
| LNR | | | | | | | | |
| LPR | | | | | X | | | |
| LR | | | | | | | | |
| LTR | | | | | | | | |
| M | X | | | | | | X | X |
| MH | X | | | | | | X | X |
| MP | X | X | | | | | X | X |
| MR | | | | | | | | X |
| MVC | X | | | | | | X | |
| MVCL | X | | | | | | X | X |
| MVI | X | | | | | | X | |
| MVN | X | | | | | | X | |
| MVO | X | | | | | | X | |
| MVZ | X | | | | | | X | |
| N | X | | | | | | X | X |
| NC | X | | | | | | X | |
| NI | X | | | | | | X | |
| NR | | | | | | | | |
| O | X | | | | | | X | X |
| OC | X | | | | | | X | |
| OI | X | | | | | | X | |
| OR | | | | | | | | |
| PACK | X | | | | | | X | |
| S | X | | | | X | | X | X |
| SH | X | | | | X | | X | X |
| SL | X | | | | | | X | X |
| SLA | | | | | X | | | |
| SLDA | | | | | X | | | X |
| SLDL | | | | | | | | X |
| SLL | | | | | | | | |
| SLR | | | | | | | | |
| SP | X | X | X | | | | X | |
| SPM | | | | | | | | |
| SR | | | | | X | | | |
| SRA | | | | | | | | |
| SRDA | | | | | | | | X |

| *Mnemonic* | *A* | *D* | *DO* | *DD* | *FD* | *FO* | *P* | *S* |
|---|---|---|---|---|---|---|---|---|
| SRDL | | | | | | | | X |
| SRL | | | | | | | | |
| SRP | X | X | X | | | | X | |
| ST | X | | | | | | X | X |
| STC | X | | | | | | X | |
| STCM | X | | | | | | X | |
| STH | X | | | | | | X | X |
| STM | X | | | | | | X | X |
| TM | X | | | | | | X | |
| TR | X | | | | | | X | |
| TRT | X | | | | | | X | |
| UNPK | X | | | | | | X | |
| X | X | | | | | | X | X |
| XC | X | | | | | | X | |
| XI | X | | | | | | X | |
| XR | | | | | | | | |
| ZAP | X | X | X | | | | X | |

# Appendix E

# Interrupts and the Supervisor

## INTERRUPTS

The Supervisor is a program that is kept permanently in main storage. The function of this program is to provide a variety of services to user application programs and to handle unusual conditions that could cause the processing of an application program to be temporarily suspended. Since the Supervisor and any application program constitute two distinct programs, processing in the central processing unit (CPU) alternates between the two. The CPU is said to be in the *supervisor state* when the Supervisor is being executed and in the *problem state* when an application program is being executed.

Electronic circuitry, known as the automatic interrupt system, transfers control from an application program to the Supervisor. Such a transfer of control is termed an *interrupt*. Before discussing the precise nature of an interrupt, several preliminary details must be covered.

First, recall that the PSW (Program Status Word) contains pertinent status information about a program, including

- the address of the next instruction to be executed
- the condition code
- the program mask

Some of the other status information contained in the PSW will be covered later in this appendix. However, for the moment it is critical to remember that the PSW keeps track of the next instruction to be executed. Transfer of control to the Supervisor is effected through a complete change of the PSW.

Another background detail is that the Supervisor resides in low storage; that is, it starts at the address 000000. An application program can begin anywhere beyond the end of the Supervisor. This results in the following general picture of main storage:

| | |
|---|---|
| 000000 | Supervisor |
| | User programs |
| | Unused |

There are five types of interrupts on an IBM System/360: I/O, program, external, machine-check, and supervisor-call. (The Sytem/370 includes a sixth type of interrupt. However, its function is well beyond the scope of this discussion.) Of these interrupts, the first four notify the Supervisor of a specific condition that requires action, while the fifth is initiated by the application program to request a service from the Supervisor. Corresponding to each of the five types of interrupts are two doublewords at fixed memory locations. One doubleword of each of these pairs is provided for the storage of an "old" PSW, and the other contains a "new" PSW. The following diagram indicates the locations of these doublewords:

| | |
|---|---|
| 000018 | External old PSW |
| 000020 | Supervisor-call old PSW |
| 000028 | Program old PSW |
| 000030 | Machine-check old PSW |
| 000038 | I/O old PSW |
| | |
| 000058 | External new PSW |
| 000060 | Supervisor-call new PSW |
| 000068 | Program new PSW |
| 000070 | Machine-check new PSW |
| 000078 | I/O new PSW |
| | ⋮ |

Now we can describe the exact sequence of events that occurs when one of the conditions causing an interrupt is encountered. Assume that a condition that will cause one of the five types of interrupts has arisen. Then, the automatic interrupt system performs the following actions:

- The current PSW is stored in the location reserved for the old PSW for that particular type of interrupt.
- The doubleword stored in the location that contains the new PSW for that type of interrupt is loaded as the current PSW.

As an example, suppose that a condition that causes an external interrupt has been encountered. Then,

- The current PSW is stored in the doubleword at 000018, the area marked external old PSW.
- The doubleword at 000058, the area marked external new PSW, becomes the current PSW.

The next instruction address contained in the new PSW, which is activated as a result of the interrupt, is the address of a routine that processes the conditions that may have caused the interrupt. This routine is a part of the Supervisor; hence, control of the CPU has been effectively transferred to the Supervisor, as a result of the interrupt.

If control is to be returned to the application program after the condition that caused the interrupt has been processed, this can be accomplished by making the old PSW (stored as a result of the interrupt) the current PSW again. This would result in the resumption of the processing of the application program at the point where the interrupt occurred. The LPSW (Load PSW) instruction is provided for this purpose. This is one of a class of "privileged" instructions that only the Supervisor can issue. Privileged instructions will be covered more thoroughly later in this appendix.

A partial list of the conditions that can cause each type of interrupt is as follows:

1. An external interrupt is most often generated by a hardware device called a timer. The timer can be set to generate an interrupt after any predetermined time interval. This allows control to be passed to the Supervisor from a program that has exceeded its time limit, perhaps because it is in an infinite loop.
2. A supervisor-call interrupt is generated when an application program issues an

   SVC n (*Supervisor-Call*)

   instruction. The operand n is a nonnegative integer that is stored in the old PSW when the interrupt occurs. A supervisor-call is issued whenever it is necessary to call upon the Supervisor to perform some service. The integer n stored in the old PSW determines what service is to be performed.
3. A program interrupt occurs when an error is detected in an application program. This allows control to be passed to the Supervisor so that a dump can be generated or another required task can be performed. This

type of interrupt includes addressing, protection, etc.

4. A machine-check interrupt indicates a hardware failure.
5. An I/O interrupt signifies that an I/O operation has been completed. This will be covered in more detail later in this appendix.

The following example illustrates how a user might request a service from the Supervisor (such as determining the time or the correct date) and how the Supervisor would honor such a request:

1. The user's program issues an SVC instruction, causing a supervisor-call interrupt. As a result, the current PSW is stored in the doubleword at 000020 and a new PSW is taken from the doubleword at 000060.
2. The address specified in the PSW taken from the doubleword at 000060 is the address of a routine that will do the following:
   a. Save the old PSW (from 000020) and the user's registers.
   b. Determine what service the user wants by examining the operand of the SVC instruction. (Remember, this operand is available in the PSW at 000020.)
   c. Perform the requested service.
   d. Restore the user's registers (except those that can be used to return an answer).
   e. Issue an LPSW instruction to reload the user's PSW. (This causes control to be returned to the user's program.)
3. Processing of the user's program resumes immediately following the SVC instruction.

## STORAGE PROTECTION

At the beginning of this appendix, we indicated that when instructions in the Supervisor are being executed, the CPU is normally in the supervisor state, and when instructions in an application program are being executed, the CPU is in the problem state. Bit 15 of the PSW indicates which state the CPU is in at any given time. If this bit is 0, the CPU is in the supervisor state; if it is 1, the CPU is in the problem state. The sole difference between these two states is that the previously mentioned class of privileged instructions can be executed only when the CPU is in the supervisor state.

The process by which the CPU is correctly switched between the supervisor and problem states is quite simple. The PSW initially assigned to any application program has a 1 in bit 15. If an interrupt occurs, the new PSW loaded to transfer control to the Supervisor has a value of 0 in bit 15, and thus the CPU is automatically switched to the supervisor state. For the Supervisor to return control to an application program, an LPSW must be

issued to load the old PSW associated with that program. This old PSW, of course, contains a 1 in bit 15, and so the CPU is switched back to the problem state with the execution of this instruction.

The previous discussion should make it clear that the user must depend on the Supervisor to perform any service that requires the use of privileged instructions. One such service provided by the Supervisor is storage protection.

The main storage of an IBM 360/370 is divided into 2K (or 2,048-byte) blocks. A five-bit protection key is associated with each block of storage. This key can be altered only by the execution of the privileged instruction SSK (Set Storage Key). The current PSW contains a four-bit protection key. Whenever the execution of an instruction in any program would alter an area in storage, the protection key in the PSW is matched against the four high-order bits of the protection key for that block of storage. If these keys do not match, a protection exception (a particular type of program interrupt) occurs. This protection against alteration is called *store protection.*

A block may be protected against being read as well as against being altered. Such protection is called *store and fetch protection.* If the fifth bit (the low-order bit) of the protection key for a block is 0, the block is protected against alteration only. If this bit is 1, the block is protected against read requests as well as alteration.

The above discussion requires one amendment: If the protection key in the PSW is 0000, no matches against storage protection keys are performed. A PSW with a protection key of 0000 should be current only when the CPU is in the supervisor state. Hence, the Supervisor, and the Supervisor alone, is executed under a protection key of 0000.

Storage protection is essential to the maintenance of the role of the Supervisor. To illustrate this, suppose that storage protection did not exist. Then, a user could write a program that would do the following:

1. Alter the areas in storage where the new PSWs for interrupts are stored. (This could be done so as to change the next instruction addresses in these PSWs to addresses of instructions in the user program.)
2. Generate an interrupt.

This interrupt would transfer control back to the user program, rather than to an interrupt routine in the Supervisor. Furthermore, the user program would now be executed with the CPU in the supervisor state. Thus, the user would gain unrestricted use of the machine. Sections of the Supervisor could be wiped out, and general chaos could result.

It should, at this point, be clear to the reader that, through the combined effects of storage protection and the distinction between the problem and supervisor states, the role of the Supervisor is rigidly maintained.

In the simplest situation, when the Supervisor and only one application program are in storage, the sole function of storage protection is to protect

the Supervisor against errors in the application program. This, however, is not the normal situation. Since the execution of a program must frequently be suspended to await the completion of I/O operations, it is often desirable to allow several application programs to reside in storage simultaneously. Then, when the execution of one program must be suspended, control can be turned over to another program for a time. This is called *multiprogramming*, and it is practiced extensively on most large computers.

In a multiprogramming environment, storage protection must secure each program from errors that can occur in the others. To provide this protection, the Supervisor is programmed to perform the following functions:

- When a program is loaded into storage, an unused protection key must be found and assigned to all the storage blocks to be used by that program. Since the Supervisor operates with the key 0000, the keys 0001 through 1111 (15 in all) are available for assignment to application programs.
- When execution of a program is terminated, the protection key and storage blocks used by that program must be freed for reallocation.

Storage protection is controlled by the Supervisor through the use of two privileged instructions. The SSK (Set Storage Key) instruction allows the five-bit key on any block to be set to any value, and the ISK (Insert Storage Key) instruction allows the storage key for a storage block to be retrieved for examination. These instructions, as well as the other privileged instructions, will never be used unless a programmer is actually working on the coding of a Supervisor. However, a rudimentary understanding of their functions should give the reader some insight into the interaction that takes place between the Supervisor and application programs.

## I/O OPERATIONS

A brief, general discussion of what is involved in an I/O operation is presented in this section. The fact that these operations often require time intervals equivalent to the execution of thousands of instructions presents problems that should be understood. The interested reader is urged to consult the IBM System/360 or System/370 Principles of Operation Manual for further details about I/O operations.

As a prelude to this discussion, it will be necessary to distinguish between some of the major hardware subsystems of an IBM System/360/370. For this purpose, Figure E-1 depicts the basic machine broken down into a central processing unit (CPU), main storage, channels, control units, and specific devices.

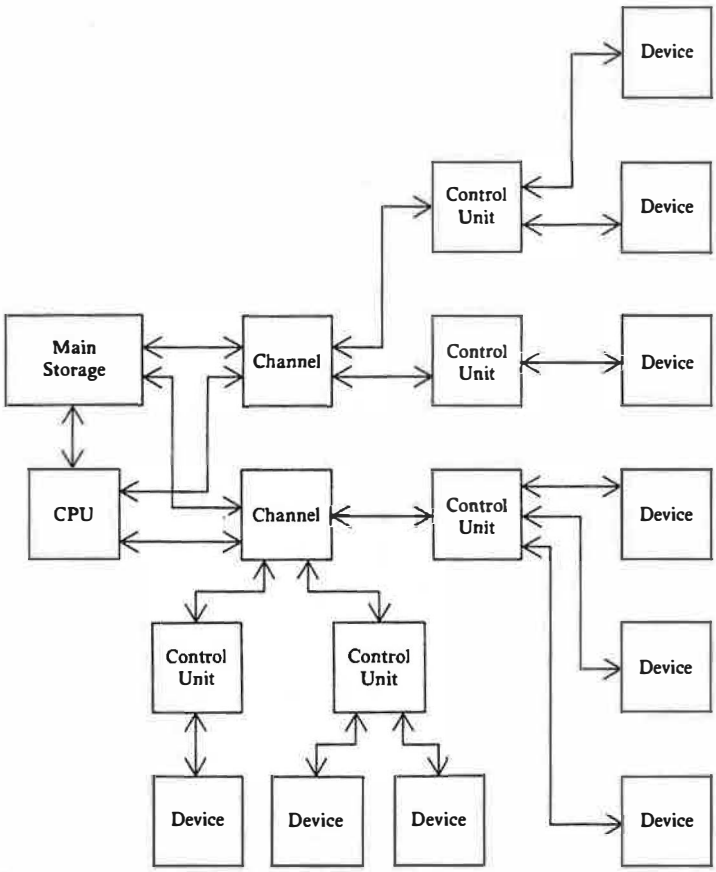



**Figure E-1**

The execution of application programs and the Supervisor takes place in the CPU. The channels are themselves small computers that supervise I/O operations. The fact that channels are separate computers makes it possible for a channel and a CPU to operate simultaneously on different tasks. Thus, the processing of user programs can take place in the CPU while the channels are managing the transfer of data to and from I/O devices through the control units. This potential for overlapping instruction processing and I/O processing is very important. It is the responsibility of the Supervisor to utilize this capability while managing I/O requests from application programs. Some details of how this is accomplished are presented next.

A channel, like any other computer, executes programs. Such a program—called a *channel program*—must be constructed in main storage before any request to initiate an I/O operation is issued. The instructions in a channel program are called *channel command words* (CCWs). Each CCW occupies one doubleword of storage. A channel program, then, is a sequence of CCWs that must be executed by the channel to cause an I/O operation to be performed. For example, a channel program for a print operation might consist of two CCWs—one to cause the printer to skip to the top of the next page and another to cause a line to be printed.

The format and rules for the construction of CCWs can be found in the IBM *Principles of Operation Manual*. Since the types of operations that can be performed vary with each I/O device, it is necessary to consult the manual giving the physical characteristics of a particular device before attempting to write a channel program to initiate an I/O operation on that device.

To initiate an I/O operation (that is, to actually communicate to a channel that a task is to be performed), the following three steps must be taken:

1. A channel program must be constructed in an area in main storage.
2. The word at address 000048, known as the *channel address word* (CAW), must be set up such that the following are true:
   a. Bits 0–3 contain a protection key. This key will be matched against the key of any main storage block involved in a transfer of data during the I/O operation.
   b. Bits 4–7 are 0000.
   c. Bits 8–31 contain the address of the channel program to be initiated.
3. A Start I/O (SIO) instruction must be issued. This instruction has an operand that must contain the information required to designate the particular channel and I/O device to perform the operations specified in the channel program.

The first step is usually performed by the user program or by a routine written by a systems programmer and called by the user program. The next two steps must be performed by the Supervisor because

- the CAW is in a main storage block that is protected from the user program
- the SIO instruction is a privileged instruction

When the SIO instruction is issued, the information required to initiate the operation is passed to the channel. Execution of this instruction causes the condition code to be set to reflect whether initiation of the operation was successful. The initiation will not be successful if, for some reason, the device is unavailable. If the I/O operation has been initiated, the CPU can be utilized to perform any appropriate action, and an overlap between CPU and channel activity will occur.

As an example, an operation to read a card could be initiated as follows:

1. The user program creates a channel program that will cause one card to be read and the data to be stored in a specified area of main storage.
2. The user program issues an SVC instruction with the appropriate operand to pass control to the I/O handling routine in the Supervisor. It is the responsibility of this routine to start the I/O request and then pass control back to the user program.
3. The Supervisor routine takes the address of the channel program (from a previously agreed-upon register) and the protection key (from the old PSW) and fills in the CAW.
4. The Supervisor routine issues an SIO instruction specifying the correct channel and device.

Suppose that an I/O operation has been initiated through a particular channel. When this operation is completed (successfully or otherwise), it is the responsibility of the channel involved to communicate this fact to the Supervisor. This is accomplished through the generation of an I/O interrupt with the following effects.

- A change in PSWs occurs, just as it would with any interrupt.
- Status information is stored in the doubleword at location 000040, the channel status word (CSW). This information reflects whether the I/O operation was successful.

The routine in the Supervisor that processes I/O interrupts is responsible for passing the status information back to the user program that made the request.

The question of what use will be made of the CPU while an I/O operation is in progress remains unanswered. There are, essentially, three alternatives:

1. If execution of the active user program can be continued while the I/O operation is being performed, control can be passed back to this program via the old PSW. Then, when the I/O interrupt is initiated by the channel, the Supervisor will post a flag in the user program to indicate that the I/O operation has been completed.
2. In a multiprogramming environment, the Supervisor may pass control to another user program.
3. If neither of these alternatives is possible, the Supervisor can load a PSW with a 1 in bit 14. This puts the CPU into the "wait" state (as opposed to the normal "running" state). The CPU will then sit idle until a new PSW goes into effect. This will occur with the next interrupt, which could be the I/O interrupt from the channel.

# Appendix F

# Listing of Structured Programming Macros

```
        MACRO
        COND
.*********************************************************************
.*                                                                   *
.* MACRO:      COND--ATTACH CONDITION TO AN "IF" OR "DO" MACRO.      *
.*                                                                   *
.* FUNCTION:   TO GENERATE AN INSTRUCTION SET WHICH WILL TEST THE    *
.*             CONDITION SPECIFIED BY THE USER.                      *
.*                                                                   *
.* PARAMETERS: CODED AS A LIST OF INSTRUCTIONS AND LOGICAL OPERANDS  *
.*             AS FOLLOWS:                                           *
.*                                                                   *
.*             (INSTRUCTION),LOGICAL-OPERATOR,(INSTRUCTION),ETC...   *
.*                                                                   *
.*             THE LOGICAL OPERATORS ARE AND, OR, ANDIF, AND ORIF.   *
.*                                                                   *
.*             ALSO CAN BE CODED AS "ELSE" WHICH CAN ONLY BE CODED   *
.*             WITHIN AN "IF" MACRO AS LAST OF ALL COND'S WITHIN THE *
.*             "IF" AND MUST NOT BE THE ONLY COND.  IF THE USER DOES *
.*             NOT USE "COND  ELSE" WITHIN AN "IF" AND NONE OF THE   *
.*             COND'S CODED ARE SATISFIED, THE ROUTINE WILL ABEND.   *
.*                                                                   *
.* XREF:       MACROS USED--CPARSE                                   *
.*             MODULES CALLED--NONE                                  *
.*                                                                   *
.* AUTHOR:     DAVID T. CARPENTER.                                   *
.*                                                                   *
.* DATE:       10 OCTOBER 1976.                                      *
.*                                                                   *
.* SEE THE "NIU STRUCTURE MACROS"  WRITEUP FOR FURTHER DOCUMENTATION. *
.*                                                                   *
.*********************************************************************
```

```
         GBLA  &LVLPTR              LEVEL OF MACRO INVOCATION
         GBLA  &CONDEX(50)          STACK OF COND SEQUENCE LABELS
         GBLA  &DOIFEX(50)          STACK OF UNIQUE LABELS PER LEVEL
         GBLB  &ELSE(50)            INDICATOR OF ELSE PROCESSED AT LEVEL
         GBLB  &EXCODE(50)          TYPE OF MACRO AT GIVEN LEVEL
         GBLB  &ERRFLAG             INTERMACRO ERROR INDICATOR
         GBLB  &FIRSTC              INDICATOR OF FIRST $COND PROCESSED
&ERRFLAG SETB  0                    SET &ERRFLAG=OFF
         AIF   (&EXCODE(&LVLPTR) EQ 1).FORIF IF "IF"-->.FORIF
         AIF   ('&SYSLIST(1)' NE 'ELSE').CHKERR  IF "ELSE" NOT PARM
&ERRFLAG SETB  1                    SET &ERRFLAG=ON
         MNOTE 12,'*** USE OF ELSE PARM ON COND WITHIN DO ILLEGAL ***'
         AGO   .CHKERR              GO TO CHKERR
.FORIF   ANOP
         AIF   (&ELSE(&LVLPTR) EQ 0),NOELSE  IF NO ELSE YET-->.NOELSE
         MNOTE 12,'*** PREVIOUS COND ELSE MUST BE LAST OF CONDS ***'
         AGO   .CHKERR              GO TO .CHKERR
.NOELSE  ANOP
         AIF   ('&SYSLIST(1)' NE 'ELSE').CHKERR IF NOT ELSE -->.CHKERR
         AIF   (&FIRSTC EQ 1).BADELSE  IF ELSE IS FIRST $COND-->BADELS
&ELSE(&LVLPTR) SETB  1              SET THE ELSE FLAG ON AT THAT LEVEL
         AGO   .CHKERR              GO TO .CHKERR
.BADELSE ANOP
&ERRFLAG SETB  1                    SET THE &ERRFLAG=ON
         MNOTE 12,'*** COND ELSE AS FIRST COND IS ILLEGAL ***'
.CHKERR  ANOP
         AIF   (&ERRFLAG EQ 1).CHKC  IF &ERRFLAG=ON, GO TO CHKC
         AIF   (&FIRSTC EQ 1).SETC  IF THIS IS THE FIRST $COND-->.SETC
         BC    15,@#EX&DOIFEX(&LVLPTR) BRANCH TO ENDIF OR DO
         EXLBL COND                 GENERATE BRANCH LABEL FROM LAST COND
         AGO   .CHKELSE             GO TO .CHKELSE
.SETC    ANOP
&FIRSTC  SETB  0                    INDICATE FIRST $COND PROCESSED
.CHKELSE ANOP
         AIF   (&ELSE(&LVLPTR) EQ 1).NOMORE IF PARM IS ELSE-->.NOMORE
         AIF   (N'&SYSLIST EQ 1).ISSIMP CHECK FOR SINGLE CONDITION
         CPARSE  &SYSLIST(1),&SYSLIST(2),&SYSLIST(3),&SYSLIST(4),&SYSLIX
               ST(5),&SYSLIST(6),&SYSLIST(7),&SYSLIST(8),&SYSLIST(9),&SX
               YSLIST(10),&SYSLIST(11),&SYSLIST(12),&SYSLIST(13),&SYSLIX
               ST(14),&SYSLIST(15),&SYSLIST(16),&SYSLIST(17),&SYSLIST(1X
               8),&SYSLIST(19),&SYSLIST(20),&SYSLIST(21),&SYSLIST(22),&X
               SYSLIST(23),&SYSLIST(24),&SYSLIST(25)
         AGO   .NOMORE              GO TO .NOMORE
.ISSIMP  ANOP
         GENCODE &SYSLIST(1),@#EX&CONDEX(&LVLPTR),NOT
         AGO   .NOMORE
.CHKC    ANOP
         AIF   (&FIRSTC EQ 0).NOMORE  IF &FIRSTC NOT ON-->.NOMORE
&FIRSTC  SETB  0                    ELSE SET IT OFF
.NOMORE  ANOP
         MEND
```

```
         MACRO
         CPARSE
.* ******************************************************************
.*
.*   MACRO:      'CPARSE'
.*
.*   FUNCTION:   TO GENERATE TESTING AND BRANCHING CODE IMPLEMENTING
.*               THE 'COND' MACRO.
.*
.*   OPERANDS:   BEGINNING AND ENDING WITH SIMPLE CONDITIONS, THE
.*               OPERAND LIST CONSISTS OF SIMPLE CONDITIONS AND
.*               LOGICAL OPERATORS APPEARING IN TURNS.
.*               FOR FULL INFORMATION ABOUT SIMPLE CONDITIONS AND
.*               LOGICAL OPERATIONS, CONSULT 'CODING OF CONDITIONS'
.*               IN USER'S MANUAL.
.*
.*   XREF:       MACROS USED - 'GENCODE'
.*
.*   AUTHOR:     NAIPING LEE.
.*
.*   DATE:       24 OCT 1976
.*
.* ******************************************************************
         GBLB  &ERRFLAG            FLAG WHEN ON, MEANS ERROR OCCURRED
         GBLA  &LVLPTR             PTR TO CURRENT LEVEL
         GBLA  &CONDEX(50)         STACK CONTAINING LABEL SUFFIX OFNEXT -
                                   COND SEGMENT
         GBLA  &N1                 SUFFIX # TO DISTINGUISH 'LO' LABEL
         GBLA  &N2                 SUFFIX # TO DISTINGUISH 'NH' LABEL
         GBLA  &N3                 SUFFIX # TO DISTINGUISH 'HO' LABEL
         GBLA  &N4                 SUFFIX # TO DISTINGUISH 'CD' LABEL
         LCLB  &LOFLAG             FLAG, WHEN ON, INDICATES PREVIOUS    -
                                   LOGICAL OPR IS 'AND'
         LCLB  &NHFLAG             FLAG, WHEN ON, INDICATES OR IN       -
                                   CURRENT LOW LEVEL
         LCLB  &HOFLAG             FLAG, WHEN ON, LAST HIGH LEVEL IS    -
                                   'ENDIF'
         LCLB  &ENDFLAG            FLAG, WHEN ON, INDICATES END OF PARMS
         LCLA  &CNTR               POINTER TO CPARSE PARM BEING PROCESSD
         LCLA  &LOSTPTR            STACK PTR OF &LOSTACK
         LCLA  &LOSTACK(6)         STACK OF LO LABELS EQU NEXT HO
         LCLA  &NHSTPTR            STACK PTR OF &NHSTACK
         LCLA  &NHSTACK(6)         STACK OF NH LABELS EQU NEXT CD
.*
&CNTR    SETA  1                   POINT CNTR TO 1ST PARAMETER
.*
.QUITEST AIF   (&ERRFLAG).CPREXIT   IF ERRFLAG OR
         AIF   (NOT &ENDFLAG).CHKCNTR   ENDFLAG IS ON
.CPREXIT MEXIT                          THEN MEXIT
.*
.CHKCNTR AIF   ('&SYSLIST(&CNTR)' EQ '').EVEN#P BRANCH ON EVEN# PARMS
         AIF   ('&SYSLIST(&CNTR+1)' EQ '').NULL BRANCH TO PROPERLY PROC
         AIF   ('&SYSLIST(&CNTR+1)' EQ 'AND').AND    PARMS ACCORDING TO
         AIF   ('&SYSLIST(&CNTR+1)' EQ 'OR').OR      TYPE OF CURRENT
         AIF   ('&SYSLIST(&CNTR+1)' EQ 'ANDIF').ANDIF   LOGICAL OPR
         AIF   ('&SYSLIST(&CNTR+1)' EQ 'ORIF').ORIF
         AGO   .OTHER
```

```
.*
.AND      GENCODE &SYSLIST(&CNTR),@#LO&N1,NOT  GENERATE TESTING CODE
          AIF   (&ERRFLAG).INCNTR                SKIP ON ANY ERROR
&LOFLAG   SETB  1                   INDICATE PREVIOUS LOGICAL OPR IS 'AND
          AGO   .INCNTR             GO TO STEP 10
.*
.OR       GENCODE &SYSLIST(&CNTR),@#NH&N2  GENERATE TESTING CODE
          AIF   (&ERRFLAG).INCNTR            SKIP ON ANY ERROR
.*
          AIF   (NOT &LOFLAG).SETF2  BRANCH IF NO LO LABEL TO BE GENED
@#LO&N1   EQU   *
&N1       SETA  &N1+1               UPDATE LO SUFFEX # N1
&LOFLAG   SETB  0                   TURN OFF LOFLAG
.*
.SETF2    ANOP
&NHFLAG   SETB  1                   TURN ON NHFLAG
          AGO   .INCNTR             GO TO STEP 10
.*
.ANDIF    GENCODE &SYSLIST(&CNTR),@#HO&N3,NOT  GENERATE TESTING CODE
          AIF   (&ERRFLAG).INCNTR                SKIP ON ANY ERROR
.*
          AIF   (NOT &LOFLAG).AF2TEST  BRANCH IF NO LO LABEL TO BE GENED
&LOSTPTR  SETA  &LOSTPTR+1          INCREMENT LO STACK PTR BY 1
&LOSTACK(&LOSTPTR)  SETA  &N1       STACK LO LABEL SUFFIX # TO BE GENED
&N1       SETA  &N1+1               UPDATE LO SUFFEX # N1
&LOFLAG   SETB  0                   TURN OFF LOFLAG
.*
.AF2TEST  AIF   (NOT &NHFLAG).SETF3  BRANCH IF NO NH LABEL TO BE GENED
@#NH&N2   EQU   *
&N2       SETA  &N2+1               UPDATE NH SUFFIX # N2
&NHFLAG   SETB  0                   TURN OFF NHFLAG
.*
.SETF3    ANOP
&HOFLAG   SETB  1                   TURN ON HOFALG
          AGO   .INCNTR             GO TO STEP 10
.*
.ORIF     GENCODE &SYSLIST(&CNTR),@#CD&N4  GENERATE TESTING CODE
          AIF   (&ERRFLAG).INCNTR   SKIP ON ANY ERROR
.*
          AIF   (NOT &LOFLAG).OF2TEST  BRANCH IF NO LO LABEL TO BE GENED
@#LO&N1   EQU   *
&N1       SETA  &N1+1               UPDATE LO SUFFEX # N1
&LOFLAG   SETB  0                   TURN OFF LOFLAG
.*
.OF2TEST  AIF   (NOT &NHFLAG).OF3TEST  BRANCH IF NO NH LABEL TO BE GENED
&NHSTPTR  SETA  &NHSTPTR+1          INCREMENT NH STACK PTR BY 1
&NHSTACK(&NHSTPTR)  SETA  &N2       STACK NH LABEL SUFFIX # TO BE GENED
&N2       SETA  &N2+1               UPDATE NH SUFFIX # N2
&NHFLAG   SETB  0                   TURN OFF NHFLAG
.*
.OF3TEST  AIF   (NOT &HOFLAG).INCNTR  BRANCH IF NO HO LABEL TO GENED
.OFLOLP   AIF   (&LOSTPTR EQ 0).OFGENHO BRANCH ON END OF STACKED LOLABEL
@#LO&LOSTACK(&LOSTPTR)   EQU   *
&LOSTPTR  SETA  &LOSTPTR-1             DECREMENT STACK POINTER BY 1
          AGO   .OFLOLP                LOOP BACK TO TEST
```

```
.OFGENHO ANOP
@ #HO&N3  EQU   *
&N3       SETA  &N3+1                UPDATE HO LABEL SUFFIX # N3
&HOFLAG   SETB  0                    TURN OFF HOFLAG
          AGO   .INCNTR              GO TO STEP 10
.*
.NULL     GENCODE &SYSLIST(&CNTR),@ #EX&CONDEX(&LVLPTR),NOT
          AIF   (&ERRFLAG).INCNTR    SKIP ON ANY ERROR
.*
          AIF   (NOT &LOFLAG).NF2TEST  BRANCH IF NO LO LABEL TO BE GENED
&LOSTPTR  SETA  &LOSTPTR+1           INCREMENT LO STACK PTR BY 1
&LOSTACK(&LOSTPTR)  SETA  &N1        STACK LO LABEL SUFFIX # TO BE GENED
&N1       SETA  &N1+1                UPDATE LO SUFFEX # N1
&LOFLAG   SETB  0                    TURN OFF LOFLAG
&HOFLAG   SETB  1                    TRUN ON HOFLAG
.*
.NF2TEST  AIF   (NOT &NHFLAG).NF3TEST  BRANCH ON NO NH LABEL TO BE GENED
&NHSTPTR  SETA  &NHSTPTR+1           INCREMENT NH STACK PTR BY 1
&NHSTACK(&NHSTPTR)  SETA  &N2        STACK NH LABEL SUFFIX # TO BE GENED
&N2       SETA  &N2+1                UPDATE NH SUFFIX # N2
&NHFLAG   SETB  0                    TURN OFF NHFLAG
.*
.NF3TEST  AIF   (NOT &HOFLAG).NHLOOP
          B     *+8
.NLOLOOP  AIF   (&LOSTPTR EQ 0).NGENHO BRANCH ON END OF STACKED LO LABEL
@ #LO&LOSTACK(&LOSTPTR)   EQU   *
&LOSTPTR  SETA  &LOSTPTR-1              DECREMENT STACK POINTER BY 1
          AGO   .NLOLOOP                LOOP BACK TO TEST
.NGENHO   ANOP
@ #HO&N3  B     @ #EX&CONDEX(&LVLPTR)
&N3       SETA  &N3+1                UPDATE HO LABEL SUFFIX # N3
&HOFLAG   SETB  0                    TURN OFF HOFLAG
.*
.NHLOOP   AIF   (&NHSTPTR EQ 0).GENCD BRANCH ON END OF STACKED NH LABELS
@ #NH&NHSTACK(&NHSTPTR)   EQU   *
&NHSTPTR  SETA  &NHSTPTR-1              DECREMENT STACK POINTER BY 1
          AGO   .NHLOOP              LOOP BACK TO TEST
.GENCD    ANOP
@ #CD&N4  EQU   *
&N4       SETA  &N4+1                UPDATE CD LABEL SUFFIX # N4
&ENDFLAG  SETB  1                    INDICATE END OF PROCESSING
          AGO   .INCNTR              GO TO STEP 10
.*
.OTHER    MNOTE 12,'*** ERROR: INVALID LOGICAL OPERATER OCCURRED AFTER P-
                ARM &CNTR ***'
&ERRFLAG  SETB  1                    SET ON ERROR FLAG
          AGO   .INCNTR              GO TO STEP 10
.*
.EVEN#P   MNOTE 12,'*** ERROR: UNBALANCED (EVEN) NUMBER OF PARAMETERS **-
                *'
&ERRFLAG  SETB  1                    SET ON ERROR FLAG
.*
.INCNTR   ANOP
&CNTR     SETA  &CNTR+2              UPDATE PTR TO CURRENT PARMS
          AGO   .QUITEST             GO TO STEP 2
        MEND
```

```
         MACRO
         DO    &WHILE=
.*****************************************************************
.*                                                               *
.*  MACRO:  DO                                                   *
.*                                                               *
.*  FUNCTION:  THE DO MACRO FORMS THE INITIAL DELIMITER FOR A    *
.*      DO-COND-ENDDO MACRO SEQUENCE.  IT PERFORMS THE STACK INITIAL-*
.*      IZATION FUNCTIONS FOR THE SEQUENCE AND GENERATES AN END LABEL.*
.*      IN ORDER TO ACCOMMODATE THE CODING FORMAT FOR THE IBM CONCEPT *
.*      14 MACROS, ANY ARGUMENTS CODED WITH THE DO MACRO ARE PASSED  *
.*      TO A GENERATED COND.                                         *
.*                                                               *
.*  PARAMETERS:                                                  *
.*                                                               *
.*     &WHILE=  A CONDITION IS CODED WITH THIS PARAMETER WHICH IS *
.*              PASSED TO A GENERATED COND.                      *
.*                                                               *
.*  XREF:  MACROS USED - PUSHNEST, EXLBL.                        *
.*                                                               *
.*****************************************************************
         GBLB  &FIRSTC            FLAG INDICATING START OF SEQUENCE
         AIF   (&FIRSTC EQ 0).DOK IF NOT ON PROCEED NORMALLY
         MNOTE 12,'***ERROR: DO OCCURS IMMEDIATELY AFTER DO OR IF***'
         AGO   .END
.DOK     ANOP
&FIRSTC  SETB  1                  TURN ON &FIRSTC
         PUSHNEST DO              INITIALIZE STACKS
         EXLBL DOIF               GENERATE THE DO LABEL
         AIF   (N'&SYSLIST EQ 0 AND '&WHILE' EQ '').END IF NO ARGS EXIT
         AIF   ('&WHILE' EQ '').MULTARG  MULTIPLE ARGS GIVEN
         COND  &WHILE             PASS ARGS TO COND
         AGO   .END               THEN LEAVE
.MULTARG COND &SYSLIST(2),&SYSLIST(3),&SYSLIST(4),&SYSLIST(5),         X
               &SYSLIST(6),&SYSLIST(7),&SYSLIST(8),&SYSLIST(9),        X
               &SYSLIST(10),&SYSLIST(11),&SYSLIST(12),&SYSLIST(13),    X
               &SYSLIST(14),&SYSLIST(15),&SYSLIST(16),&SYSLIST(17),    X
               &SYSLIST(18),&SYSLIST(19),&SYSLIST(20),&SYSLIST(21),    X
               &SYSLIST(22),&SYSLIST(23),&SYSLIST(24),&SYSLIST(25),    X
               &SYSLIST(26)
.END     MEND


         MACRO
         ELSE
.*****************************************************************
.*                                                               *
.*  MACRO:  ELSE                                                 *
.*                                                               *
.*  FUNCTION - ELSE ACCOMMODATES THE CODING FORMAT OF THE        *
.*             IBM CONCEPT-14 IF-ELSE-ENDIF MACRO FORMAT.        *
.*                                                               *
.*****************************************************************
         COND ELSE
         MEND
```

```
         MACRO
         ENDDO
.*********************************************************************
.*                                                                   *
.*  MACRO:  ENDDO                                                    *
.*                                                                   *
.*  FUNCTION:  THE ENDDO MACRO FORMS THE ENDING DELIMITER FOR A      *
.*      DO-COND-ENDDO MACRO SEQUENCE.  IT GENERATES AN END LABEL     *
.*      AND DECREMENTS THE STACKS POINTER, CLEARING THE STACKS FOR   *
.*      THIS SEQUENCE.                                               *
.*                                                                   *
.*  PARAMETERS:  NONE.                                               *
.*                                                                   *
.*  XREF:  MACROS USED - EXLBL.                                      *
.*                                                                   *
.*********************************************************************
         GBLB  &EXCODE(50)        THE STACK FOR $IF OR $DO ID
         GBLA  &LVLPTR            THE STACKS INDEX
         GBLA  &DOIFEX(50)        THE $DO OR $IF END LABEL STACK
         GBLB  &FIRSTC            INDICATOR OF SEQUENCE START
         AIF   (&LVLPTR GT 0).CHKF  CHECK INVALID STACK LEVEL
         MNOTE 12,'***ERROR: UNMATCHED ENDDO***'
         AGO   .END
.CHKF    AIF   (&FIRSTC EQ 0).EOK  IF NOT ON PROCEED NORMALLY
         MNOTE 12,'***ERROR: ENDDO IMMEDIATELY FOLLOWS DO OR IF***'
&FIRSTC  SETB  0                  TURN OFF &FIRSTC
         AGO   .DECR
.EOK     B     @#EX&DOIFEX(&LVLPTR)  BRANCH BACK TO $DO
         EXLBL COND               GENERATE END LABEL
         AIF   (&EXCODE(&LVLPTR) EQ 0).DECR  CHECK INVALID MATCH
         MNOTE 12,'***ERROR: ENDDO PAIRED WITH IF***'
.DECR    ANOP
&LVLPTR  SETA  &LVLPTR-1          DECREMENT STACKS INDEX
.END     MEND


         MACRO
         ENDIF
.*********************************************************************
.*                                                                   *
.*  MACRO:  ENDIF                                                    *
.*                                                                   *
.*  FUNCTION:  ENDIF FORMS THE ENDING DELIMITER FOR A IF-COND-ENDIF  *
.*      MACRO SEQUENCE.  IT GENERATES END LABELS AND A CON-          *
.*      DITIONAL ABEND INSTRUCTION DEPENDING ON THE &ELSE FLAG,      *
.*      WHICH INDICATES THE PRESENCE OF A PRECEDING COND WITH AN     *
.*      ELSE ARGUMENT.  IN ADDITION, THE &ARGS FLAG INDICATES TO     *
.*      ENDIF WHETHER THE IBM CONCEPT-14 FORMAT IS BEING UTILIZED,   *
.*      WHICH ALSO SUPPRESSES THE ABEND GENERATION.  LASTLY, THE     *
.*      ENDIF MACRO DECREMENTS THE STACKS POINTER TO CLEAR THE       *
.*      STACKS FOR THIS SEQUENCE.                                    *
.*                                                                   *
.*  PARAMETERS:  NONE.                                               *
.*                                                                   *
.*  XREF:  MACROS USED - EXLBL                                       *
.*                                                                   *
.*********************************************************************
```

```
         GBLB  &FIRSTC            FLAG TO DETECT START OF SEQUENCE
         GBLB  &ELSE(50)          STACK TO DETECT $COND ELSE PRESENCE
         GBLB  &ARGS(50)          INDICATES SIMPLE IF-ELSE-ENDIF STRUC
         GBLB  &EXCODE(50)        THE STACK FOR $IF OR $DO ID
         GBLA  &LVLPTR            THE STACKS INDEX
         GBLA  &DOIFEX(50)        THE $DO OR $IF END LABEL STACK
         AIF   (&LVLPTR GT 0).CHKF  CHECK INVALID STACK LEVEL
         MNOTE 12,'***ERROR: UNMATCHED ENDIF***'
         AGO   .END
.CHKF    AIF   (&FIRSTC EQ 0).CHKNXT IF NOT ON, PROCEED NORMALLY
         MNOTE 12,'***ERROR: ENDIF IMMEDIATELY FOLLOWS IF OR DO***'
&FIRSTC  SETB  0                  TURN OFF &FIRSTC
         AGO   .DEC
.CHKNXT  AIF   (&ELSE(&LVLPTR) EQ 1).ABCOM  DONT GENERATE ABEND
         AIF   (&ARGS(&LVLPTR) EQ 0).ABND  THEN GENERATE ABEND
         EXLBL COND               GENERATE LABEL
         AGO   .ABCOM             BRANCH TO GET LABEL
.ABND    B     @#EX&DOIFEX(&LVLPTR)  BRANCH AROUND ABEND
         EXLBL COND               GENERATE LABEL
         ABEND 50,DUMP
.ABCOM   AIF   (&EXCODE(&LVLPTR) EQ 1).DECR  THEN MATCH OK
         MNOTE 12,'***ERROR: ENDIF PAIRED WITH DO***'
.DECR    EXLBL DOIF               GENERATE ENDIF LABEL
&ELSE(&LVLPTR) SETB  0            TURN &ELSE OFF
&ARGS(&LVLPTR) SETB  0            TURN OFF &ARGS
.DEC     ANOP
&LVLPTR  SETA  &LVLPTR-1          DECREMENT STACKS INDEX
.END     MEND
```

```
         MACRO
         EXLBL &TYPE
.*********************************************************************
.*                                                                   *
.*  MACRO:  EXLBL                                                    *
.*                                                                   *
.*  FUNCTION:  THE EXLBL MACRO IS AN INTERNALLY INVOKED SUPPORT      *
.*      MACRO.  IT PERFORMS THE OPERATION OF CONDITIONALLY GENERATING *
.*      TWO DIFFERENT TYPES OF END LABELS DEPENDING ON THE ARGUMENT  *
.*      &TYPE.                                                       *
.*                                                                   *
.*  PARAMETERS:                                                      *
.*                                                                   *
.*     &TYPE  INDICATES THE TYPE OF INVOCATION:                      *
.*            DOIF - CAUSES THE GENERATION OF A LABEL FROM THE DOIFEX *
.*                STACK, WHICH IS THE LABEL ASSOCIATED WITH THE ENDIF *
.*                OR DO MACROS.                                      *
.*            COND - CAUSES THE GENERATION OF A LABEL FROM THE CONDEX *
.*                STACK WHICH IS PART OF THE SEQUENCE OF LABELS      *
.*                CARRIED BETWEEN CONDS.  AFTER GENERATION A NEW     *
.*                UNIQUE LABEL IS PLACED ON THE STACK.               *
.*                                                                   *
.*********************************************************************
```

```
         GBLA  &EXGEN              THE LABEL COUNTER
         GBLA  &LVLPTR             INDEX INTO THE STACKS
         GBLA  &DOIFEX(50)         STACK FOR $ENDIF AND $DO LABELS
         GBLA  &CONDEX(50)         STACK FOR $COND END LABELS
         GBLB  &EXCODE(50)         STACK FOR $DO OR $IF TYPE INDICATORS
         AIF   ('&TYPE' NE 'DOIF').GENLBL  THEN WANT CONDEX LABEL
@#EX&DOIFEX(&LVLPTR) EQU  *
         AGO   .END                LEAVE
.GENLBL  ANOP
@#EX&CONDEX(&LVLPTR) EQU  *
&CONDEX(&LVLPTR) SETA &EXGEN       PLACE VALUE OF &EXGEN ON &CONDEX
&EXGEN   SETA  &EXGEN+1            INCREMENT &EXGEN BY 1
.END     MEND


         MACRO
         GENCODE &INST,&LBL,&TYPE
.*********************************************************************
.*                                                                   *
.* MACRO:      GENCODE--GENERATE INSTRUCTION OF COND PARAMETER LIST. *
.*                                                                   *
.* FUNCTION:   TO PARSE THE INSTRUCTION SUBLIST PASSED AND GENERATE  *
.*             THE PROPER CONDITIONAL BRANCH ACCORDING TO PARAMETERS *
.*             PASSED.                                               *
.*                                                                   *
.* PARAMETERS:                                                       *
.*                                                                   *
.*         &INST   THE INSTRUCTION SUBLIST (EXACT ALLOWABLE FORMS    *
.*                 SPECIFIED IN THE "NIU STRUCTURED MACROS" WRITEUP). *
.*                                                                   *
.*         &LBL    LABEL TO BE ATTACHED TO THE CONDITIONAL BRANCH.   *
.*                                                                   *
.*         &TYPE   IS EQUAL TO "NOT" WHEN CODED; SPECIFIES THAT BRANCH*
.*                 TO BE TAKEN IF SPECIFIED CONDITION IS NOT TRUE.   *
.*                                                                   *
.* XREF:       MACROS USED--GETCC                                    *
.*             MODULES CALLED--NONE                                  *
.*                                                                   *
.* AUTHOR:     DAVID T. CARPENTER.                                   *
.*                                                                   *
.* DATE:       10 OCTOBER 1976.                                      *
.*                                                                   *
.* SEE THE "NIU STRUCTURE MACROS"  WRITEUP FOR FURTHER DOCUMENTATION. *
.*                                                                   *
.*********************************************************************
         GBLB  &ERRFLAG            INTERMACRO ERROR FLAG
         GBLB  &LBLFLAG            FLAG INDICATES USER MNEMONIC
         GBLA  &CCVAL              RETURNED CC VALUE FROM GETCC
         LCLA  &CCLOC              LOCATION OF CONDITION IN SUBSTRING
         AIF   (N'&INST EQ 1).ISCC  IF SUBLTRING OF ONE-->.ISCC
         AIF   ('&INST(1)'(1,1) EQ 'C').ISCOMP IF INST COMPARE-->ISCOMP
         AIF   (N'&INST NE 5).CHKFOUR IF NOT 3-OP-->CHKFOUR
         &INST(1) &INST(2),&INST(3),&INST(4)
&CCLOC   SETA  5                   CONDITION IS 5TH OF SUBSTRING
         AGO   .CHKERR             GO TO .CHKERR
.CHKFOUR ANOP
         AIF   (N'&INST NE 4).CHKTRI  IF NOT 2-OP-->CHKTRI
         &INST(1) &INST(2),&INST(3)
```

```
&CCLOC   SETA  4                    CONDITION IS 4TH IN SUBSTRING
         AGO   .CHKERR              GO TO .CHKERR
.CHKTRI  ANOP
         AIF   (N'&INST NE 3).BADLIST  IF NOT 1-OP-->BADLIST
         &INST(1) &INST(2)
&CCLOC   SETA  3                    CONDITION IS 3RD IN SUBSTRING
         AGO   .CHKERR              GO TO .CHKERR
.BADLIST ANOP
         MNOTE 12,'*** IMPROPER NON-COMPARE SUBLIST ***'
&ERRFLAG SETB  1                    SET &ERRFLAG=ON
         AGO   .CHKERR              GO TO .CHKERR
.ISCOMP  ANOP
         AIF   (N'&INST NE 5).CHEKFOR  IF NOT 3-OP-->CHEKFOR
         &INST(1) &INST(2),&INST(3),&INST(5)
&CCLOC   SETA  4                    CONDITION IS 4TH IN SUBSTRING
         AGO   .CHKERR              GO TO .CHKERR
.CHEKFOR ANOP
         AIF   (N'&INST NE 4).BADLST  IF NOT 2-OP-->BADLST
         &INST(1) &INST(2),&INST(4)
&CCLOC   SETA  3                    CONDITION IS 3RD IN SUBSTRING
         AGO   .CHKERR              GO TO .CHKERR
.BADLST  ANOP
         MNOTE 12,'*** IMPROPER COMPARE SUBLIST ***'
&ERRFLAG SETB  1                    SET &ERRFLAG=ON
         AGO   .CHKERR              GO TO .CHKERR
.ISCC    ANOP
&CCLOC   SETA  1                    CONDITION IS THE SUBSTRING
.CHKERR  ANOP
         AIF   (&ERRFLAG EQ 1).ISERR  IF ERROR-->ISERR
         GETCC &INST(&CCLOC)        CONVERT AND CHECK CONDITION VALUE
         AIF   (&LBLFLAG EQ 1).ISLBL   IF USER MEM-->ISLBL
         AIF   ('&TYPE' EQ 'NOT').GENNOT  IF A 'NOT'-->GENNOT
         BC    &CCVAL,&LBL
         MEXIT
.GENNOT  ANOP
         BC    15-&CCVAL,&LBL
         MEXIT
.ISLBL   ANOP
&LBLFLAG SETB  0                    SET &LBLFLAG OFF
         AIF   ('&TYPE' EQ 'NOT').GENNLBL
         BC    &INST(&CCLOC),&LBL
         MEXIT
.GENNLBL ANOP
         BC    15-&INST(&CCLOC),&LBL
         MEXIT
.ISERR   ANOP
         MEND
```

```
         MACRO
         GETCC &COND
.*****************************************************************
.*                                                               *
.* MACRO:      GETCC--RETURN PROPER CC VALUE TO CALLING MACRO.   *
.*                                                               *
.* FUNCTION:   TO VERIFY AND TRANSLATE IF NECESSARY THE SPECIFIED *
.*             USER CONDITION.                                   *
.*                                                               *
.* PARAMETERS:                                                   *
.*                                                               *
.*         &COND   THE SYMBOL SPECIFYING THE USER CONDITION THAT IS *
.*                 TO BE VERIFIED AND TRANSLATED.                *
.*                                                               *
.* XREF:       MACROS USED--NONE                                 *
.*             MODULES CALLED--NONE                              *
.*                                                               *
.* AUTHOR:     DAVID T. CARPENTER.                               *
.*                                                               *
.* DATE:       10 OCTOBER 1976.                                  *
.*                                                               *
.* SEE THE "NIU STRUCTURE MACROS"  WRITEUP FOR FURTHER DOCUMENTATION. *
.*                                                               *
.*****************************************************************
         GBLA  &CCVAL
         GBLB  &LBLFLAG           FLAG INDICATES USER MNEMONIC
         LCLC  &LWK1
         AIF   ('&COND'(1,1) LT '0' OR '&COND'(1,1) GT '9').NOTNUM
         AIF   (K'&COND GT 2).NUMERR
         AIF   (K'&COND EQ 1).NUMOK
         AIF   ('&COND'(1,2) GE '10' AND '&COND'(1,2) LE '15').NUMOK
.NUMERR  ANOP
         MNOTE 12,'*** INVALID NUMERIC CONDITION ***'
         MEXIT
.NUMOK   ANOP
&CCVAL     SETA  &COND
           MEXIT
.NOTNUM  AIF   (K'&COND NE 1).TWOCHAR
&LWK1      SETC  '&COND'
           AGO   .CALCC
.TWOCHAR AIF   (K'&COND NE 2).INVCOND
           AIF   ('&COND'(1,1) NE 'N').OTHERMN
&LWK1        SETC  '&COND'(2,1)
           AGO   .CALCC
.OTHERMN   AIF   ('&COND' EQ 'EQ').BC8
           AIF   ('&COND' EQ 'LT').BC4
           AIF   ('&COND' NE 'LE').TRYGT
&CCVAL       SETA 13
           MEXIT
.TRYGT     AIF   ('&COND' EQ 'GT').BC2
           AIF   ('&COND' NE 'GE').INVCOND
&CCVAL       SETA  11
           MEXIT
.CALCC   AIF   ('&LWK1' NE '0').TRYH
&CCVAL     SETA 1
         AGO   .TSTN
.TRYH    AIF   ('&LWK1' EQ 'P' OR '&LWK1' EQ 'H').BC2
           AIF ('&LWK1' EQ 'L' OR '&LWK1' EQ 'M').BC4
```

```
            AIF ('&LWK1' EQ 'E' OR '&LWK1' EQ 'Z').BC8
              AGO   .INVCOND
.BC8        ANOP
&CCVAL      SETA 8
            AGO   .TSTN
.BC4       ANOP
&CCVAL     SETA 4
           AGO   .TSTN
.BC2      ANOP
&CCVAL    SETA 2
.TSTN     AIF  ('&COND'(1,1) NE 'N').DONE
&CCVAL       SETA  15-&CCVAL
.DONE     MEXIT
.INVCOND ANOP
&LBLFLAG SETB  1                    INDICATE USER MNEMONIC
         MEND



         MACRO
         IF
.*****************************************************************
.*                                                               *
.*  MACRO:  IF                                                   *
.*                                                               *
.*  FUNCTION:  THE IF MACRO FORMS THE BEGINNING DELIMITER FOR A  *
.*      STRUCTURED IF-COND-ENDIF MACRO SEQUENCE.  IT PERFORMS THE *
.*      INITIAL STACK PROCESSING FOR THE SEQUENCE.  IN ADDITION, IN *
.*      ORDER TO ACCOMMODATE THE CODING FORMAT FOR THE IBM CONCEPT-14 *
.*      MACROS, ANY ARGUMENTS CODED WITH THE IF MACRO ARE PASSED TO *
.*      A GENERATED COND.  A FLAG, &ARGS, IS ALSO SET TO INDICATE *
.*      THIS CONDTION.                                           *
.*                                                               *
.*  PARAMETERS:  ARGUMENTS MAY BE PASSED THROUGH &SYSLIST.       *
.*                                                               *
.*  XREF:  MACROS USED - PUSHNEST.                               *
.*                                                               *
.*****************************************************************
         GBLB  &FIRSTC            FLAG TO SIGNAL START OF SEQUENCE
         GBLB  &ARGS(50)          INDICATES SIMPLE IF-ELSE-ENDIF STRUC
         GBLA  &LVLPTR            THE STACKS INDEX
         AIF   (&FIRSTC EQ 0).TURNON IF NOT PROCEED NORMALLY
         MNOTE 12,'***ERROR: IF IMMEDIATELY FOLLOWS IF OR DO***'
         AGO   .END               LEAVE
.TURNON  ANOP
&FIRSTC  SETB  1                  TURN ON &FIRSTC
         PUSHNEST IF              INITIALIZE STACKS
         AIF   (N'&SYSLIST EQ 0).END IF NO ARGS, EXIT
&ARGS(&LVLPTR) SETB  1            TURN ON &ARGS FLAG
         COND  &SYSLIST(1),&SYSLIST(2),&SYSLIST(3),&SYSLIST(4),        X
               &SYSLIST(5),&SYSLIST(6),&SYSLIST(7),&SYSLIST(8),        X
               &SYSLIST(9),&SYSLIST(10),&SYSLIST(11),&SYSLIST(12),     X
               &SYSLIST(13),&SYSLIST(14),&SYSLIST(15),&SYSLIST(16),    X
               &SYSLIST(17),&SYSLIST(18),&SYSLIST(19),&SYSLIST(20),    X
               &SYSLIST(21),&SYSLIST(22),&SYSLIST(23),&SYSLIST(24),    X
               &SYSLIST(25)
.END     MEND
```

```
        MACRO
        PUSHNEST &TYPE
.*****************************************************************
.*                                                               *
.*  MACRO:  PUSHNEST                                             *
.*                                                               *
.*  FUNCTION:  THE PUSHNEST MACRO IS AN INTERNALLY INVOKED SUPPORT *
.*      MACRO WHICH PERFORMS THE INITIAL LABEL STACKING OPERATIONS *
.*      NECESSARY TO ESTABLISH AN IF-COND-ENDIF OR A DO-COND-ENDDO *
.*      SEQUENCE.  THIS INCLUDES STACKING A UNIQUE DOIF END LABEL *
.*      FOR THE ENDIF OR DO MACROS, AND STACKING A LABEL TO BE USED *
.*      BY THE INTERVENING CONDS.  THE TYPE CODE (IF OR DO) IS ALSO *
.*      STACKED TO ALLOW SUBSEQUENT MACRO COMPATIBILITY CHECKING *
.*      DURING ENDIF OR ENDDO PROCESSING.                        *
.*                                                               *
.*  PARAMETERS:                                                  *
.*                                                               *
.*     &TYPE  INDICATES THE TYPE OF INVOCATION.  CAN BE ONE OF THE *
.*            FOLLOWING:                                         *
.*            IF - PUSHNEST INVOKED FROM IF MACRO.               *
.*            DO - PUSHNEST INVOKED FROM DO MACRO.               *
.*                                                               *
.*****************************************************************
        GBLA  &EXGEN              THE LABEL COUNTER
        GBLA  &LVLPTR             THE STACKS INDEX
        GBLA  &CONDEX(50)         THE &COND LABEL STACK
        GBLA  &DOIFEX(50)         THE $DO OR $ENDIF END LABEL STACK
        GBLB  &EXCODE(50)         STACK OF MACRO TYPE CODES:
.*                                  0 = $DO
.*                                  1 = $IF
        AIF   (&LVLPTR LT 50).ADDSTK  IF NOT FULL PROCEED NORMALLY
        MNOTE 12,'***ERROR: NESTING LEVEL EXCEEDS CAPACITY***'
        AGO   .END
.ADDSTK ANOP
&LVLPTR SETA  &LVLPTR+1           INCREMENT &LVLPTR FOR NEXT ENTRY
&DOIFEX(&LVLPTR) SETA  &EXGEN     PUT &EXGEN COUNTER VALUE ON &DOIFEX
&CONDEX(&LVLPTR) SETA  &EXGEN+1   PUT NEXT &EXGEN ON &CONDEX
&EXGEN  SETA  &EXGEN+2            SET UP NEXT UNIQUE VALUE
        AIF   ('&TYPE' EQ 'IF').IFCALL  IF NOT IF PROCESS DO
&EXCODE(&LVLPTR) SETB  0          PUT DO CODE ON &EXCODE
        AGO   .END
.IFCALL ANOP
&EXCODE(&LVLPTR) SETB  1          PUT IF CODE VALUE ON &EXCODE
.END    MEND
```

# Appendix G

# Answers to Nonprogramming Exercises

## Chapter 1 Number Systems and Computer Storage

### *1.2 Binary- or Hexadecimal-to-Decimal Conversion*

| | | | | |
|---|---|---|---|---|
| 1. | a. 3 | c. 30 | e. 7 | g. 375 |
| | b. 23 | d. 59 | f. 15 | h. 7 |
| 3. | a. 15 | c. 3026 | e. 3311 | g. 241 |
| | b. 161 | d. 4096 | f. 239 | h. 294 |

### *1.3 Decimal-to-Binary or -Hexadecimal Conversion*

| | | | | |
|---|---|---|---|---|
| 1. | a. 7C | b. 2A | c. FA0 | d. 1B0 |
| 2. | a. 01111100 | b. 00101010 | c. 111110100000 | d. 000110110000 |

### *1.4 Conversions between Binary and Hexadecimal Representations*

| | | | |
|---|---|---|---|
| 1. | a. 1110 | c. 1011100101110110 | e. 1111111110101011 |
| | b. 0001000011001101 | d. 0100001000010000 | f. 1010101111001101 |

2. a. 16F b. 155 c. A d. F1 e. 5EF f. BCE2

### *1.5 Addition and Subtraction of Binary and Hexadecimal Numbers*

| | | | | |
|---|---|---|---|---|
| 1. | a. 100011 | b. 1011010 | c. 101100 | |
| 2. | a. 10100 | b. 1000 | c. 11111 | |
| 3. | a. 12D7C | b. 9C4F | c. 185D | d. 2DC3 |
| 4. | a. 6484 | b. 250F | c. 4F1F | d. 1520 |

### *1.7 Binary Representation of Integer Numbers*

| | | | |
|---|---|---|---|
| 1. | a. 00000001 | c. FFFFFFFF | e. 000020DC |
| | b. 000000F8 | d. FFFFFFF6 | f. FFFFDF24 |

*1.8 Overflow*

1. a. no b. no c. yes d. no e. yes f. yes g. no

*1.9 General-Purpose Registers and Relative Addressing*

1. a. valid, 0001E0
   b. valid, 08ACD8
   c. valid, 00005C
   d. not in the form D(B)
   e. valid, 000012
   f. valid, 000012
   g. not in the form D(B)
   h. not in the form D(B)

2. a. valid, 08ABD0
   b. valid, 00008C
   c. valid, 000002
   d. valid, 000059
   e. valid, 000059
   f. not valid
   g. valid, 8AB9D
   h. valid, 8AB9D

## Chapter 2 Basic Concepts

*2.2 RR Instructions*

1. a. 1A1F b. 1B2A c. 1AE3 d. 1B00 e. 1AFE

2. a. LR 2,0 c. SR 12,12
   b. AR 15,14 d. LR 3,4

3.

| | *R0* | *R1* | *R6* |
|---|---|---|---|
| a. | not changed | not changed | 001A2F0B |
| b. | not changed | not changed | FFE5EAE4 |
| c. | not changed | FFFFBC0B | not changed |
| d. | not changed | FFFF882D | not changed |
| e. | not changed | 00000000 | not changed |

*2.3 RX Instructions*

1. a. 58F32000 c. 58F20000 e. 58F00018
   b. 58F02000 d. 502ED014 f. 50680004

2. a. L 0,12(1,5)
   b. ST 1,4
   c. L 1,28(1,8)
   d. L 4,4(5,14)
   e. ST 2,12(3,13)

3. a. 000ABC20 b. 000C1F21—error c. 000C1F30
   d. 0016DB21—error

*2.7 The XREAD and XDECI Instructions*

1. 5C 5C F1 F2 F2 C1 F3 2. 5B 7C 7B E7 E9

*2.8 The XPRINT and XDECO Instructions*

C1 40 40 40 40
C1 C1
C2 40 C2 40 C2 40
F1 7D
50 F0
5B 5B E6 D6

*2.10 Multiplication and Division*

| | *R0* | *R1* | *R2* | *R3* |
|---|---|---|---|---|
| a. | not changed | not changed | FFFFFFFF | FFFFFFFC |
| b. | FFFFFFFF | FFFFFFFD | not changed | not changed |
| c. | not changed | not changed | 00000000 | 00000010 |
| d. | not changed | not changed | 00000000 | 0000000C |
| e. | FFFFFFFF | FFFFFFF6 | not changed | not changed |
| f. | 00000000 | 00000002 | not changed | not changed |
| g. | not changed | not changed | 00000000 | 00000028 |
| h. | not changed | not changed | FFFFFFFF | FFFFFFF8 |

| | *R1* | *R2* | *R3* | *R4* | *R5* |
|---|---|---|---|---|---|
| a. | not changed | 00000002 | 00000006 | not changed | not changed |
| b. | not changed | 00000000 | FFFFFFEC | not changed | not changed |
| c. | not changed | 00000014 | 00000000 | not changed | not changed |
| d. | not changed | not changed | not changed | 00000000 | FFFFFFB0 |
| e. | not changed | 00000000 | FFFFFFFB | not changed | not changed |
| f. | not changed | 00000006 | 00000001 | not changed | not changed |
| g. | not changed | not changed | not changed | 00000000 | 0000003C |
| h. | not changed | not changed | not changed | FFFFFFFE | FFFFFFEF |

## Chapter 3 Looping, Subroutines, and More Instructions

*3.2 The BCT and BCTR Instructions*

1. a. 6 b. loops c. 413 d. once e. too many times (that is, R-1 is decremated through negative integers)

*3.3 The BXLE and BXH Instructions*

1. a. 8 b. 4 c. 2. 5 d. 5 e. 6

## Chapter 5 Decimal Arithmetic

*5.2 The PACK and UNPK Instructions*

1. 00 01 2F
2. BA
3. 00 01 23 4F
4. 00 BD FE
5. F1 F2 F3
6. F0 F0 F2 C6
7. FC FD FE
8. F0 F0 F0 D4

*5.3 The Decimal Instructions AP, SP, and ZAP*

1. 01 23 3C
2. 01 23 5C
3. 02 1C
4. 00 10 0D
5. 00 08 0D
6. 00 00 00 0C

*5.4 The Decimal Instructions MP, DP, and CP*

1. 00 08 0C 4.
2. 00 11 7D 5.
3. 00 30 00 0C
4. 2C 00 0C
5. 40 2C 0D
6. 00 5C 00 0C

*5.6 The ED Instruction*

| | *Resulting Pattern Value* | *Character String* |
|---|---|---|
| | 40 F1 F2 F3 | _123 |
| 1. | 40 40 40 40 | ____ |
| 2. | 40 40 F1 F2 | __12 |
| 3. | 40 F1 F2 F3 | _123 |
| 4. | 40 40 40 F0 | ___0 |
| 5. | 40 40 F1 F2 | __12 |
| 6. | 5C F1 F2 F3 | *123 |
| 7. | 5C 5C 5C F0 | ***0 |
| 8. | 5C 5C F1 F2 | **12 |
| 9. | 40 F1 4B F2 F3 | _1.23 |
| 10. | 40 40 40 40 40 | ____ |
| 11. | 40 40 40 F1 F2 | __12 |
| 12. | 40 F1 4B F2 F3 | _1.23 |
| 13. | 40 40 4B F0 F0 | __.00 |
| 14. | 40 40 4B F1 F2 | __.12 |
| 15. | 40 F1 F2 6B F3 F4 F5 4B F6 F7 | _12,345.67 |
| 16. | 40 40 40 40 40 40 F1 4B F2 F3 | ____1.23 |
| 17. | 40 40 40 40 40 40 40 4B F0 F0 | _____.00 |
| 18. | 40 F1 F2 6B F3 F4 F5 4B F6 F7 40 40 40 | _12,345.67__ |
| 19. | 40 40 40 40 40 40 F1 4B F2 F3 40 40 40 | ____1.23__ |

20. 40 40 40 40 40 40 40 4B F0 F0 40 40 40 ———.00——
21. 40 40 40 40 40 F1 F2 4B F3 F4 40 C3 D9 ——12.34_CR

*5.7 The SRP Instruction*

1. 40 00 0C
2. 01 30 0D
3. 00 00 00 3C
4. 00 00 1C
5. 00 02 7C
6. 00 16 80 0C
7. 00 00 00 0C

## Chapter 10 Floating-Point Arithmetic

*10.2 Floating-Point Number Representations*

1. a. 46FE6478
   b. 3E6421A6
   c. 17AE1234
   d. 4EBCDEFA
   e. 7F1234AE
2. a. 52123456789ABCDE
   b. 2BAECBDF12345F1B
   c. 43000AECBDF12345
   d. not possible
   e. 40123456789ABCDE
3. a. $-.478100 * 16^{5}$
   b. $.478100 * 16^{6}$
   c. $-.123456 * 16^{-54}$
   d. $-.ABCDEF * 16^{7}$
   e. $.CDEF01 * 16^{47}$
4. a. $-.478100ABCDEF01 * 16^{5}$
   b. $.47810012345678 * 16^{6}$
   c. $-.123456F12345BC * 16^{-54}$
   d. $-.ABCDEF01234567 * 16^{7}$
   e. $.CDEF01FEDCBA98 * 16^{47}$

*10.4 Conversions between Decimal and Floating-Point Numbers*

*Hexadecimal to Decimal*

a. 2766.07110596
b. 18.037781
c. .99554443
d. .03721619
e. .00233459

*Decimal to Hexadecimal*

a. 2694.5879
b. .FCD3
c. .0288
d. 76.C3F1
e. 270F.FFAA

# Index


Absolute expression, 268–269
Access method, 236
Add decimal instruction, 164–165
Add Halfword instruction, 295
Add instruction, 52–53
Addition, 8, 18, 146–148
Addition of binary and hexadecimal numbers, 8–14
Add Logical instruction, 147–148
Add Logical Register instruction, 147–148
Add Register instruction, 27
Address, 15
Addressability error, 29, 410, 525
Address constant, 101–102, 272
Addressing exception, 29, 410, 525
AD instruction, 401
ADR instruction, 401
AE instruction, 400
AER instruction, 400
AGO instruction, 352
AH instruction, 295
AIF instruction, 352, 367
A instruction, 52
Alignment, 271
AL instruction, 147–148
ALR instruction, 147–148
Ampersand, 47–48
&SYSLIST, 377
&SYSNDX, 354–355
AND Immediate instruction, 279–281
AND instruction, 276–277, 282
AND operation, 275
ANOP instruction, 352–353
AP instruction, 164–165
Apostrophe, 47–48
AR instruction, 27
Arithmetic expression, 351
Arithmetic SET symbols, 360–363
Arithmetic Shift instructions, 288
Assembler, 25
Assembler instructions, 32–33
Assembler program, 25, 31
Asterisk to reference location counter, 134–135
A-type address constant, 101–103, 271
AU instruction, 406
AUR instruction, 406
AW instruction, 406
AWR instruction, 406
AXR instruction, 408

BAL instruction, 96–97
BALR instruction, 100, 322
Base-displacement addresses, 20–23
Base Register, 21, 100
BC instruction, format of, 39–40
BCR (Branch on Condition Register instruction) 34, 41
BCT instruction, 79
BCTR instruction, 79
Bias bit, 393
Binary- or hexadecimal-to-decimal conversion, 3–4
Binary representation of integer numbers, 17–18
Binary search, 196–197
Binary self-defining term, 268
Binary SET symbols, 366
Bits, 15
Blanking out print line, 132
Block diagram, 95
Blocking, 234
Blocking factor, 234
Branch on Condition (BC) instruction, 39–40
Branch on Count instruction, 79
Branch on Count Register instruction, 79
Branch on Index High instruction, 88–89
Branching, 39–41
Branch instruction, 39–41
altering masks in, 280
Branch and Link instruction, 96–97
Branch and Link Register instruction, 100
B-type constant, 271
Buffers, 236
BXH instruction, 88–89
BXLE instruction, 84–87
Byte, 15–16

Calculation of address, 20–23
Card, 42
Carriage control character, 48
Carry digit, 8, 147–148
Case structure, 438–440
CC (Condition Code), 39–40
CD instruction, 401
CDR instruction, 401
CE instruction, 401
Central processing unit (CPU), 533
CER instruction, 401
Channel address word (CAW), 540
Channel command word (CCW), 540
Channel program, 540
Channels, 539–540
Character constant, 46–47
Character expression, 369–370
Character format, 44
Characteristic, 391
Character self-defining term, 267–268

Character SET symbols, 369–371
CH instruction, 294–295
C instruction, 53
CLC instruction, 133
CLCL instruction, 300
Clearing print line, 132
CL instruction, 148
CLI instruction, 129
CLM instruction, 312–313
CLOSE macro instruction, 241, 256
Closing files, 237
CLR instruction, 148
Comment, 32, 34
Compare Decimal instruction, 167–168
Compare Halfword instruction, 294–295
Compare instruction, 53
Compare Logical Character instruction, 133
Compare Logical Characters under Mask instruction, 312–313
Compare Logical Immediate instruction, 129
Compare Logical instruction, 148
Compare Logical Long instruction, 300
Compare Logical Register instruction, 148
Compare Register instruction, 52–53
Conditional assembly, 349–355
Condition code, 39
Constants, 33, 46–48, 101–103, 158, 168–170, 208, 267–274, 293–294, 395–396
Control section, 32, 206–207
Control units, 538–539
Conversion between binary and hexadecimal representations, 6–8
Conversion of character to binary representation, 44–45
Conversion of numbers
  decimal to floating-point, 396
  packed decimal format to binary representation, 181–182
Convert to Binary instruction, 181–182
Convert to Decimal instruction, 182
Count attribute, 371
CP instruction, 167–168
CR instruction, 52–53
CSECT statement, 32, 206–207
C-type constant, 46, 271
CVB instruction, 181–182
CVD instruction, 182
Cylinder, 235

Data Control Block, 238
Data Exception, 164, 526
D(B) address format, 21
DCB macro instruction, 238–239
DC statement, 33, 46–48, 101–102, 158–159, 168–170, 208, 267–274, 293–294, 395–396
DD instruction, 404
DD statement, 251–252
DDR instruction, 404
Debugging tool (XDUMP), 35–36, 418–419
Decimal to binary or hexadecimal conversion, 4–6
Decimal-divide exception, 527
Decimal instruction set, 163–164
Decimal-overflow exception, 164, 526
Decimal self-defining term, 267
DE instruction, 404
DER instruction, 404
Digit selector, 170–171
D instruction, 61–62
Direct-access device, 234
Disk file, 234–236
Displacement, 21
Divide Decimal instruction, 167
Divide instruction, 61–62
Division of numbers by powers of, 2, 289
Documentation standards, 126–127
Doubleword, 16
Do-while structure, 430
DP instruction, 167
DROP statement, 226–228
DS Statement, 38
DSECT statement, 224–228
DTFs, 252–255
  DTFCD, 252–253
  DTFPR, 253–254
  DTFSD, 254–255
D-type constant, 271, 395–396
Dump, 421–427
Duplication factor, 270–271
D(X,B) address format, 21–22

ED instruction, 170–175
Edit algorithm, 197–201
Edit instruction, 170–175
Edit and Mark instruction, 183–184
EDMK instruction, 183–184
EJECT instruction, 109
Encoding of integer numbers, 17–18
END statement, 32–33
EOJ, 256
EQU instruction, 65
Errors
  addressing exceptions, 29, 410
  data exception, 164, 526
  decimal-divide exception, 527
  exponent overflow, 410
  exponent underflow, 410
  fixed-point divide exception, 527
  fixed-point overflow exception, 527
  floating-point divide exception, 410
  operation exception, 409, 528
  protection exception, 29, 410, 529
  significance exception, 410
  specification exception, 29, 529
E-type constant, 395–396
Even/odd pair of register, 58–59, 85
Excess 64 notation, 392
EXCLUSIVE OR Immediate instruction, 279–280
EXCLUSIVE OR instruction, 278–279
EXCLUSIVE OR operation, 275–276
Executable code, 25–26
Executable format, 31
Execute instruction, 301–302
Execution of program, 26
EX instruction, 301–302
Explicit addressing, 21
Exponent overflow exception, 410
Exponent underflow exception, 410

Extended mnemonics, 65–66
Extended-precision operations, 149
External interrupt, 535
External subroutine, 205–213

Field separator, 170
File, 232
Fill character, 170
Fixed-length format, 232
Fixed-point divide exception, 527
Floating-point divide exception, 410
Formats
  RR, 26–28
  RS, 87–88, 286
  RX, 29–30
  SI, 127–129
  SS, 130–131, 160
F-type constant, 33, 271
Fullword, 16

GBLA statement, 361
GBLB statement, 366
GBLC statement, 369
General-purpose register and relative addressing, 20–23
GET macro instruction, 240, 256
Global arithmetic SET symbol, 360–361
Global binary SET symbols, 366
Global character SET symbols, 369
Global SET symbols, 360

Halfwords, 16
  halfword addresses, 16
  halfword boundary, 16
  halfword instructions, 293–295
Hashing, 194–195
HDR instruction, 405
Header (macro), 346
HER instruction, 405
Hexadecimal constants, 168–170
Hexadecimal-to-decimal conversion, 3–4
Hexadecimal numbers, 2
Hexadecimal self-defining term, 268
H-type constant, 271

IC instruction, 77
ICM instruction, 314
If-then-else structure, 430, 435–438
Immediate byte, 128
Implicit address, 35–38
Implied length, 271
Index register, 21–22
Insert Character instruction, 77
Insert Character under Mask Instructions, 314
Insertion of Dollar Sign in Front of Number, 184
Insert Storage Key (ISK) instruction, 538
Instruction, 25–26
Integer addition, 18
Integer subtraction, 18
Integers, binary form, 17–18
Internal subroutines, 95–100
Interrecord gap, 233
Interrupts, 534–536
  causes, 535–536
I/O device, 539
I/O operation, 538–541
ISK (Insert Storage Key), 538

Job Control Language, 25, 251–252
Julian format of date, 332

K′, 371
Keyword macro definition, 377–379

Label, 32
Label records, 233
LA instruction, 69–72
LCDR instruction, 406
LCER instruction, 406
LCLA statement, 361
LCLB statement, 366
LCLC statement, 369
LCR statement, 55
LD instruction, 399
LDR instruction, 399
Left arithmetic shift, 288
Left logical shift, 286
LE instruction, 399
Length attribute, 273
Length code, 130
Length modifier, 271
LER instruction, 399
LH instruction, 294
Linkage conventions, 209–213, 216–217
L instruction, 29–30
Literals, 67, 169–170
LM instruction, 101
LNDR instruction, 406
LNER instruction, 406
LNR instruction, 56
Load Address instruction, 69–72
Load Complement instruction, 55
Loader, 204
Load Halfword instruction, 294
Load instruction, 29–30
Load Multiple instruction, 101
Load Negative instruction, 56
Load Positive instruction, 56
Load Register instruction, 28
Load and Test instruction, 56–57
Local arithmetic SET symbols, 360–361
Local binary SET symbols, 366–367
Local character SET symbols, 369
Locate mode (QSAM), 237
Location counter, 135–135
Logical comparison, 129
Logical expression, 351
Logical operation, 275
Logical record, 232
Loops, 78, 432–434
LPDR instruction, 406
LPER instruction, 406
LPR instruction, 56
LPSW (Load PSW) instruction, 535
LRDR instruction, 409
LRER instruction, 409
LR instruction, 28
LTDR instruction, 399
LTER instruction, 399
LTORG statement, 67
LTR instruction, 56–57

Machine-check interrupt, 536
Macro definition, 345
Macro header, 346
Macro instruction, 345
Macro language, 345
Macro model statement, 346
Macro prototype statement, 346
Macro trailer, 346
Main storage organization, 15–16
Mantissa, 391
Mask, 40, 313

MD instruction, 402
MDR instruction, 402
ME instruction, 402
MEND symbol, 346
MER instruction, 402
Message character, 170–171
MEXIT instruction, 373
MH instruction, 295
M instruction, 59
Mnemonic, 32
MNOTE instruction, 373
Model statement (macro), 346
Move Character instruction, 130–132
Move Immediate instruction, 128
Move Long instruction, 298–300
Move mode (QSAM), 237
Move Numerics instruction, 322–323
Move with Offset instruction, 323–324
Move Zones instruction, 323–324
Moving-head disk, 235–236
MP instruction, 166–167
MR instruction, 58–59
Multiplication of numbers by powers of 2, 288
Multiply Decimal instruction, 166–167
Multiply Halfword instruction, 295
Multiply instruction, 59
Multiply Register instruction, 58–59
Multiprogramming, 538
MVC instruction, 130–132
MVCL instruction, 298–300
MVI instruction, 128
MVN instruction, 322–323
MVO Instruction, 323–324
MVZ instruction, 323–324
MXD instruction, 408
MXDR instruction, 408
MXR instruction, 408

NC instruction, 282
NI instruction, 279–281
N instruction, 276–277
NOP instruction, 280
NOPR instruction, 280
Normalized floating-point number, 397–398
NR instruction, 276
Number attribute (N′), 376–377
Number systems
  binary, 1–2
  decimal, 1
  hexadecimal, 2
  positional, 1
Numeric digit, 157

Object module, 204
Object Module Library, 205–206
Object program, 25
OC instruction, 282
OI instruction, 163, 182, 279–281, 284
O instruction, 277
One's complement, 17
Opening files, 236–237, 240
OPEN macro instruction, 240, 255
Operands, 32
Operand sublists, 375, 377
Operation code (op code), 27, 32
Operation exception, 528
ORG instruction, 136
OR Immediate instruction, 279–281
OR operation, 278
OR Register instruction, 277
Overflow, 19–20, 147–148

Packed decimal format, 157–159
PACK instruction, 160–161
Parameter list, 209
Pattern (edit), 170–171
Physical record, 232
Positional number systems, 1–3
Positional parameters, 347
Postnormalization, 398
Prenormalization, 398
Printing lines, 48–49
Print line, blanking out, 132
Privileged instructions, 535
Problem state, 533
Program interrupt, 533
Program mask, 321
Program Status Work (PSW), 26, 39
Protection error, 29, 410, 529
Protection exception, 29, 410, 529
Protection key, 537
Prototype statement (macro), 346
Pseudo-code, 430
PSW (Program Status Word), 26, 39
  new PSW, 534
  old PSW, 534
P-type constant, 159
Punched card, 42
PUT macro instruction, 240, 256

Queued Sequential Access Method (QSAM), 236–237

R0, 23, 79, 100
R1, 209–210
R13, 210–211
R14, 34
R15, 33–34
Random number generator, 327–328
Random numbers, 327–328
Record Description Word (RDW), 233
Register linkage conventions, 209–213, 216–217
Register save area, 210
Relational operators, 351
Relocatable expression, 268–270
Relocatable term, 268
Report logic, 137–139
Right arithmetic shift, 289
Right logical shift, 286–287
RR instruction, 26–28
RS instruction, 87–88, 286
Running state, 541
RX instruction, 29–30

Save area, 210
SD instruction, 401
SDR instruction, 401
SE instruction, 401
Self-defining term, 267
Sequence symbol, 351
Sequential file, 231–233
SER instruction, 401
SETA statement, 361
SETB statement, 366
SETC statement, 369
Set Program Mask instruction, 321–322
Set Storage Key (SSK) instruction, 537
SET symbols, 360
Severity code, 373
Shell sort, 222
Shifting decimal numbers, 179–181, 322–325

Shift instructions, 179–181, 285–290
Shift Left Double Arithmetic instruction, 290
Shift Left Double Logical instruction, 287
Shift Left Single Arithmetic instruction, 288
Shift Left Single Logical instruction, 286
Shift Right Double Arithmetic instruction, 290
Shift Right Double Logical instruction, 287
Shift Right Single Arithmetic instruction, 289
Shift Right Single Logical instruction, 286
Shift and Round Decimal instruction, 179–181
SH instruction, 295
Sign (printing), 174
Sign bit, 17–18, 392
  extension of, 61
Significance exception, 410
Significance indicator, 170–171
Significance starter, 170–171
SI instruction, 127–129
S instruction, 52
SL instruction, 148
SLA instruction, 288
SLDA instruction, 290
SLDL instruction, 287
SLL instruction, 286
SLR instruction, 148
Sorting, 105–106, 222
Source file, 203
Source digits, 170
SPACE instruction, 109
Specification exception, 29, 529
SP instruction, 165
SPM instruction, 321–322
SR instruction, 28
SRA instruction, 289
SRDA instruction, 290
SRDL instruction, 287
SRL instruction, 286
SRP instruction, 179–181
SS format, 130–131, 160
SSK (Set Storage Key) instruction, 537
Standard linkage conventions, 209–213, 216–217
Start I/O (SIO) instruction, 540–541
STC instruction, 77
STCM instruction, 314
Step algorithm, 127
Stepwise refinement, 441–447
ST instruction, 30
STH instruction, 294
STM instruction, 100–101
Storage protection, 536–538
Store Character instruction, 77
Store Characters under Mask instruction, 314
Store Halfword instruction, 294
Store instruction, 30
Store Multiple instruction, 100–101
Structured logic, 429–430
Structured program, 429–430
Subroutines, 95–100, 205–213
Substring of character expression, 370
Subtract Decimal instruction, 165
Subtract Halfword instruction, 295
Subtract instruction, 52
Subtraction, 12, 18, 147
Subtraction algorithm, 12–13
Subtraction of binary and hexadecimal numbers, 8–14
Subtract Logical instruction, 148
Subtract Logical Register instruction, 148
Subtract Register instruction, 28
SU instruction, 406
Supervisor, 533
Supervisor-call interrupt, 535
Supervisor state, 533
SUR instruction, 406
SVC instruction, 535
SW instruction, 406
SWR instruction, 406
SXR instruction, 408
Symbolic instruction, 31–32
Symbolic parameters, 346
System variable symbol, 345, 354

Table
  for addition of hexadecimal digits, 11
  extended mnemonics, 516
  powers of 2, 16, 523
Tape files, 233–234
Testing of flag bits, 284
Test under Mask instruction, 283–284
TITLE instruction, 109
TM instruction, 283–284
Track, 235
Trailer (macro), 346
Translate instruction, 302–304
Translate table, 303
Translate and Test instruction, 305–308
TR instruction, 302–304
TRT instruction, 305–308
True zero, 398
Two's complement, 17
Type, 270–271

Unconditional branch, 39–41
Unnormalized floating-point number, 397–398
UNPK instruction, 162
USING statement, 38, 226–228

Variable-length format, 232–233
Variable-length logical record, standard format for, 232–233
Variable symbols, 345–346
Volume Table of Contents (VTOC), 235
V-type constant, 208

XC instruction, 281–282
XDECI instruction, 44–45
XDECO instruction, 50
XDUMP instruction, 35–36, 418–421
X instruction, 278
XI instruction, 279–280
XPRNT instruction, 49
XR instruction, 278–279
XREAD instruction, 43
X-type constant, 168–170, 271

ZAP instruction, 165–166
Zero and Add Decimal instruction, 165–166
Zone digit, 157
Zoned decimal representation, 157–160
Z-type constant, 158