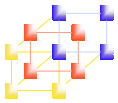


Chapter 2 Assemblers
-- Basic Assembler Functions

Outline

- Basic assembler functions
  - A simple SIC assembler
  - Assembler algorithm and data structure

Basic assembler functions

- Translating mnemonic operation codes to their machine language equivalents
- Assigning machine addresses to symbolic labels

Assembler directive

- Assembler directives are pseudo instructions
  - They provide instructions to the assembler itself
  - They are not translated into machine operation codes
- SIC assembler directive
  - START : specify name & starting address
  - END : end of source program, specify the first execution instruction
  - BYTE, WORD, RESB, RESW
  - End of record : a null char (00)
  - End of file : a zero-length record

Example program (Figure 2.1 pp. 45)

```
 5    COPY      START   1000        COPY FILE FROM INPUT TO OUTPUT
10    FIRST     STL     RETADR      SAVE RETURN ADDRESS
15    CLOOP     JSUB    RDREC       READ INPUT RECORD
20              LDA     LENGTH      TEST FOR EOF (LENGTH = 0)
25              COMP    ZERO
30              JEQ     ENDFIL      EXIT IF EOF FOUND
35              JSUB    WRREC       WRITE OUTPUT RECORD
40              J       CLOOP       LOOP
45    ENDFIL    LDA     EOF         INSERT END OF FILE MARKER
50              STA     BUFFER
55              LDA     THREE       SET LENGTH = 3
60              STA     LENGTH
65              JSUB    WRREC       WRITE EOF
70              LDL     RETADR      GET RETURN ADDRESS
75              RSUB                RETURN TO CALLER
80    EOF       BYTE    C'EOF'
85    THREE     WORD    3
90    ZERO      WORD    0
95    RETADR    RESW    1
100   LENGTH    RESW    1           LENGTH OF RECORD
105   BUFFER    RESB    4096        4096-BYTE BUFFER AREA
```

Forward reference

Example program (Figure 2.1 pp. 45)

```
110   .
115   .         SUBROUTINE TO READ RECORD INTO BUFFER
120   .
125   RDREC     LDX     ZERO        CLEAR LOOP COUNTER
130             LDA     ZERO        CLEAR A TO ZERO
135   RLOOP     TD      INPUT       TEST INPUT DEVICE
140             JEQ     RLOOP       LOOP UNTIL READY
145             RD      INPUT       READ CHARACTER INTO REGISTER A
150             COMP    ZERO        TEST FOR END OF RECORD (X'00')
155             JEQ     EXIT        EXIT LOOP IF EOR
160             STCH    BUFFER,X    STORE CHARACTER IN BUFFER
165             TIX     MAXLEN      LOOP UNLESS MAX LENGTH
170             JLT     RLOOP         HAS BEEN REACHED
175   EXIT      STX     LENGTH      SAVE RECORD LENGTH
180             RSUB                RETURN TO CALLER
185   INPUT     BYTE    X'F1'       CODE FOR INPUT DEVICE
190   MAXLEN    WORD    4096
195   .
```


Example program (Figure 2.1 pp. 45)

```
200   .         SUBROUTINE TO WRITE RECORD FROM BUFFER
205   .
210   WRREC     LDX     ZERO        CLEAR LOOP COUNTER
215   WLOOP     TD      OUTPUT      TEST OUTPUT DEVICE
220             JEQ     WLOOP       LOOP UNTIL READY
225             LDCH    BUFFER,X    GET CHARACTER FROM BUFFER
230             WD      OUTPUT      WRITE CHARACTER
235             TIX     LENGTH      LOOP UNTIL ALL CHARACTERS
240             JLT     WLOOP         HAVE BEEN WRITTEN
245             RSUB                RETURN TO CALLER
250   OUTPUT    BYTE    X'05'       CODE FOR OUTPUT DEVICE
255             END     FIRST
```


Example program (Figure 2.1 pp. 45)

- Purpose of example program
  - Reads records from input device (code F1)
  - Copies them to output device (code 05)
  - At the end of the file, writes EOF on the output device, then RSUB to the operating system
- Data transfer (RD, WD)
  - A buffer is used to store record
  - Buffering is necessary for different I/O rates
  - The end of each record is marked with a null character $(00)_{16}$
  - The end of the file is indicated by a zero-length record
- Subroutines (JSUB, RSUB)
  - RDREC, WRREC
  - Save link register first before nested jump

A simple SIC assembler

- Assembler's functions
  - Convert mnemonic operation codes to their machine language equivalents
  - Convert symbolic operands to their equivalent machine addresses
  - Decide the proper instruction format
  - Convert the data constants to internal machine representations
  - Write the object program and the assembly listing

Difficult

- Convert symbolic operands to their equivalent machine addresses
  - Forward reference
  - 2 passes
    - **First pass:** scan the source program for label definitions and assign addresses
    - **Second pass:** perform actual translation

Example program with object code (Figure 2.2 pp. 47)

Line	Loc	Source statement			Object code
5	1000	COPY	START	1000	
10	1000	FIRST	STL	RETADR	141033
15	1003	CLOOP	JSUB	RDREC	482039
20	1006		LDA	LENGTH	001036
25	1009		COMP	ZERO	281030
30	100C		JEQ	ENDFIL	301015
35	100F		JSUB	WRREC	482061
40	1012		J	CLOOP	3C1003
45	1015	ENDFIL	LDA	EOF	00102A
50	1018		STA	BUFFER	0C1039
55	101B		LDA	THREE	00102D
60	101E		STA	LENGTH	0C1036
65	1021		JSUB	WRREC	482061
70	1024		LDL	RETADR	081033
75	1027		RSUB		4C0000
80	102A	EOF	BYTE	C'EOF'	454F46
85	102D	THREE	WORD	3	000003
90	1030	ZERO	WORD	0	000000
95	1033	RETADR	RESW	1	
100	1036	LENGTH	RESW	1	
105	1039	BUFFER	RESB	4096	
110		.			

Example program with object code (Figure 2.2 pp. 47)

110		.			
115		.	SUBROUTINE TO READ RECORD INTO BUFFER		
120		.			
125	2039	RDREC	LDX	ZERO	041030
130	203C		LDA	ZERO	001030
135	203F	RLOOP	TD	INPUT	E0205D
140	2042		JEQ	RLOOP	30203F
145	2045		RD	INPUT	D8205D
150	2048		COMP	ZERO	281030
155	204B		JEQ	EXIT	302057
160	204E		STCH	BUFFER,X	549039
165	2051		TIX	MAXLEN	2C205E
170	2054		JLT	RLOOP	38203F
175	2057	EXIT	STX	LENGTH	101036
180	205A		RSUB		4C0000
185	205D	INPUT	BYTE	X'F1'	F1
190	205E	MAXLEN	WORD	4096	001000
195					

Example program with object code (Figure 2.2 pp. 47)

```
195       .
200       .     SUBROUTINE TO WRITE RECORD FROM BUFFER
205       .
210   2061  WRREC  LDX     ZERO        041030
215   2064  WLOOP  TD      OUTPUT      E02079
220   2067         JEQ     WLOOP       302064
225   206A         LDCH    BUFFER,X    509039
230   206D         WD      OUTPUT      DC2079
235   2070         TIX     LENGTH      2C1036
240   2073         JLT     WLOOP       382064
245   2076         RSUB                4C0000
250   2079  OUTPUT BYTE    X'05'       05
255                END     FIRST
```


Format of object program (Figure 2.3 pp.49)

- **Header record**
  - Col. 1 H
  - Col. 2~7 Program name
  - Col. 8~13 Starting address of object program (hex)
  - Col. 14-19 Length of object program in bytes (hex)
- **Text record**
  - Col. 1 T
  - Col. 2~7 Starting address for object code in this record (hex)
  - Col. 8~9 Length of object code in this record in bytes (hex)
  - Col. 10~69 Object code, represented in hex (2 col. per byte)
- **End record**
  - Col.1 E
  - Col.2~7 Address of first executable instruction in object program (hex)

- "^" is only for separation only

Format of object program (Figure 2.3 pp.49)

```
HCOPY ^001000^00107A
T^001000^1E^141033^482039^001036^281030^301015^482061^3C1003^00102A^0C1039^00102D
T^00101E^15^0C1036^482061^081033^4C0000^454F46^000003^000000
T^002039^1E^041030^001030^E0205D^30203F^D8205D^281030^302057^549039^2C205E^38203F
T^002057^1C^101036^4C0000^F1^001000^041030^E02079^302064^509039^DC2079^2C1036
T^002073^07^382064^4C0000^05
E^001000
```

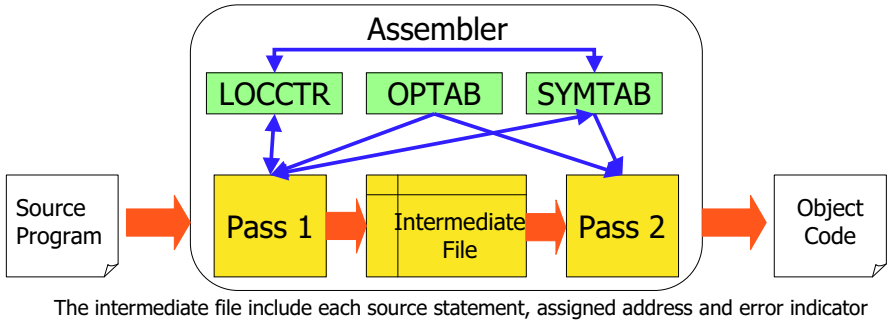
Address 1033 ~ 2038: reserve storage by loader
- RETADR: 3 bytes
- LENGTH: 3 bytes
- BUFFER: 4096 bytes = $(1000)_{16}$

The two passes of an assembler

- Pass 1 (define symbols)
  - Assign addresses to all statements in the program
  - Save the addresses assigned to all labels for use in Pass 2
  - Perform assembler directives, including those for address assignment, such as BYTE and RESW
- Pass 2 (assemble instructions and generate object program)
  - Assemble instructions (generate opcode and look up addresses)
  - Generate data values defined by BYTE, WORD
  - Perform processing of assembler directives not done during Pass 1
  - Write the object program and the assembly listing

Assembler algorithm and data structures

- OPTAB: operation code table
- SYMTAB: symbol table
- LOCCTR: location counter



The intermediate file include each source statement, assigned address and error indicator

OPTABLE

- Mnemonic operation codes ⇔ Machine code
- Contain instruction format and length
  - LOCCTR ← LOCCTR + (instruction length)
- Implementation
  - It is a static table
  - Array or hash table
    - `Usually use a hash table (mnemonic opcode as key)`

LOCCTR

- Initialize to be the beginning address specified in the “START” statement
- LOCCTR ← LOCCTR + (instruction length)
- The current value of LOCCTR gives the address to the label encountered

SYMTAB

- Label name ⇔ label address, type, length, flag
  - To indicate error conditions (Ex: multiple define)
- It is a dynamic table
  - Insert, delete and search
  - Usually use a hash table
    - `The hash function should perform non-random key (Ex: LOOP1, LOOP2, X, Y, Z)`

Algorithm Pass 2 (Figure 2.4(b), pp.54)

Pass 2:

```
begin
  read first input line {from intermediate file}
  if OPCODE = 'START' then
     begin
        write listing line
        read next input line
     end {if START}
  write Header record to object program
  initialize first Text record
  while OPCODE ≠ 'END' do
     begin
        if this is not a comment line then
           begin
              search OPTAB for OPCODE
              if found then
                 begin
                    if there is a symbol in OPERAND field then
                       begin
                          search SYMTAB for OPERAND
                          if found then
                             store symbol value as operand address
                          else
                             begin
                                store 0 as operand address
                                set error flag (undefined symbol)
                             end
                       end {if symbol}
                    else
                       store 0 as operand address
                    assemble the object code instruction
                 end {if opcode found}
              else if OPCODE = 'BYTE' or 'WORD' then
                 convert constant to object code
              if object code will not fit into the current Text record then
                 begin
                    write Text record to object program
                    initialize new Text record
                 end
              add object code to Text record
           end {if not comment}
        write listing line
        read next input line
     end {while not END}
  write last Text record to object program
  write End record to object program
  write last listing line
end {Pass 2}
```


Algorithm Pass 1 (Figure 2.4(a), pp.53)

Pass 1:

```
begin
  read first input line
  if OPCODE = 'START' then
     begin
        save #[OPERAND] as starting address
        initialize LOCCTR to starting address
        write line to intermediate file
        read next input line
     end {if START}
  else
     initialize LOCCTR to 0
  while OPCODE ≠ 'END' do
     begin
        if this is not a comment line then
           begin
              if there is a symbol in the LABEL field then
                 begin
                    search SYMTAB for LABEL
                    if found then
                       set error flag (duplicate symbol)
                    else
                       insert (LABEL,LOCCTR) into SYMTAB
                 end {if symbol}
              search OPTAB for OPCODE
              if found then
                 add 3 {instruction length} to LOCCTR
              else if OPCODE = 'WORD' then
                 add 3 to LOCCTR
              else if OPCODE = 'RESW' then
                 add 3 * #[OPERAND] to LOCCTR
              else if OPCODE = 'RESB' then
                 add #[OPERAND] to LOCCTR
              else if OPCODE  = 'BYTE' then
                 begin
                    find length of constant in bytes
                    add length to LOCCTR
                 end {if BYTE}
              else
                 set error flag (invalid operation code)
           end {if not a comment}
        write line to intermediate file
        read next input line
     end {while not END}
  write last line to intermediate file
  save (LOCCTR - starting address) as program length
end {Pass 1}
```