Chapter 11: Handling Decimal Data

This chapter covers decimal data, which refers to numeric data that are handled one digit at a time as opposed to binary integer arithmetic or floating point arithmetic. As will be soon noticed, the decimal format is particularly well adapted to the accounting and other business computation that predominates in the companies which represent IBM's primary markets.

In the IBM S/370 architecture, there are two primary types of decimal data: zoned decimal data and packed decimal data. As far as your author can determine, the zoned format serves mostly as an intermediate form between digital character data in EBCDIC form and the packed decimal format that is used for many computations.

Zoned Decimal Data

The **zoned decimal format** is a modification of the EBCDIC format. It seems not to be used in any numeric processing and might best be viewed as an intermediate form in the process of translating digits in EBCDIC form into the internal representation of a number. The format seems to be a modification to facilitate processing decimal strings of variable length.

The length of zoned data may be from 1 to 16 digits, stored in 1 to 16 bytes. Note that, as in the character representation, this format calls for one byte per digit.

We have the address of the first byte for the decimal data, but need some "tag" to denote the last (rightmost) byte, as the format is not fixed length. The assembler places a "sign zone" for the rightmost byte of the zoned data.

The common standard is	**`X'C'`** for non–negative numbers, and
	`X'D'` for negative numbers.

Other than the placing of a hexadecimal digit **`X'C'`** or **`X'D'`** for the zone part of the last digit, the zoned decimal format is rather similar to the EBCDIC format.

Consider the negative number **`–12345`**, and its various representations in which the spaces are inserted for readability only. Note that **`X'60'`** is the EBCDIC representation of the "–".

As a string of EBCDIC characters it is hexadecimal **`60 F1 F2 F3 F4 F5`**.

In the zoned decimal representation it is hexadecimal **`F1 F2 F3 F4 D5`**.

As packed decimal format (to be discussed soon) it is stored as **`12 34 5D`**.

There are a few more things that might be said about the zoned format, such as how to declare a zoned decimal constant (the format type is Z). As your author views the zoned format as an intermediate format, we shall discuss it further only in the context of conversion between EBCDIC characters and packed decimal digits.

Packed Decimal Data

The preferred use of packed decimal data format was introduced in Chapter 4, where it was shown not to have the round–off problem that is commonly found in all floating–point formats. The standard floating–point formats can guarantee either seven digits of accuracy or fifteen digits of accuracy. People in business want all digits to be accurate. If a sales total takes 17 digits to represent, all 17 digits in the number must be correct.

Packed Decimal Format

Here, we discuss the packed decimal format, beginning with packed decimal constants.

A packed decimal constant is a signed integer, with between 1 and 31 digits (inclusive). The number of digits is always odd, with a 0 being prefixed to a constant of even length.

A sign "half byte" or hexadecimal digit is appended to the representation. The common sign–representing hexadecimal digits are as follows:

C	non–negative
D	negative
F	non–negative, seen in the results of a PACK instruction.

If a DC (Define Constant) declarative is used to initialize storage with a packed decimal value, one may use the length attribute. Possibly the only good use for this would be to produce a right–adjusted value with a number of leading zeroes.

For example **`DC PL6'1234'`** becomes

00	00	00	01	23	4C

Remember that each of these bytes holds two hexadecimal digits, not the value indicated in decimal, so 23 is stored as **`0010 0011`** and 4C as **`0100 1100`**.

Some Examples and Cautions

Here are some examples of numbers being represented in packed decimal format.

`DC P'+370'` becomes **`370C`**

`DC P'–500'` becomes **`500D`**

`DC P'+92'` becomes **`092C`**

Here are some uses that, while completely logical, might best be avoided. The problem with the first example is that the length in bytes is not sufficient to store the packed decimal number, so that the five leftmost digits are truncated. The second example shows the use of a DC declarative to define three constants in a manner that is difficult to read.

`P1          DC PL2'12345678'` is truncated to become 678C.
Why give a value only to remove most of it?

```
PCON   DC PL2'123','–456','789'
```

This creates three constants, stored as **`123C`**, **`456D`**, and **`789C`**.
Only the first constant can be addressed directly.

I would prefer the following sequence, with the labels P2 and P3 being optional.

```
P1   DC PL2'123'
P2   DC PL2'–456'
P3   DC PL2'789'
```

More Examples
The packed decimal format is normally considered as a fixed point format, with a specified number of digits to the right of the decimal point. It is important to note that decimal points are ignored when declaring a packed value. When such are found in a constant, they are treated by the assembler as comments.

Consider the following examples and the assembly of each. Note that spaces have been inserted between the bytes for readability only. They do not occur in the object code.

	Statement	Object Code	Comments
P1	**DC P‘1234’**	**01 23 4C**	Standard expansion to 5 digits
P2	**DC P‘12.34’**	**01 23 4C**	The decimal is ignored.
P3	**DC PL4‘-12.34’**	**00 01 23 4D**	Negative and lengthened to 4 bytes. Leading zeroes added.
P4	**DC PL5’12.34’**	**00 00 01 23 4C**	Five bytes in length. This gives 2 bytes of leading zeroes.
P5	**DC 3PL2‘0’**	**00 0C 00 0C 00 0C**	Three values, each 2 bytes.

Explicit Base Addressing for Packed Decimal Instructions
We now discuss a number of ways in which the operand addresses for character instructions may be presented in the source code. One should note that each of these source code representations will give rise to object code that appears almost identical. These examples are taken from Peter Abel [R_02, pages 273 & 274]. Consider the following source code, taken from Abel. This is based on a conversion of a weight expressed in kilograms to its equivalent in pounds; assuming 1kg. = 2.2 lb. Physics students will please ignore the fact that the kilogram measures mass and not weight.

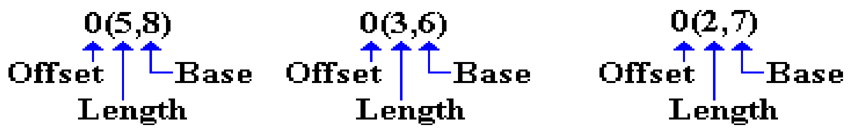
```
         ZAP  POUNDS,KGS      MOVE KGS TO POUNDS
         MP   POUNDS,FACTOR   MULTIPLY BY THE FACTOR
         SRP  POUNDS,63,5     ROUND TO ONE DECIMAL PLACE

KGS      DC   PL3‘12.53’      LENGTH 3 BYTES
FACTOR   DC   PL2‘2.2’        LENGTH 2 BYTES, AT ADDRESSS KGS+3
POUNDS   DS   PL5             LENGTH 5 BYTES, AT ADDRESS KGS+5
```

The value produced is 12.53•2.2 = 27.566, which is rounded to 27.57.

The instructions we want to examine in some detail are the **MP** and **ZAP**, each of which is a type SS instruction with source code format **OP D1(L1,B1),D2(L2,B2)**. Each of the two operands in these instructions has a length specifier. In the first example of the use of explicit base registers, we assign a base register to represent the address of each of the arguments. The above code becomes the following:

```
         LA R6,KGS            ADDRESS OF LABEL KGS
         LA R7,FACTOR         ADDRESS
         LA R8,POUNDS
         ZAP 0(5,8),0(3,6)
         MP  0(5,8),0(2,7)
         SRP 0(5,8),63,5
```

Each of the arguments in the MP and ZAP have the following form:



Recall the definitions of the three labels, seen just above. We analyze the instructions.

```
ZAP 0(5,8),0(3,6)  Destination is at offset 0 from the address
                   stored in R8. The destination has length 5 bytes.

                   Source is at offset 0 from the address stored
                   in R6.  The source has length 3 bytes.

MP  0(5,8),0(2,7)  Destination is at offset 0 from the address
                   stored in R8. The destination has length 5 bytes.

                   Source is at offset 0 from the address stored
                   in R7.  The source has length 2 bytes.
```

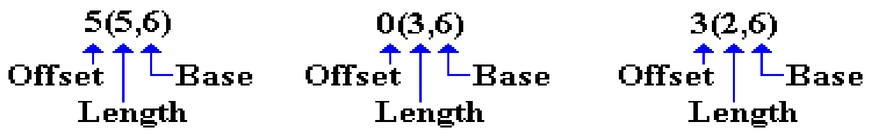
But recall the order in which the labels are declared. The implicit assumption that the labels are in consecutive memory locations will here be made explicit.

```
KGS       DC   PL3'12.53'     LENGTH 3 BYTES
FACTOR    DC   PL2'2.2'       LENGTH 2 BYTES, AT ADDRESSS KGS+3
POUNDS    DS   PL5            LENGTH 5 BYTES, AT ADDRESS KGS+5
```

In this version of the code, we use the label KGS as the base address and reference all other addresses by displacement from that one. Here is the code.

```
          LA R6,KGS           ADDRESS OF LABEL KGS
          ZAP 5(5,6),0(3,6)
          MP  5(5,6),3(2,6)
          SRP 5(5,6),63,5
```

Each of the arguments in the MP and ZAP have the following form:



Recall the definitions of the three labels, seen just above. We analyze the instructions.

```
ZAP 5(5,6),0(3,6)  Destination is at offset 5 from the address
                   stored in R6. The destination has length 5 bytes.

                   Source is at offset 0 from the address stored
                   in R6.  The source has length 3 bytes.

MP  5(5,6),3(2,6)  Destination is at offset 5 from the address
                   stored in R6. The destination has length 5 bytes.

                   Source is at offset 3 from the address stored
                   in R6.  The source has length 2 bytes.
```

In other words, the base/displacement **6000** refers to a displacement of 0 from the address stored in register 6, which is being used as an explicit base register for this operation. As the address in R6 is that of KGS, this value represents the address **KGS**. This is the object code address generated in response to the source code fragment **0(3,6)**.

The base/displacement **6003** refers to a displacement of 3 from the address stored in register 6, which is being used as an explicit base register for this operation. As the address in R6 is that of KGS, this value represents the address **KGS+3**, which is the address **FACTOR**. This is the object code address generated in response to the source code fragment **3(2,6)**.

The base/displacement **6005** refers to a displacement of 5 from the address stored in register 6, which is being used as an explicit base register for this operation. As the address in R6 is that of KGS, this value represents the address **KGS+5**, which is the address **POUNDS**. This is the object code address generated in response to the source code fragment **5(5,6)**.

It is worth notice, even at this point, that the use of a single register as the base from which to reference a block of data declarations is quite suggestive of what is done with a **DSECT**, also called a "Dummy Section".

Packed Decimal: Moving Data
There are two instructions that might be used to move packed decimal data from one memory location to another. The preferred instruction is **ZAP** (Zero and Add Packed).

MVC S1,S2	Copy characters from location S2 to location S1
ZAP S1,S2	Copy the numeric value from location S2 to location S1.

Each of the two instructions can lead to truncation if the length of the receiving area, S1, is less than the source memory area, S2. If the lengths of the receiving field and the sending field are equal, either instruction can be used and produce correct results.

The real reason for preferring the ZAP instruction for moving packed decimal data comes when the length of the receiving field is larger than that of the sending field. The ZAP instruction copies the contents of the sending field right to left and then pads the receiving field with zeroes, producing a correct result.

The MVC instruction will copy extra bytes if the receiving field is longer than the sending field. The MVC instruction makes a left–to–right copy and will copy the required number of bytes, probably copying garbage. Consider the following example.

```
F1  DC P'0000000'  stored as 0000 000C, this takes 4 bytes,
F2  DC P'123'      stored as 12 3C, this takes 2 bytes.
F3  DC P'4567'     stored as 04 56 7C, this takes 3 bytes.
```

Executing **ZAP F1, F2** will cause F1 to be set to **0000 123C**, which is correct.

Executing **MVC F1, F2** will set F1 to **123C 0456**, which not only is the wrong answer, but also fails to be in any recognizable packed decimal format.

Bottom line: Use the ZAP instruction to move packed decimal data.

Packed Decimal Data: ZAP, AP, CP, and SP
We have four instructions with similar format.

`ZAP S1,S2`	Zero S1 and add packed S2	(This is the move discussed above)
`AP S1,S2`	Add packed S2 to S1	
`CP S1,S2`	Compare S1 to S2, assuming the packed decimal format.	
`SP S1,S2`	Subtract packed S2 from S1.	

These are of the form **`OP D1(L1,B1),D2(L2,B2)`**, which provide a 4–bit number representing the length for each of the two operands. The object code format is as follows.

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	OP	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The first byte contains the operation code, which is **`X'F8'`** for **`ZAP`**, **`X'F9'`** for **`CP`**, **`X'FA'`** for **`AP`**, **`X'FB'`** for **`SP.`**

The second byte contains two hexadecimal digits, each representing an operand length.

Each of L_1 and L_2 encodes one less than the length of the associated operand. This allows 4 bits to encode the numbers 1 through 16, but disallows arguments of length 0.

The next four bytes contain two addresses in base register/displacement format.

Packed Decimal Data: Additional Considerations
For all four instructions, the second operand must be a valid packed field terminated with a valid sign. The usual values are '**`C`**', '**`D`**', and occasionally '**`F`**', though the hexadecimal digits '**`A`**', '**`B`**', and '**`E`**' are legal. As noted above, the sign digit '**`D`**' is standard for negative numbers, while the sign digit '**`C`**' is standard for non–negative numbers. The sign digit '**`F`**' will be seen in data converted from Zoned Decimal by the PACK instruction.

For AP, CP, and SP, the first operand must be a valid packed field terminated with a valid sign. For ZAP, the only consideration is that the destination field be large enough.

If either the sending field or the destination field (AP and SP) have just been created by a PACK instruction, the sign half–byte may be represented by the sign digit '**`F`**'.
This is changed by the processing to '**`C`**' or '**`D`**' as necessary.

Some textbook hint that using ZAP to transfer a packed decimal number with '**`F`**' as the sign half–byte will convert that to '**`C`**'. This seems reasonable.

Any packed decimal value with a sign half–byte of D (for negative) is considered to sort less than any packed decimal value with a sign half–byte of C or F (positive). This follows the standard arithmetic in which any negative number is less than any positive number.

The number 0 is always represented as **`0C`** (possibly with more leading zeroes), but is never validly represented as **`0D`**. There is no negative zero.

Example of Packed Decimal Instructions
The form is **`OP D1(L1,B1),D2(L2,B2)`**. The object code format is as follows:

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	OP	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

Consider the assembly language statement below, which adds **`AMOUNT`** to **`TOTAL`**.

```
AP TOTAL,AMOUNT
```

Assume:
1. **`TOTAL`** is 4 bytes long, so it can hold at most 7 digits.
2. **`AMOUNT`** is 3 bytes long, so it can hold at most 5 digits.
3. The label **`TOTAL`** is at an address specified by a displacement of **`X'50A'`** from the value in register **`R3`**, used as a base register.
4. The label **`AMOUNT`** is at an address specified by a displacement of **`X'52C'`** from the value in register **`R3`**, used as a base register.

The object code looks like this: **`FA 32 35 0A 35 2C`**

The Disassembly of the Above Example
Consider **`FA 32 35 0A 35 2C.`** The operation code **`X'FA'`** is that for the Add Packed (Add Decimal) instruction, which is a type SS(2). The above format applies.

The field **`32`** is of the form L_1 L_2.
The first value is **`X'3'`**, or 3 decimal. The first operand is 4 bytes long.
The second value is **`X'2'`**, or 2 decimal. The second operand is 3 bytes long.

The two–byte field **`35 0A`** indicates that register 3 is used as the base register for the first operand, which is at displacement **`X'50A'`**.

The two–byte field **`35 2C`** indicates that register 3 is used as the base register for the second operand, which is at displacement **`X'52C'`**.

It is quite common for both operands to use the same base register.

Condition Codes
Each of the ZAP, AP, and SP instructions will set the condition codes. As a result, one may execute conditional branches based on these operations. The branches are:

BZ	Branch Zero	BNZ	Branch Not Zero
BM	Branch if negative	BNM	Branch if not negative
BP	Brach if positive	BNP	Branch if not positive
BO	Branch on overflow	BNO	Branch if overflow has not occurred.

An **overflow** will occur if the receiving field is not large enough to accept the result.

My guess is that leading zeroes are not considered in this; so that the seven–digit packed decimal number 0000123 can be moved to a field accepting four digit packed numbers.

Additional Rules for ZAP, AP, and SP
These rules are as follows:

1. The maximum length for each field is 16 bytes, allowing for a maximum of 31 digits. Either field, or both, may have an explicit length operand with a maximum value of 16. Remember that this operand is a byte length.
2. If the operand 1 (destination) field is shorter than the operand 2 (source) field, a program interrupt may occur. The length of the first field should be sized for the expected result of the operation and not just based on the length associated with the first value. For addition, the operand 1 field should be one digit larger than the lengths of either of the values to be added.
3. The CPU extends the shorter field (presumably that associated with the second operand) to that of the longer field by left padding with zeroes. This is necessary for the results to be in accordance with standard arithmetic.

Examples of ZAP, AP, and SP
Here are a few examples of the use of the three instructions AP, SP, and ZAP. The examples are to be viewed as independent executions of code, so that the values associated with the data labels are always the same at the beginning of each.

Suppose that we start with definitions as follows.

```
P0        DC P‘666’      Stored as 66 6C
P1        DC P‘222’      Stored as 22 2C
P2        DC P‘1234’     Stored as 01 23 4C
P3        DC P‘1234567’  Stored as 12 34 56 7C
```

For these examples, we assume that the data stored represent integer values, and that none has an implied decimal or “digits to the right of the decimal”.

```
CASE1     ZAP P3,P1      RESULTS IN P3 = 00 00 22 2C
CASE2     ZAP P2,P1      RESULTS IN P2 = 00 22 2C
CASE3     AP  P2,P1      RESULTS IN P2 = 01 45 6C.
                         Recall this starts with P2 = 01 23 4C.
CASE4     SP  P2,P1      RESULTS IN P2 = 01 01 2C
CASE5     SP  P3,P1      RESULTS IN P3 = 12 34 34 5C.
```

In other words, the arithmetic is not blindly done left to right, but with the digits “lined up” as one would expect in standard arithmetic.

```
CASE6     AP P1,P1       RESULTS IN P1 = 44 4C.
CASE7     AP P0,P0       This causes an overflow.
```

Here we see the importance of design so that the first argument can store not just its initial value, but also the result of any reasonably contemplated arithmetic operation.

```
CASE8     SP P0,P0       RESULT IS 0, PRESUMABLY STORED AS 0C.
```

Comparing Packed Decimal Values
The rules for the CP instruction are the same as those for the AP and SP instructions.

1. Both operands must contain valid packed data, with maximum length of 16 bytes. Either operand or both may contain an explicit length indicator.
2. If the fields are not of the same length, the CPU extends the shorter field by padding with left zeroes to the length of the longer field. The comparison remains valid.
3. All comparisons are as in standard algebra. +0 is considered equal to –0, but otherwise any positive value is larger than any negative value.

The **CP** (Compare Packed) instruction is used to compare packed decimal values. This sets the condition codes that can be used in a conditional branch instruction, as just discussed. Is there any reason to compare and not then have a conditional branch?

In some sense, the **CLC** (Compare Character) instruction is similar and may be used to compare packed decimal data. However, this use is dangerous, as the CLC does not allow for many of the standards of standard algebra.

Consider the two values 123C (representing +123) and 123D (representing –123).
CP will correctly state that 123D < 123C; indeed –123 is less than +123.
CLC will state that 123D > 123C, as 12 = 12, but 3D > 3C. Remember that these are being compared as sequences of characters without numeric values.

Consider the two values 123C (representing +123) and 123F (also representing +123).
CP will correctly state that 123C = 123F; as 123 = 123.
CLC will state that 123F > 123C, as 12 = 12, but 3F > 3C.

Consider the two values 125C (representing +123) and 12345C (representing +12345).
CP will work correctly, noting that 12345 > 00125. CLC will compare character by character. As ‘5C’ > ‘34’, it will conclude that 125 > 12345

The best way to understand the results of this last comparison is to line up the two constants, and note that the comparison is left to right.

```
12 5C
12 34 5C
```

Examples of CP
Here are some examples. Consider the following data definitions.

```
P1       DC P‘6’      STORED AS 6C
P2       DC P‘42’     STORED AS 04 2C
P3       DC P‘122’    STORED AS 12 2C
P4       DC P‘-56’    STORED AS 05 6D
```

Here are some comparisons.

```
         CP P1,P2     P1 < P2.  Compared as 00 6C to 04 2C
         CP P1,P3     P1 < P3   BRANCH ON LOW (BL or BM)
         CP P1,P4     P1 > P4   BRANCH ON HIGH (BH or BP)
         CP P2,P3     P2 < P3
         CP P2,P4     P2 > P4
         CP P4,P4     P4 = P4   BRANCH ON EQUAL (BE or BZ)
```

Handling Decimal Precision

There is a small problem that arises due to the fact that the decimal point is not explicitly stored in the packed decimal format. Consider the following addition.

The positive number 234.12, represented as **`23 41 2C`**
is added to the positive number 4.5678, represented as **`45 67 8C`**.
The sum might be represented as **`69 09 0C`**, which
is not correct. We must keep better track of the decimal.

It seems that the best approach is to store all values to be used in a given computation in the same format, with the same number of implied decimal digits. Assume that the above values are used in computations in which the most precise data have five decimal digits. Then we would be required to have the following.

The value 234.12 would be treated as 234.12000, and stored as **`02 34 12 00 0C`**.

The value 4.5678 would be treated as 4.56780, and stored as **`04 56 78 0C`**.

The sum will then be correctly stored as **`02 38 68 78 0C`**.

MP: Multiply Packed

This is of the form **`OP D1(L1,B1),D2(L2,B2)`**, which provide a 4–bit number representing the length for each of the two operands. The object code format is as follows.

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	`X 'FC'`	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

A typical source code example would be **`MP S1, S2`**. Before the multiplication, field S1 holds the multiplicand and field S2 holds the multiplier. After the multiplication, field S1 holds the product. The rules for the MP instruction are as follows.

1. Both fields must contain valid packed data.
2. The maximum length of the first operand is 16 bytes, or 31 digits. However, this is the maximum length of the product, not of the multiplicand. See below.
3. The maximum length of the second operand is 8 bytes, or 15 digits.
4. Either operand or both may contain an explicit length specifier.
5. The standard rules of algebra apply: Like signs yield a positive product and unlike signs yield a negative product.
6. The number of digits in the product is usually equal to the sum of the count of digits in the multiplicand and the count of digits in the multiplier.

Put another way, prior to multiplication, for each byte in the multiplier, the field to hold the product must contain one byte of zero digits to the left of the significant digits that represent the multiplicand. One preferred use would be to use the ZAP instruction to move a smaller multiplicand into the product field, as shown in the illustration below.

Consider the following sequence, which might be typical of the use.

```
         ZAP PAY, HOURS
         MP  PAY, RATE

PAY      DC PL7'0000000'  STANDARD IS 980.00 OR 98 00 0C
HOURS    DC PL3'400'      40.0 HOURS PER WEEK
RATE     DC PL3'245'      PAY RATE $24.50 PER HOUR
```

Handling Decimal Precision
Recall that the assembler does not track the position of the decimal point in any packed decimal representation. That is the responsibility of the programmer, who must write assembly language instructions specifically to correct the product. Consider the example above. A simplistic product might be expressed as **`09 80 00 0C`**. Is this read as $9,800.00 (a bonus for the worker) or $980.000 (too many decimal places).

In general, the number of decimal positions in the product is equal to the sum of the number of decimal places in the multiplier and the number of decimal places in the multiplicand. If either of these is zero (or both are zero), no adjustment is required. Otherwise, the number of decimal places in the product must be adjusted.

The reason that this adjustment is required is that the number of decimal places is never tracked, but is always explicit. The only way to be able to assume the number of decimal places in a numeric representation that does not indicate that number is to have every arithmetic operation adjust the result to the correct count.

As an aside, one could write code to track the decimal position explicitly. One might store the above results as pairs of numbers, such as (1, 400) for hours, (2, 2450) for the rate, etc. However, this is not the standard approach. What is needed is a way to truncate a product to the correct number of decimal places; the SRP instruction does exactly that.

SRP: Shift and Round Packed
The SRP instruction was designed to shift packed data to the left or right, effectively dividing or multiplying by a power of ten, and then rounding the number so produced. The standard use seems to be a way to round decimal data in the usual fashion; the value 2.416 is rounded to either 2.42 or 2.4 depending on the number of decimals required. The instruction seems to support the other option, possibly called "un–rounding", of extending 2.416 to 2.4160, etc.

While the SRP instruction can be used with the results of AP, SP, and ZAP; we discuss it here within the more natural context of MP (multiplication of packed decimal data). The reason for this choice should be obvious. The addition of two numbers with equal counts of decimal places produces a similar result; thus 2.32 + 4.56 = 6.88. On the other hand, if we multiply 2.32 by 4.56, the result is 10.5792. Depending on the application, it is common to round the result to something like 10.58, preserving the count of decimal places.

While on the subject of addition and subtraction, we do not want to overlook an obvious application of SRP. Consider the sum 2.416 + 7.32. While this is not likely to be seen in a standard assembly language program, as the programmer surely will have been careful to keep all decimal points consistent, it is a theoretical possibility. In this case, it would be necessary to use the SRP instruction to convert this to one of the two equivalent forms: either 2.416 + 7.320 = 9.736 or 2.42 + 7.32 = 9.74.

The SRP instruction is a storage–to–storage (type SS) instruction, with opcode **X'F0'**. Although the SRP is a type SS instruction, it has three operands. The source code is commonly written in the form **SRP PACKVAL,SHIFTCNT,ROUNDVAL**.

Operand 1, here **PACKVAL**, denotes a packed field to shifted and possibly rounded.

Operand 2, here **SHIFTCNT**, indicates the count of digits to shift. The maximum shift count is 31, which is the maximum size of a packed decimal field.

Operand 3, here **ROUNDVAL**, contains a single digit (0 – 9) which is to be added to the original value before shifting. This converts a shift operation into a rounding. Normally, the values are 0 for left shifts and 5 for right shifts.

The use of the rounding value can be seen by an attempt to round the number 2.416 by shifting right one place. A pure shift would change 2.416 to 2.41, which does have one less decimal place. Use of SRP with a rounding value of 5 would first convert 2.416 to 2.421 and then shift right to obtain the value 2.42, considered as a proper rounding of 2.416.

The SRP operation sets the condition codes to indicate zero, minus, or plus.

The SRP instruction was not a part of the original S/360 architecture, but was added with the introduction of the S/370 to replace the MVO (Move with Offset) instruction. We shall not discuss the MVO instruction here; the reader is directed to reference R_02 for details.

The format of the instruction is **SRP D1(L,B1),D2(B2),I3**.

The object code format for the SRP instruction is represented in the figure below.

Type	Bytes	Form	1	2	3	4	5	6
SS(1)	6	**D1(L,B1),D2(B2),I3**	**X'F0'**	L I_3	B_1 D_1	D_1 D_1	B_2 D_2	D_2 D_2

L is the length indicator for the field to be shifted, denoted by **PACKVAL** in the example above. Remember that the length is a byte count that is one more than the value stored. Thus, the single hexadecimal digit can represent a value between 0 and 15 inclusive, to represent a field length between 1 and 16 inclusive.

I_3 is the decimal digit to be added before shifting.

The two bytes B_1 D_1 D_1 D_1 represent the address of the field to be shifted (**PACKVAL**), denoted in the standard base/displacement form.

The two bytes B_2 D_2 D_2 D_2 represent the shift count, using the standard base/displacement format to represent a count and not an address. The normal use would be either to use a register to hold the count, or to set the register field to 0 (indicating no base register) and use the displacement field to hold the constant value of the shift count.

There is an interesting feature of this part of the instruction that arises from the inability of the assembler to process a negative displacement. Recall that the amount shifted is given by a count in the range 0 through 31. Left shifts are denoted by positive numbers. It should be obvious that these shift counts can be represented by a five–bit binary number.

Conceptually, the right shifts used as a part of rounding are represented by negative numbers in the range from –1 through –31 inclusive. The actual format of the shift count is dictated by the need to find another way to represent these negative numbers.

The best way to view this shift count is as a six–bit two's–complement signed integer. Such a format can represent integers in the range from –32 to +31 inclusive. Some of the more common shift values would then be stored as follows.

Shift Description	Hexadecimal Value	Decimal Value
1 left	01	1
2 left	02	2
3 left	03	3
4 left	04	4
1 right	3F	63
2 right	3E	62
3 right	3D	61
4 right	3C	60

Each of the values for right shifts can be obtained by calculating the representation as a six–bit two's–complement integer. Consider the value for "3 right".

The value +3 as a six–bit binary number	**`00 0011`**	or **`X'03'.`**
The one's complement of this number	**`11 1100`**	or **`X'3C'.`**
Add one to this value to get	**`11 1101`**	or **`X'3D'.`**

The default format for the source code is based on decimal values and not hexadecimal. Hexadecimal values can be specifically indicated; e.g., **`X'3D'`**. The easier way is to use a formula:

formula:	N digits left	encode with the decimal number N.
	N digits right	encode with the decimal number (64 – N).

Examples of the SRP Instruction

In each of the following examples the value in **`AMNT2`** is being rounded by adding the value 5 and shifting right two places. The field **`AMNT2`** is assumed to be at an address specified by the offset **`0B2`** from the value in base register 12 (**`X'C'`**). The first example, showing the use of register 10 (**`X'A'`**) to specify the shift count, uses an instruction that will be defined later.

```
48E030 C2         SHIFT01   LH  10,=H'-2'        R14 GETS NEGATIVE 2
F045 C0B2 A000              SRP AMNT2,0(10),5

F045 C0B2 003E    SHIFT02   SRP AMNT2,X'3E',5

F045 C0B2 003E    SHIFT03   SRP AMNT2,62,5

                  AMNT2     DS  PL5              LENGTH IS FIVE BYTES
```

Disassembly of the above

In each of the above instructions (except the first, which is a load register from halfword), the opcode is **`X'F0'`**, indicating a SRP instruction. The second byte is to be viewed as two independent hexadecimal digits. The first digit, with value **`4`**, indicates that the length of the field to be shifted (**`AMNT2`**) is five bytes. The second digit, with value **`5`**, is the value to be added to the field before it is shifted. The next two bytes (**`C0 B2`**) specify the address of the field to be shifted. The last two bytes specify the count for the shift.

In the first example, the count is specified by adding 0 to the value stored in a register. In the other two, the count is specified by a constant with no base register. One might use a combination of the two (as in **`A0 04`**), but this usage seems a bit strange.

DP: Divide Packed

The DP (Divide Packed) instruction divides one packed field (the dividend) by another (the divisor), producing a quotient and a remainder. The DP instruction is a storage–to–storage instruction, with opcode `X'FD'`. The form is `OP D1(L1,B1),D2(L2,B2)`, which provide a 4–bit number for the length for operand. The object code format is as follows.

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	`X 'FD'`	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The lengths and address calculations are just as in the other packed decimal instructions. The rules for the DP instruction are as follows.

1. Each operand must contain data in valid packed decimal format.
2. The maximum length of the first operand (the dividend) is 16 bytes (31 digits). The maximum length of the second operand (the divisor) is 8 bytes (15 digits).
3. Either operand may specify an explicit length.
4. A zero divisor will cause a program interrupt.
5. DP uses the normal rules of algebra. Like signs in the dividend and divisor produce a positive quotient; unlike signs produce a negative quotient.
6. After the division, the field that first contained the dividend now contains the quotient and remainder, each with a sign half–byte.

Before division	Dividend	
After division	Quotient	Remainder

The remainder field has a size equal to that of the divisor. Together, the quotient and remainder occupy the entire dividend field. The address of the quotient is the same as that for the dividend. The address of the remainder must be computed.

In the original operands, the dividend had length $(L_1 + 1)$ and the divisor a length $(L_2 + 1)$. In the results of the operation, the length of the remainder is also $(L_2 + 1)$, the same as that for the divisor. Thus, the length of the quotient is $(L_1 + 1) – (L_2 + 1) = (L_1 – L_2)$, and its length code would be one less: $(L_1 – L_2 – 1)$. As a result, the address of the remainder is given by A(Quotient) + $(L_1 – L_2)$.

As is the case with packed decimal multiplication, the program should use the SRP instruction to adjust the number of decimal places in both the quotient and remainder. As a general rule the number of decimal places in the remainder is the same as the number in the divisor, and the number of decimal places in the quotient is the difference between the count in the dividend and that in the divisor. If the dividend does not already contain a sufficient number of decimal places, it is necessary to use the SRP instruction to generate additional positions by left shifting the dividend. In this case, the value for rounding would be 0.

This brief discussion of the DP instruction concludes our list of instructions for decimal arithmetic operations.

Conversion between EBCDIC and Packed Decimal

We have now examined a number of packed decimal arithmetic instructions. It is now time to face the problem of conversion of digits between EBCDIC format and packed decimal format. At a later time we shall address the problem of conversion between packed decimal format and two's–complement fullword format.

When a number is read from input, it is presented as a sequence of EBCDIC characters. Arithmetic based on this input must be done in one of the standard numeric formats, unless one wants to write an extraordinary amount of support code. The results must then be converted back to EBCDIC and formatted for output. We now present a number of instructions used for this purpose.

Along the way, we shall note the inability of the standard instructions to handle signed data as input. The digits '0' through '9' can be processed, but the signs '+' and '–' cannot be. We shall comment on a number of standard tricks that older assembly language programs use to get around this problem and then write some procedures to handle the issue.

The main issue in the conversion between EBCDIC and packed decimal format is suggested by the names of the operations that can be used for those conversions PACK and UNPACK. In the EBCDIC and zoned decimal format, each decimal digit requires an 8–bit byte for its representation. In the packed decimal format, each digit requires a 4–bit hexadecimal digit. This representation introduces an amusing, but totally unimportant, ambiguity. In a value such as represented by **`X'789D'`**, are the numeric values decimal or hexadecimal? The answer is that it does not matter, each digit requires four bits for encoding.

One of the key ideas in understanding the zoned decimal format is the division of the byte into two "half bytes" or hexadecimal digits. The most significant is called the zone part and the least significant is called the numeric part. The figure below illustrates this division.

Portion	Zone				Numeric			
Bit	0	1	2	3	4	5	6	7

There are two instructions specifically designed to process these half–byte fields. These are:

MVZ	Move the zone half byte, and
MVN	Move the numeric half byte.

Each of these instructions is a type SS instruction, more properly classified as character instructions than packed decimal instructions. The two are included here because their sole use seems to involve translation to and from packed decimal format.

The format of each instruction is **`OP D1(L,B1),D2(B2).`** This format reflects the fact that each of the source and destination addresses is specified by a base register (often the default base register) and a displacement. Here is the format of the object code.

Type	Bytes	Form	1	2	3	4	5	6
SS(1)	6	D1(L,B1),D2(B2)	**OP**	L	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The opcode for MVZ is **X'D3'**, that for MVN is **X'D1'**. The instruction is commonly written in source code in the form OP S1, S2. Characteristics of the two instructions include the following.

1. Each moves half bytes from the address specified by the second operand to an address specified by the first operand.
2. Each may move from 1 to 256 half–bytes, as specified by the length byte in the object code representation.
3. Neither move affects the contents of the second operand.
4. All of the addressing conventions used by the character instruction MVC may be used with either of these instructions.
5. Each instruction moves the half–byte associated with it and does not affect the other half byte.
6. The MVZ (Move Zones) moves the zone portion of each source byte to the zone portion of the corresponding destination byte. It does not change the numeric portion of the destination byte.

   The MVN (Move Numeric) moves the numeric portion of each source byte to the numeric portion of the corresponding destination byte. It does not change the zone portion of the destination byte.

As we shall soon see, the MVZ instruction is of more immediate interest to this course, which nevertheless covers both as important. As always, we shall illustrate the operation of the instructions by considering two fields defined by the DC directives.

Assume that we have the following two data fields defined with initialized storage.

```
S1    DC  C'123'        Stored as F1 F2 F3
S2    DC  X'45 67 C8'   Stored as 45 67 C8
```

Execute the instruction MVN S2, S1. This moves the numeric portion of each byte in S1 to the numeric portion of the corresponding byte in S2.

```
        F1 F2 F3   becomes     F1 F2 F3
        45 67 C8               41 62 C3
```

Independently, execute the instruction MVZ S2, S1. This moves the zone portion of each byte in S1 to the zone portion of the corresponding byte in S2.

```
        F1 F2 F3   becomes     F1 F2 F3
        45 67 C8               F5 F7 F8
```

We shall jump ahead to mention one good use of the MVZ instruction, as it applies to the process of unpacking data using the UNPK instruction. The goal of the unpacking process is to turn packed decimal data into EBCDIC format suitable for printing. However, the UNPK instruction converts from packed decimal format to zoned decimal format.

Consider the positive decimal number 1234, represented in packed decimal format as **01 23 4C**. The result of an unpack instruction will be represented in zoned decimal format as **F0 F1 F2 F3 C4**, which will print as the string **123D**, as **X'C4'** is EBCDIC for **'D'**.

The use of the MVZ instruction is illustrated by the following. Consider the following declaration, given in hexadecimal just to make it easier to read.

```
S3          DC  X'F0F1F2F3C4'  Stored as F0 F1 F2 F3 C4
```

The byte **X'C4'** is at location S3 + 4. The following instruction is executed.

```
            MVZ S3+4(1),=X'F0'
```

In the above instruction, the source operand is specified as a literal. Note that the second hexadecimal digit is unimportant. It is the hexadecimal digit **F** that occupies the zone part of the byte, and it is only that part that is moved.

The address associated with the destination is given by the relative address **S3+4**; it is four bytes offset from the address **S3**. In other words, it is the fifth byte of the five–byte string.

The **(1)** part of the instruction indicates that only one zone in the destination is to be changed. Here it is the zone part of the byte at the address **S3+4**.

The zoned decimal data stored as **F0 F1 F2 F3 C4**
is changed to data stored as **F0 F1 F2 F3 F4**
which is the proper EBCDIC for the digit string **"01234"**.

PACK

The pack instruction is designed to convert data in zoned decimal format, one digit per byte, to packed decimal format, with approximately two digits per byte. Due to the similarity of EBCDIC format to zoned decimal format, the instruction is commonly used to convert from EBCDIC format into packed decimal format.

The PACK instruction is a storage–to–storage (type SS) instruction, with opcode **X'F2'**. The instruction may be written in source code as **PACK PACKED,ZONED**. The affect of this instruction is to take the zoned data in the field represented by the second operand, translate it to packed format, and place the data into the field represented by the first operand.

The instruction is of the form **PACK D1(L1,B1),D2(L2,B2)**, which uses the standard base/displacement addressing form for each of the two operands. Note that the length of each operand (in bytes) is also encoded. The object code format is as follows.

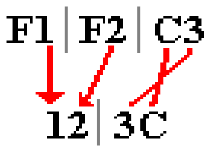
Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	**X 'F2'**	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The following are the rules for PACK:

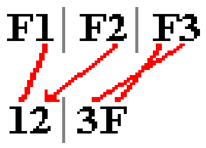
1. Operand 2 must hold data representing digits or blanks, and the rightmost byte must hold the code for a digit. The coding may be EBCDIC or zoned decimal.
2. The maximum length for each operand is 16 bytes.
3. Bytes referenced by operand 2 are packed one byte at a time from right to left.
4. other than the rightmost byte, all zones are ignored and only the numeric part of the code is copied. For the rightmost byte, the half bytes are reversed. The zone part of the last byte in zoned decimal becomes the sign half byte in packed decimal.

Consider the following two representations of the positive number 123.
As a string of EBCDIC characters, it is the three bytes **`F1 F2 F3`**.
As stored in zoned decimal format, it is the three bytes **`F1 F2 C3`**.

When executed according to its original design, the PACK instruction operates on data in the zoned decimal format. Its action on this example is shown below.



When the instruction operates on digital data in EBCDIC form, it functions identically.

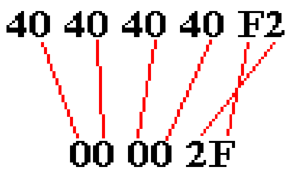


Note that the zone part of the last byte has become the sign half–byte in the packed decimal format. It is for this reason that **`X'F'`** is recognized as a valid sign indicator.

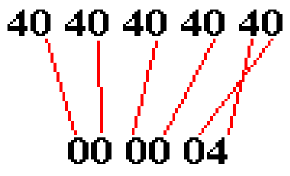
We now focus on conversions of decimal data between the two formats that may be used to represent them:

1. The EBCDIC character encoding used for input and output.
2. The packed decimal format used for decimal arithmetic.

Packing Blanks
While the PACK instruction can handle leading blanks, a serious problem can arise if the field to be packed contains all blanks (EBCDIC code 0x40). Consider first an acceptable input. Suppose that the five character string **`"    2"`** or EBCDIC **`40 40 40 40 F2`** is input. What happens here? Note that the numeric part of the EBCDIC code for the blank is the same as the numeric part of the EBCDIC code for the digit "**`0`**". This works, producing the packed string "**`00002F`**", as illustrated below.



Now consider the five character input **`"     "`** or EBCDIC **`40 40 40 40 40`**. This will pack to the string **`"000004"`**, which lacks a valid sign, as shown below. This invalid packed input cannot be processed by any packed decimal instruction.



Some authors suggest checking all input fields and replacing those that are blank with all zeroes. This suggests a very common meaning of blanks as equivalent to 0.

Here is the code, directly from Abel's textbook. The input field, **RATEIN**, is supposed to contain one to five digits, but no more than five.

```
     CLC  RATEIN,=CL5‘ ’      Is this a field of five blanks
     BNE  D50                 No, it is not all blanks
     MVC  RATEIN,=CL5‘00000’  Replace 5 blanks with 5 zeroes
D50  PACK RATEPK,RATEIN       Store packed value in RATEPK
```

More on Input of Digits to be Formatted as Packed Data
Recall that the input of packed data is a two–step procedure.

1. Input the digits as a string of EBCDIC characters.
2. Convert the digits to packed format.

The format of the input is dictated by the appropriate data declarations.

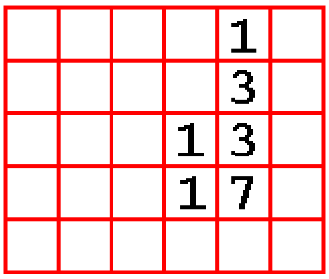
In this example, we consider the following declaration of the form of the input, which is best viewed as an 80–column card. Here is a part of a program to read numbers, one per line.

```
RECORDIN DS 0CL80     80 CHARACTER CARD IMAGE
DIGITS   DS  CL5      FIRST FIVE COLUMNS ARE INPUT
FILLER   DS  CL75     THE OTHER 75 ARE IGNORED
```

Here is a properly formatted input sequence.

```
    1      Four blanks before the “1”.
    3
   13      Three blanks before the “13”.
```

In order to see that this is the proper format for the digits, we look at a representation that emphasizes the column placement of the digits.



Reading from right to left:	Column 5 is the units column
	Column 4 is the tens column
	Column 3 is the hundreds column, etc.

Note that each digit is properly placed; the first line is really **00001**.

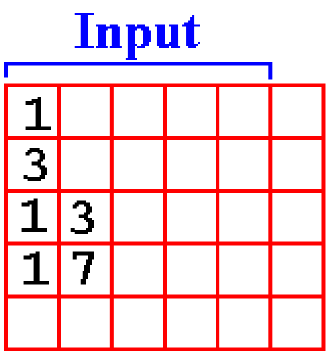
One Error: Assuming Free–Formatted Input

Here is some input from the same program. Recall that it was designed to read numbers, one per line, and to output the sum.. It **did not** work.

```
1
3
13
17
```

The student expected free–form input and assumed that this would be interpreted as the sum 1 + 3 + 13 + 17 = 34. But free–form input is an artifact of a well–written run time system, with particular attention to the user interface.

Here is the way that the input was interpreted.



To me this looks like **10000** + **30000** + **13000** + **17000**. I had expected the above input to give a sum of 70000. It did not. Here is the code loop for the processing routine.

```
B10DOIT  MVC    DATAPR,RECORDIN      FILL THE PRINT AREA
         PUT    PRINTER,PRINT        START THE PRINT
         PACK   PACKIN,DIGITSIN      CONVERT INPUT TO DECIMAL
         AP     PACKSUM,PACKIN       ADD IT UP
         BR     R8                   RETURN FROM SUBROUTINE
```

Here is the actual output. All we get is the header line and a print echo of the first line input. The header line had been printed by an earlier part of the program.

```
          ***PROGRAM FOUR CSU SPRING 2009 ***********
          1
```

A Diagnostic

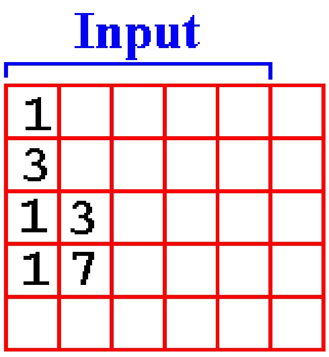
Here is the code that isolated the problem. Note the one line commented out.

```
B10DOIT  MVC    DATAPR,RECORDIN      FILL THE PRINT AREA
         PUT    PRINTER,PRINT        START THE PRINT
         PACK   PACKIN,DIGITSIN      CONVERT INPUT TO DECIMAL
***      AP     PACKSUM,PACKIN       ADD IT UP
         BR     R8                   RETURN FROM SUBROUTINE
```

The program ran to completion. Here is the output for the code fragment above.

```
************** TOP OF DATA *****************************
      ***PROGRAM FOUR CSU SPRING 2009 ***********
      1
      3
      13
      17
THE SUM = 000000
************ BOTTOM OF DATA ****************************
```

The Diagnosis
Look again at the input.



The first line, as EBCDIC characters is read as follows. **`F1 40 40 40 40`**

The PACK command processes right to left. It will process any kind of data, even data that do not make sense as digits. This input will pack to **`X'10004'`**, an invalid packed format.

With no valid sign indicator, the AP instruction fails and the program terminates.

Printing Packed Data
In order to print packed decimal data, it must be converted back to a string of EBCDIC characters. The UNPK command is a part of this conversion. It converts digital data from the packed decimal form to the zoned decimal form, which must be processed further.

The UNPK instruction is a storage–to–storage (type SS) instruction, with opcode **`X'F3'`**. The instruction may be written in source code as **`UNPK ZONED,PACKED`**. The affect of this instruction is to take the packed data in the field represented by the second operand, translate it to zoned decimal format, and place the data into the field represented by the first operand.

The instruction is of the form **`UNPK D1(L1,B1),D2(L2,B2)`**, which uses the standard base/displacement addressing form for each of the two operands. Note that the length of each operand (in bytes) is also encoded. The object code format is as follows.

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	**`X 'F3'`**	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The following are the rules for PACK:

1. The maximum length for each field is 16 bytes, which implies a maximum length of 8 bytes for the field holding the packed data. Suppose that the packed data is stored in 9 bytes, which would represent 17 digits. This would unpack to 17 bytes.
2. Bytes referenced by operand 2 are unpacked right to left, one byte at a time.
3. For all but the rightmost byte of the packed data, each hexadecimal digit is handled separately, being inserted into the numeric zone of the zoned data format.
4. The rightmost byte of the packed data has its half bytes reversed, with its sign half byte being moved to the zone part of the zoned data and the left half byte being moved to the numeric part of the zoned data. Consider the number 47, which would be represented internally as **04 7C**.

When this is unpacked, we might want it to become **F0 F4 F7,** which would print as the three–digit string **"047"** or perhaps as the two–digit string **"47"**. However, UNPK just swaps the sign half byte to produce **F0 F4 C7**.

This prints as **"04G"**, because **X'C7'** is the EBCDIC code for the letter 'G'.

We have to correct the zone part of the last byte. The problem occurs when handling the sign code, "**C**" or "**D**" in the Packed Decimal format. This occurs in the rightmost byte of a packed decimal value.

Printing Packed Data (Part 2)
Here is the code that works for five digit numbers. It is written as a subroutine, that is called as **BALR R8,NUMOUT**.

```
NUMOUT   CP   QTYPACK, =P'0'       IS THE NUMBER NEGATIVE
         BNM  NOTNEG               NO, IT IS NOT.
         MVI  QTYOUT+5,C'-'        YES, IT IS. PLACE SIGN AT QTYOUT+5
NOTNEG   UNPK QTYOUT,QTYPACK       PRODUCE FORMATTED NUMBER
         MVZ  QTYOUT+4(1),=X'F0'   MOVE 1 BYTE TO ADDRESS QTYOUT+4
*                                  THIS SETS THE ZONE PART CORRECTLY
         BR 8                      RETURN ADDRESS IN REGISTER 8
QTYPACK  DS PL3                    HOLDS FIVE DIGITS IN THREE BYTES
QTYOUT   DS 0CL6
DIGITS   DS CL5                    THE FIVE DIGITS
         DC CL1' '                 THE SIGN
```

Again, the expression **QTYOUT+4** is an **address**, not a value.
If **QTYOUT** holds C'**01234**', then **QTYOUT+4** holds C '**4**'.

Here, we have accidentally introduced the standard simplistic way of representing negative numbers in the printout of an assembly language program. This is done because it is far simpler than formatting the output in the standard manner, in which the minus sign is to the left of the most significant digit in the output. The table below will illustrate the two output options as might be seen for a five–digit number.

Internal Value	Standard Print Format	Simple Print Format
01 23 4C	**1234**	**01234**
01 23 4D	**-1234**	**01234-**

Unpacking and Editing Packed Decimal Data

Each of the UNPK (Unpack) and the ED (Edit) instruction will convert packed decimal data into a form suitable for printing. The ED and EDMK instructions seem to be more useful than the UNPK. In addition to producing the correct print representation of all digits, each allows for the standard output formats.

The ED instruction is a storage–to–storage (type SS) instruction, with opcode **`X'DE'`**. The instruction may be written in source code as **`ED PRNTREP,PACKED`**.

The EDMK instruction is also a storage–to–storage (type SS) instruction, with opcode **`X'DF'`**. It may be written in source code as **`EDMK PRNTREP,PACKED`**.

Each instruction is of the form **`OP D1(L1,B1),D2(L2,B2)`**, which uses the standard base/displacement addressing form for each of the two operands. Note that the length of each operand (in bytes) is also encoded. The object code format is as follows.

Type	Bytes	Form	1	2	3	4	5	6
SS(2)	6	D1(L1,B1),D2(L2,B2)	**OP**	L_1 L_2	B_1 D_1	D_1D_1	B_2 D_2	D_2D_2

The use of the ED instruction is a two–step process.

1. Define an edit pattern to represent the punctuation, sign, and handling of leading zeroes that is required. Use the MVC instruction to move this into the output position, which is **`PRNTREP`** in the above example.
2. Use the ED instruction to overwrite the output position with the output string that will be formatted as specified by the edit pattern. The first character in the edit pattern is a fill character that is not overwritten.

The EDMK instruction is identical to the ED instruction, except that it "marks" the leftmost significant digit by returning its address as the contents of general–purpose register 1. Think of the print output being scanned left to right, towards increasing byte addresses. The most significant digit is the leftmost. We shall discuss this more thoroughly in just a bit.

Here is an example. Note that there are a number of length constraints, specifically that the length of the edit pattern match the length of the output area.

```
         MVC  COUNPR,=X'40202020'     Four bytes of pattern
         ED   COUNPR,COUNT
```

More code here

```
COUNT    DC   PL'001'
COUNPR   DS   CL4
```

Note the sequence of events in these two lines of code.

1. The edit pattern is moved into the output field. The leading pair of hexadecimal digits, 0x40, state that a blank,' ', will replace all leading zeroes.
2. The decimal value is edited into the output field COUNPR, overwriting the edit pattern.

The result is printed as the four character sequence **`"   1"`**, represented in EBCDIC as **`X'4040 40F1'`**.

ED: Basic Rules
The basic form of the instruction is `ED S1,S2`

The first operand, S1, references the leftmost byte of the edit word, which has been placed in the output area. This field will be filled with the formatted output.

The second operand, S2, references a packed field to be edited.

One key concept in the editing for output is called **"significance"**. In many uses, leading zeroes are not treated as significant and are replaced by the fill character.

Thus, the number represented in packed decimal format as **001C** might print as **"   1"** or as **"001"** depending on whether or not leading zeroes are required.

There are times in which one wants one or more leading zeroes to be printed. As an example, consider the real number 0.25, which is stored as **025C**. It might best be printed as **"0.25"** with at least one leading zero. This leads to the concept called **"forcing significance"**, in which leading zeroes are printed.

The Fill Character
The leftmost hexadecimal byte in the output area before the execution of the instruction begins represents the fill character to use when replacing non–significant leading zeroes.

Two standard values are:	**X'40'**	a blank	**' '**	
	X'5C'	an asterisk	**'*'**	Often used in check printing.

Consider the three digit number 172, stored internally as **172C**. For now, assume that the field from which it will be printed allows for five digits. With a fill character of **X'40'** (blank), this would normally be printed as **172**.

We can force significance to cause either **0172** or **00172** to be printed. For this number, with a fill character of **X'40'**, our options would be one of the three following.

```
  172
 0172
00172
```

With a fill character of **X'5C'**, we might have one of the three following. Note that the function of the leading **"*"** is to prevent other digits from being inserted at the left.

```
**172
*0172
00172
```

By itself, the leading asterisk is an inadequate security feature. However, when combined with other printing conventions (noted below), it can prevent many obvious ways of altering the amount of a check.

An amount on a properly printed check might appear as **$**1,234.00**.

The Edit Word: Encountering Significance

Here are some of the commonly used edit characters. Note that it is more convenient to represent these by their hexadecimal EBCDIC.

One key idea is the **encounter of significance**. The instruction generates digits for possible printing from left (most significant) to right (least significant). Two events cause this encounter: 1) a non–zero digit is generated, and 2) a digit is encountered that is associated with the 0x21 edit pattern. As noted above, the first character in the edit word is the fill character. The codes that are used for the digit positions are as follows:

`0x20`	Digit selector. This represents a digit to be printed, unless it happens to be a leading non–significant zero. In that case, the fill character is printed.
`0x21`	Digit selector and significance starter. This not only represents a digit to be printed, but it also forces significance. Each digit to the right will be printed, even if a leading zero.

Unless one is careful, ED might result in an output field that is all blanks. For printing integer values, one might seriously consider ending the edit pattern with the values **`0x2120`**. Significance is forced after the next–to–last digit, forcing at least one digit to be printed.

As noted above, the EDMK instruction will insert the address (not the offset) of the leftmost significant digit into general–purpose register 1. This address can be decremented by 1 and then used to place a currency sign or other prefix. Please see the example below.

The Edit Word: Formatting the Output

Part of the function of the **`ED`** and **`EDMK`** commands is to allow standard formatting of the output, including decimal points and commas. Handling of negative numbers is a bit strange.

Here are the standard formatting patterns.

`0x4B`	The decimal point. If significance has been encountered, the decimal point is printed. Otherwise, the fill character is printed.
`0x6B`	The comma. If significance has been encountered, the comma is printed. Otherwise, the fill character is printed.
`0x60`	The minus sign, "–". This is used in an unexpected way.

The standard for use of the minus sign arises from conventions found in commercial use. The minus sign is placed **<u>at the end</u>** of the number.

Thus the three digit positive number 172 would be printed as **`172`**
and the three digit negative number –172 would be printed as **`172-`**.

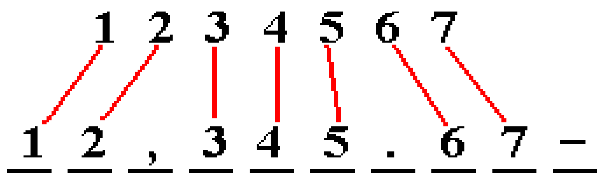
The edit pattern for this output (ignoring the significance issue) would be as follows:

`0x4020202060`.	The fill character is a blank. There are three digits followed by a sign field, which is printed as either "**`-`**" or the fill character.

ED: An Example with Formatting
In this example, it is desired to print a seven digit number, formatted as follows.

1. It is a fixed point number, with two digits to the right of the decimal.
2. It has five digits to the left of the decimal and places a comma in the standard location if significance has been encountered.
3. It will be printed with a terminating "–" if the number is negative.

This situation is illustrated in the following graphic.



The edit pattern for this example would be as follows:

	1	2		3	4	5		6	7	
40	20	20	6B	20	21	20	4B	20	20	60

Note: The significance forcer at digit 4 will insure that digit 5 is printed, even if it is a zero.

EDMK: An Example
Here we shall give an example of the use of the Edit and Mark instruction, using the edit word that we have just discussed. Here is the sample code:

```
         MVC  AMTPR,EDPAT       MOVE EDIT PATTERN TO PRINT FIELD
         EDMK AMTPR,AMTPAK      FORMAT THE PACKED FOR PRINTING
*
*        HERE REGISTER 1 CONTAINS THE BYTE ADDRESS OF THE MOST
*        SIGNIFICANT DIGIT.  THE ADDRESS IS NOT LESS THAN
*        (AMTPR + 1), THE ADDRESS OF "DIGIT 1" IN THE PATTERN ABOVE.
*
         SH R1,=H'1'        DECREMENT ADDRESS BY 1
         MVI 0(1),C'$'      PLACE THE DOLLAR SIGN
EDPAT    DC X'4020206B2021204B202060'   THE PATTERN ABOVE
AMTPAK   DC P'12345'                    THE AMOUNT TO DISPLAY
AMTPR    DS CL11                        THE PRINT REPRESENTATION
```

If the value in AMTPAK were formatted with the ED instruction, we would not be able to use the code above to place the "$" character. Here are the two outputs.

With the ED operator, the output is `$    123.45`
With the EDMK instruction, the output is `$123.45`

ED: More on the "*" Fill Character
One option for the fill character is 0x**5C**, the asterisk. Why is this used? Consider the above seven–digit example, in which the number is to be viewed as a money amount. We shall use the dollar sign, "**$**", in the amount.

Consider the amount **$123.45**. We would like to print it in this fashion, but placing the dollar sign in this way presents difficulties. Standard coding practice would have been to place the dollar sign in a column just prior to that for the digits. The format would have been as follows.

Column	0	1	2	3	4	5	6	7	8	9	10
	$	Digits		,		Digits		.	Digits		–

If the blank fill character were chosen, this would print as **$ 123.45**.
Note the spaces before the first digit. To prevent fraud, we print **$***123.45**

ED: A More Complete Example
We now show the complete code for producing a printable output from the seven digit packed number considered above. We shall use "*" as a fill character. Note that the output will be eleven EBCDIC characters. Here is the code.

```
PRINTAMT MVC AMNTPR,EDITWD

         ED  AMTPR,AMTPACK

*  The fill character is "*".  Also punctuation as follows
                       ,       .     -
EDITWD   DC X'5C20206B2021204B202060'

*

AMTPACK  DS PL4     FOUR BYTES TO STORE SEVEN DIGITS.

AMTPR    DS CL11    THE FORMATTED PRINT OUTPUT
```

ED: Another Example Using an Edit Pattern
This example is adapted from Abel's textbook. Suppose that we have the following.

The packed value to be printed is represented by
DC PL3'7' This is represented as **00 00 7C**.

The edit pattern, when placed in the output area beginning at byte address 90, is as shown below.

Address	90	91	92	93	94	95	96	97
Code	40	20	21	20	4B	20	20	60

Note the structure here: 3 digits to the left of the decimal (at least one will be printed),
the decimal point, and
two digits to the right of the decimal.

This might lead one to expect something like "000.07" to be printed.

At address 90 the contents are 0x40, assumed to be the fill character.
This location is not altered.

Address	90	91	92	93	94	95	96	97
Code	40	20	21	20	4B	20	20	60

At address 91 the contents 0x20 is a digit selector. The first digit
of the packed amount is examined. It is a 0. **0**0007C
ED replaces the 0x20 with the fill character, 0x40.

Address	90	91	92	93	94	95	96	97
Code	40	40	21	20	4B	20	20	60

At address 92 the contents 0x21 is a digit selector and a significance forcer
for what follows. The second digit 0**0**007C
of the packed amount is of the packed amount is examined.
It is a 0. ED replaces the 0x21 with the fill character, 0x40.

Address	90	91	92	93	94	95	96	97
Code	40	40	40	20	4B	20	20	60

At address 93 the contents 0x20 is a digit selector. Significance has been
encountered. The third digit of the packed 00**0**07C
amount is of the packed amount is examined.
It is a 0. ED replaces the 0x20 with 0xF0, the code for ‘0’.

Address	90	91	92	93	94	95	96	97
Code	40	40	40	F0	4B	20	20	60

At address 94 the contents 0x4B indicate that a decimal point is to be printed
if significance has been encountered. It has been, so the pattern
is not changed. Had significance not been encountered, this
would have been replaced by the fill character.

Address	90	91	92	93	94	95	96	97
Code	40	40	40	F0	4B	20	20	60

At address 95 the contents 0x20 is a digit selector. Significance has been
encountered. The fourth digit of the packed 000**0**7C
amount is of the packed amount is examined.
It is a 0. ED replaces the 0x20 with 0xF0, the code for ‘0’.

Address	90	91	92	93	94	95	96	97
Code	40	40	40	F0	4B	F0	20	60

At address 96 the contents 0x20 is a digit selector. Significance has been encountered. The fourth digit of the packed amount is of the packed amount is examined. It is a 7. ED replaces the 0x20 with 0xF7, the code for '7'. 00007C

Address	90	91	92	93	94	95	96	97
Code	40	40	40	F0	4B	F0	F7	60

At address 97 the contents 0x60 indicate to place a minus sign if the number to be printed is found to be negative. It is not, so the instruction replaces the negative sign with the fill character.

Address	90	91	92	93	94	95	96	97
Code	40	40	40	F0	4B	F0	F7	40

At this point, the process terminates. We have the EBCDIC representation of the string to be printed. As characters, this would be **"   0.07 "**. Note that there is a trailing space in this printout; it occupies a column in the listing.

Note that additional code would be required to print something like **" $ 0.07 "**. This would involve a scan of the output of the ED instruction and placing the dollar sign at a place deemed appropriate.

Suppose now that the packed value to be printed is represented by
DC   PL3'7'   This is represented as **00 00 7D**.

Suppose that the edit pattern is specified as follows:

Address	90	91	92	93	94	95	96	97
Code	5C	20	21	20	4B	20	20	60

The reader should verify that the print representation would be **"***0.07-"**.