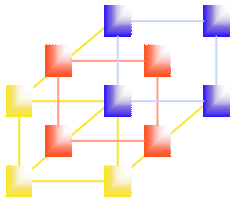
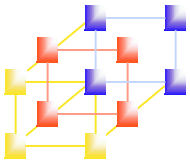
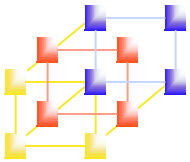


Chapter 2 Assemblers
-- Basic Assembler Functions



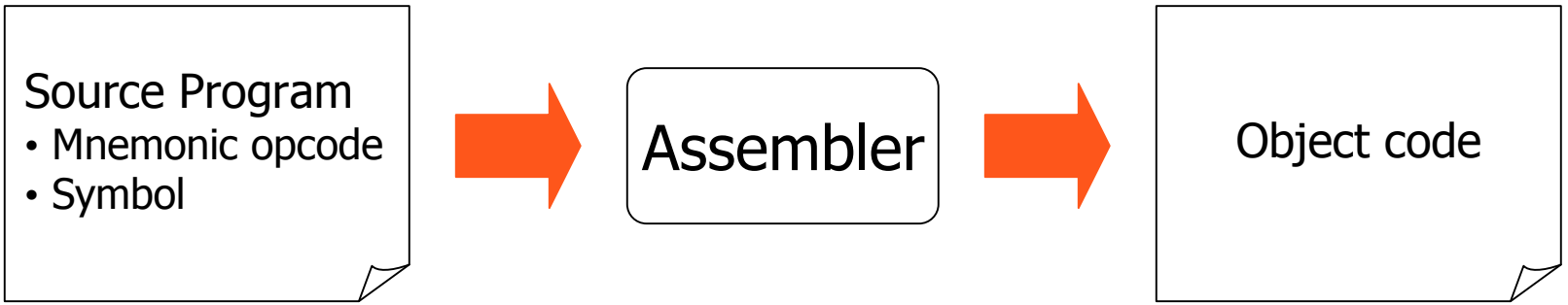
Outline

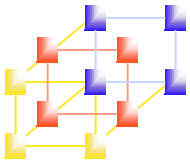
- Basic assembler functions
  - A simple SIC assembler
  - Assembler algorithm and data structure



Basic assembler functions

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

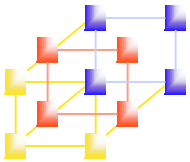




Assembler directive

- 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

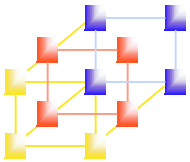
  - End of record : a null char (00)
  - End of file : a zero-length record



Example program (Figure 2.1 pp. 45)

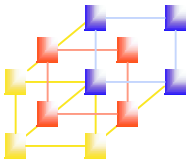
```
 5     COPY      START   1000        COPY FILE FROM INPUT TO OUTPUT
10     FIRST     STL     RETADR      SAVE RETURN ADDRESS
15     CLOOP     JSUB    RDREC       READ INPUT RECORD
20               LDA     LENGTH      TEST FOR EOF (LENGTH = 0)
25               COMP    ZERO
30               JEQ     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



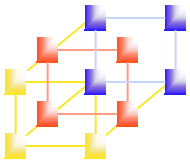
Example program (Figure 2.1 pp. 45)

```
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     .
```



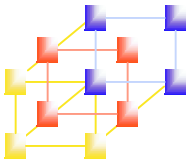
Example program (Figure 2.1 pp. 45)

```
195         .
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
```



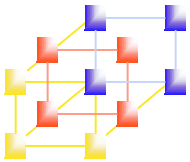
Example program (Figure 2.1 pp. 45)

- 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

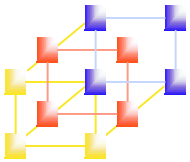
- Assembler's functions
  - Convert mnemonic operation codes to their machine language equivalents
  - Convert symbolic operands to their equivalent machine addresses
  - Decide the proper instruction format
  - Convert the data constants to internal machine representations
  - Write the object program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



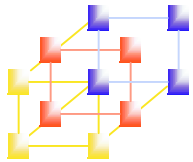
Difficult

- 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		.			

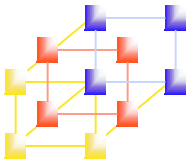


Example program with object code (Figure 2.2 pp. 47)

```
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)

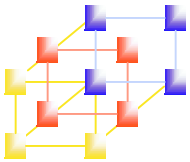
- “^” is only for separation only

Format of object program (Figure 2.3 pp.49)

```
HCOPY  001000001007A
T0010001E141033482039001036281030301015482061 3C100300102A0C103900102D
T00101E150C10364820610810334C0000454F46000003000000
T002039 1E041030001030E0205D30203FD8205D28103030205754903 92C205E38203F
T002057 1C1010364C0000F1001000041030E02079302064509039DC20792C1036
T002073073820644C000005
E001000
```

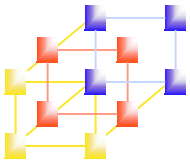
Address 1033 ~ 2038: reserve storage by loader

- RETADR: 3 bytes
- LENGTH: 3 bytes
- BUFFER: 4096 bytes = $(1000)_{16}$



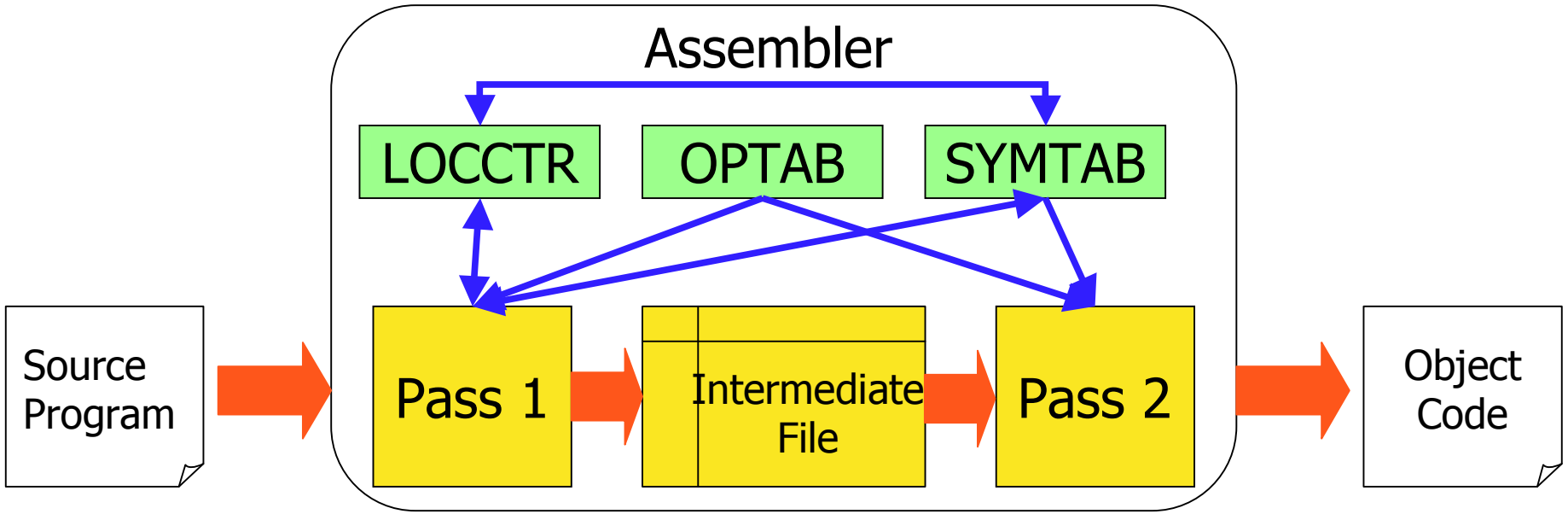
The two passes of an assembler

- 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

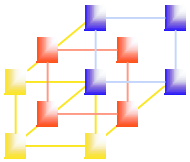


Assembler algorithm and data structures

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

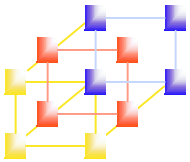


The intermediate file include each source statement, assigned address and error indicator



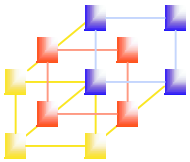
OPTABLE

- 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

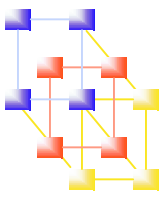
- Initialize to be the beginning address specified in the “START” statement
- LOCCTR ← LOCCTR + (instruction length)
- The current value of LOCCTR gives the address to the label encountered



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)`

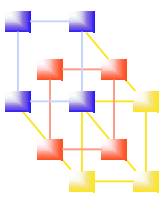
Algorithm Pass 1 (Figure 2.4(a), pp.53)



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}
```

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}
```