System Programming

System Software:
An Introduction to Systems Programming

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Chapter 1
Background

Outline

- Introduction
- System Software and Machine Architecture
- The Simplified Instructional Computer (SIC)
  - SIC Machine Architecture
  - SIC/XE Machine Architecture
  - SIC Programming Examples
- Traditional (CISC) Machines
- RISC Machines

1.1 Introduction

- System Software consists of a variety of programs that support the operation of a computer.
- The programs implemented in either software and (or) firmware that makes the computer hardware usable.
- The software makes it possible for the users to focus on an application or other problem to be solved, without needing to know the details of how the machine works internally.
- Firmware: software that is programmed into chips.

  Example: BIOS (Basic Input Output System)

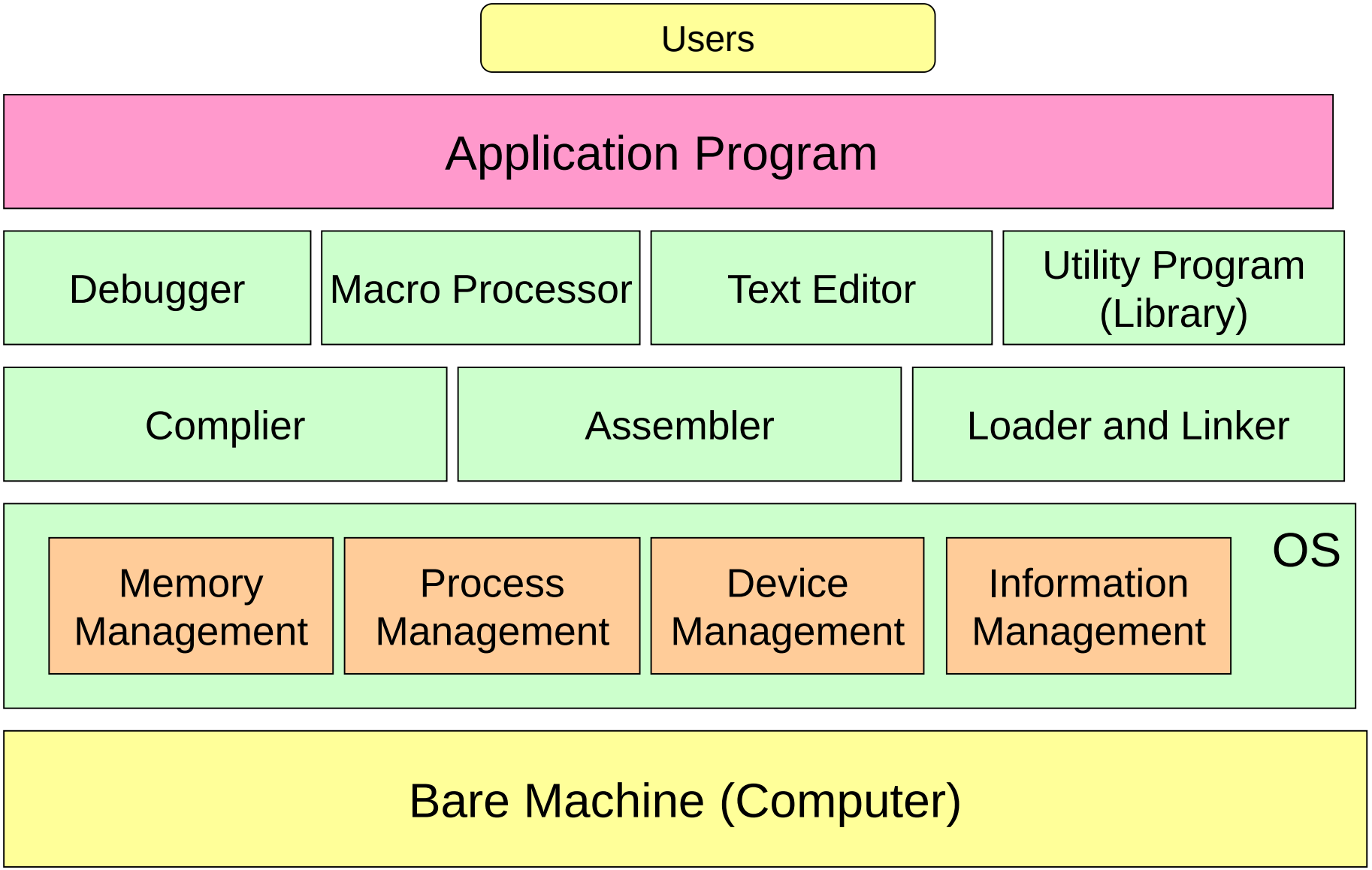
1.2 System Software and Machine Architecture

- System Software vs Application
  - One characteristic in which most system software differs from application software is machine dependency.
  - System programs are intended to support the operation and use of the computer itself, rather than any particular application.
- Examples of system software
  - Text editor, assembler, compiler, loader or linker, debugger, macro processors, operating system, database management systems, software engineering tools, ...

1.2 System Software and Machine Architecture

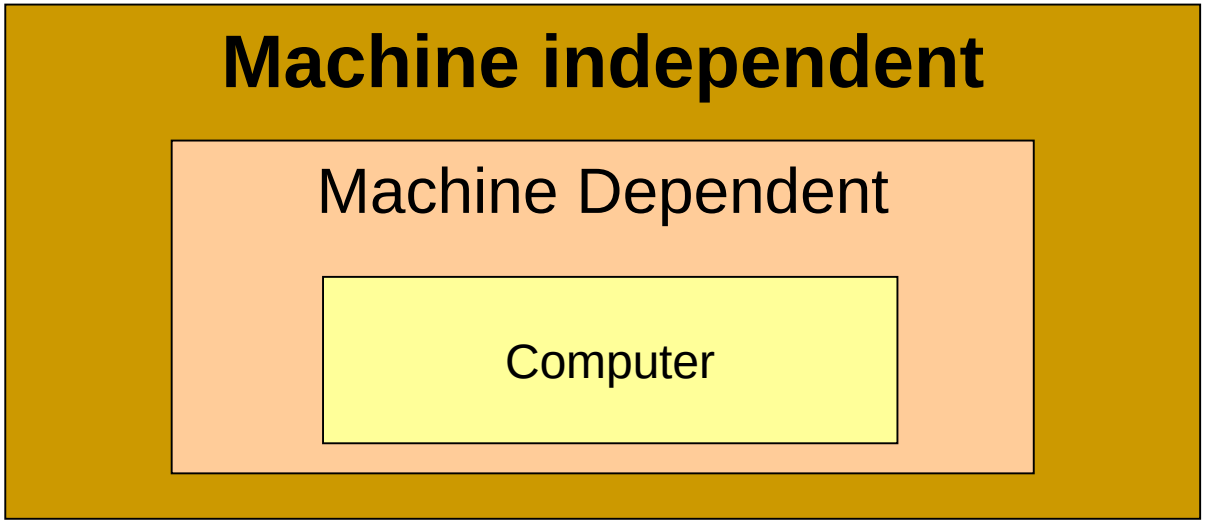
- Text editor
  - Creates and modifies the program
- Compiler and assembler
  - Translates these programs into machine language
- Loader or linker
  - The resulting machine program is loaded into memory and prepared for execution. Linker combines all object files and creates a single executable file.
- Debugger
  - Helps detect errors in the program

System Software Concept



System Software and Machine Architecture

- **Machine dependent**
  - **Instruction Set, Instruction Format, Addressing Mode, Assembly language …**
- **Machine independent**
  - **General design logic/strategy, Two passes assembler…**



1.3 The Simplified Instructional Computer (SIC)

- Like many other products, SIC comes in two versions
  - The standard model
  - An XE version
    - “extra equipments”, “extra expensive”
- The two versions have been designed to be upward compatible
- SIC (Simplified Instructional Computer)
- SIC/XE (Extra Equipment)

1.3 The Simplified Instructional Computer

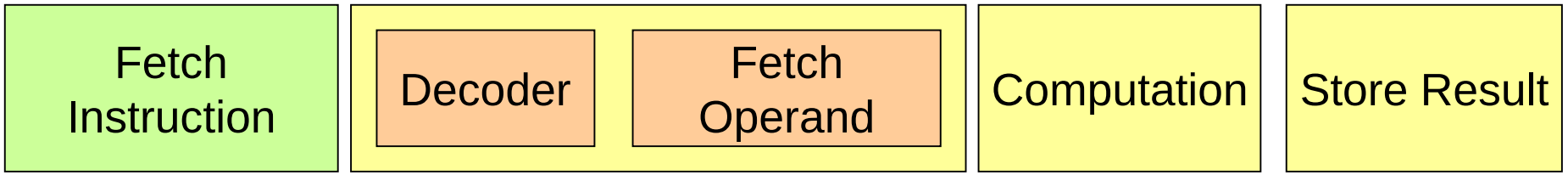
- SIC
  - Upward compatible
  - Memory consists of 8-bit bytes, 3 consecutive bytes form a word (24 bits)
  - There are a total of 32768 bytes (32 KB) in the computer memory.
  - 5 registers, 24 bits in length
    - A 0 Accumulator
    - X 1 Index register
    - L 2 Linkage register (JSUB)
    - PC 8 Program counter
    - SW 9 Status word (Condition Code)

1.3.1 SIC Machine Architecture

- Data Formats
  - Integers are stored as 24-bit binary number
  - 2's complement representation for negative values
  - Characters are stored using 8-bit ASCII codes
  - No floating-point hardware on the standard version of SIC

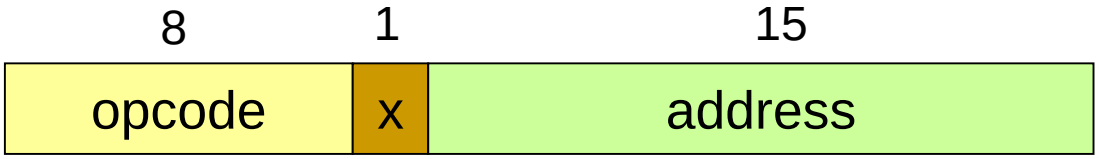
Instruction Cycle

- **CPU**
  - **Control Unit (CU)**
  - **Arithmetic and Logic Unit (ALU)**
  - **Register**
- **Instruction Cycle**
  - **Fetch Cycle**
  - **Execution Cycle**



1.3.1 SIC Machine Architecture

- Instruction format
  - 24-bit format
  - The flag bit x is used to indicate indexed-addressing mode



- Addressing Modes
  - There are two addressing modes available
    - Indicated by x bit in the instruction
    - (X) represents the contents of reg. X

Mode	Indication	Target address calculation
Direct	x = 0	TA = address
Indexed	x = 1	TA = address + (X)

1.3.1 SIC Machine Architecture

- Instruction set
  - Format 3
  - Load and store registers (LDA, LDX, STA, STX, etc.)
  - Integer arithmetic operations (ADD, SUB, MUL, DIV)
  - Compare instruction (COMP)
  - Conditional jump instructions (JLT, JEQ, JGT)
  - JSUB jumps to the subroutine, placing the return address in register L.
  - RSUB returns by jumping to the address contained in register L.

1.3.1 SIC Machine Architecture

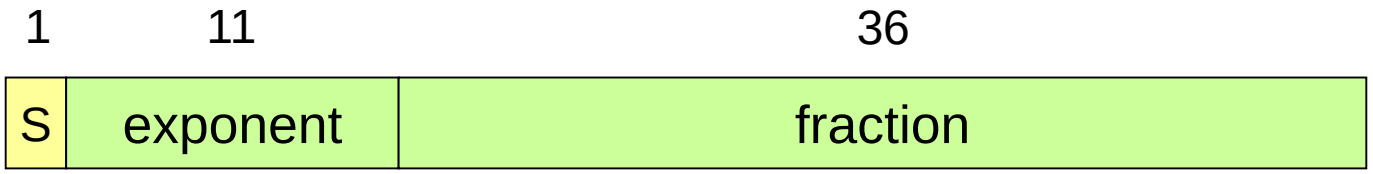
- I/O
  - I/O are performed by transferring 1 byte at a time to or from the rightmost 8 bits of register A.
  - Each device is assigned a unique 8-bit code as an operand.
  - Test Device (TD): tests whether the addressed device is ready to send or receive
    - < ready = not ready
  - Read Data (RD)
  - Write Data (WD)

1.3.2 SIC/XE Machine Architecture

- 1 megabytes (1024 KB) in memory
- 3 additional registers, 24 bits in length
  - B 3 Base register; used for addressing
  - S 4 General working register
  - T 5 General working register
- 1 additional register, 48 bits in length
  - F 6 Floating-point accumulator (48 bits)

1.3.2 SIC/XE Machine Architecture

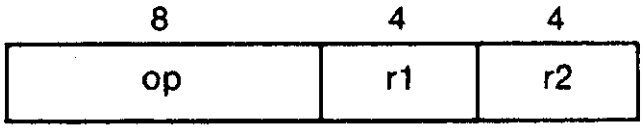
- Data format
  - 24-bit binary number for integer, 2's complement for negative values
  - 48-bit floating-point data type
  - The exponent is between 0 and 2047
  - $f*2^{(e-1024)}$
  - 0: set all bits to 0



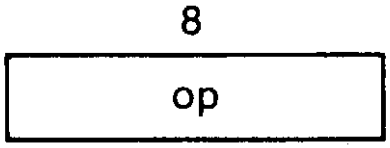
1.3.2 SIC/XE Machine Architecture

- Instruction formats
  - Relative addressing - format 3 (e=0)
  - Extend the address to 20 bits - format 4 (e=1)
  - Don't refer memory at all - formats 1 and 2

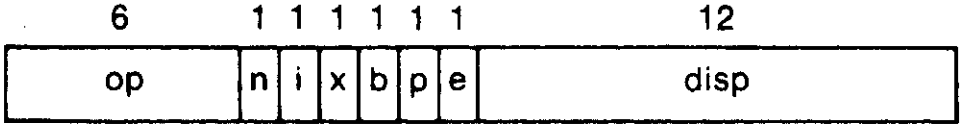
Format 2 (2 bytes):



Format 1 (1 byte):



Format 3 (3 bytes):



Format 4 (4 bytes):

1.3.2 SIC/XE Machine Architecture

- Addressing modes
  - n i x b p e
  - Simple n=0, i=0 (SIC) or n=1, i=1
  - Immediate n=0, i=1 TA=Valus
  - Indirect n=1, i=0 TA=(Operand)
  - Base relative b=1, p=0 TA=(B)+disp

    0 <= disp <= 4095
  - PC relative b=0, p=1 TA=(PC)+disp

    -2048 <= disp <= 2047

Mode	Indication	Target address calculation	
Base relative	b = 1, p = 0	TA = (B) + disp	(0 ≤ disp ≤ 4095)
Program-counter relative	b = 0, p = 1	TA = (PC) + disp	(–2048 ≤ disp ≤ 2047)

1.3.2 SIC/XE Machine Architecture

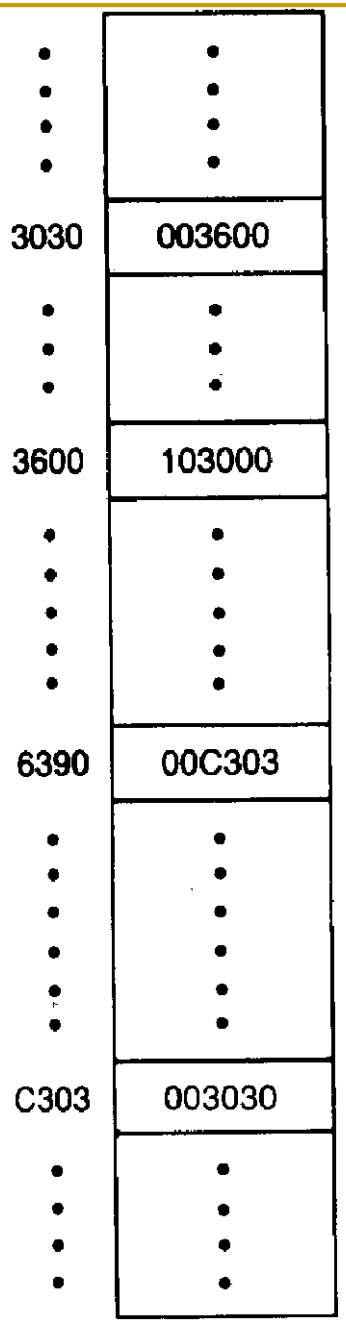
- Addressing mode
  - Direct — b=0, p=0 — TA=disp
  - Index — x=1 — $TA_{new}=TA_{old}+(X)$
  - Index+Base relative — x=1, b=1, p=0 — TA=(B)+disp+(X)
  - Index+PC relative — x=1, b=0, p=1 — TA=(PC)+disp+(X)
  - Index+Direct — x=1, b=0, p=0
  - Format 4 — e=1
- Appendix and Fig. 1.1 Example

Figure 1.1

(B) = 006000

(PC) = 003000

(X) = 000090



(a)

- Memory address
  - 00000

(0000 0000 0000 0000 0000)

  - ~FFFFF (Byte)

(1111 1111 1111 1111 1111)

(B) = 006000

(PC) = 003000

(X) = 000090

Machine instruction										
Hex	Binary								Target address	Value loaded into register A
	op	n	i	x	b	p	e	disp/address		
032600	000000	1	1	0	0	1	0	0110 0000 0000	3600	103000
03C300	000000	1	1	1	1	0	0	0011 0000 0000	6390	00C303
022030	000000	1	0	0	0	1	0	0000 0011 0000	3030	103000
010030	000000	0	1	0	0	0	0	0000 0011 0000	30	000030
003600	000000	0	0	0	0	1	1	0110 0000 0000	3600	103000
0310C303	000000	1	1	0	0	0	1	0000 1100 0011 0000 0011	C303	003030

(b)

1.3.2 SIC/XE Machine Architecture

- Instruction set
  - Format 1, 2, 3, or 4
  - Load and store registers (LDB, STB, etc.)
  - Floating-point arithmetic operations (ADDF, SUBF, MULF, DIVF)
  - Register-to-register arithmetic operations (ADDR, SUBR, MULR, DIVR)
  - A special supervisor call instruction (SVC) is provided
- I/O
  - 1 byte at a time, TD, RD, and WD
  - SIO, TIO, and HIO are used to start, test, and halt the operation of I/O channels.

1.3.3 SIC Programming Examples

- Sample data movement operations
  - No memory-to-memory move instructions (Fig. 1.2)

```
        LDA     five            LDA     #5
        ...                     ...
five    word    5
```

```
        LDA     FIVE        LOAD CONSTANT 5 INTO REGISTER A
        STA     ALPHA       STORE IN ALPHA
        LDCH    CHARZ       LOAD CHARACTER 'Z' INTO REGISTER A
        STCH    C1          STORE IN CHARACTER VARIABLE C1
          .
          .
          .
ALPHA   RESW    1           ONE-WORD VARIABLE
FIVE    WORD    5           ONE-WORD CONSTANT
CHARZ   BYTE    C'Z'        ONE-BYTE CONSTANT
C1      RESB    1           ONE-BYTE VARIABLE
```

1.3.3 SIC Programming Examples

```
        LDA     #5              LOAD VALUE 5 INTO REGISTER A
        STA     ALPHA           STORE IN ALPHA
        LDA     #90             LOAD ASCII CODE FOR 'Z' INTO REG A
        STCH    C1              STORE IN CHARACTER VARIABLE C1
          .
          .
          .
ALPHA   RESW    1               ONE-WORD VARIABLE
C1      RESB    1               ONE-BYTE VARIABLE
```

(b)

Figure 1.2 Sample data movement operations for (a) SIC and (b) SIC/XE.

1.3.3 SIC Programming Examples

- Sample arithmetic operations
  - (ALPHA+INCR-1) assign to BETA (Fig. 1.3)
  - (GAMMA+INCR-1) assign to DELTA

```
            LDA     ALPHA       LOAD ALPHA INTO REGISTER A
            ADD     INCR        ADD THE VALUE OF INCR
            SUB     ONE         SUBTRACT 1
            STA     BETA        STORE IN BETA
            LDA     GAMMA       LOAD GAMMA INTO REGISTER A
            ADD     INCR        ADD THE VALUE OF INCR
            SUB     ONE         SUBTRACT 1
            STA     DELTA       STORE IN DELTA
              .
              .
              .
ONE         WORD    1           ONE-WORD CONSTANT
.                               ONE-WORD VARIABLES
ALPHA       RESW    1
BETA        RESW    1
GAMMA       RESW    1
DELTA       RESW    1
INCR        RESW    1
```

1.3.3 SIC Programming Examples

```
        LDS     INCR        LOAD VALUE OF INCR INTO REGISTER S
        LDA     ALPHA       LOAD ALPHA INTO REGISTER A
        ADDR    S,A         ADD THE VALUE OF INCR
        SUB     #1          SUBTRACT 1
        STA     BETA        STORE IN BETA
        LDA     GAMMA       LOAD GAMMA INTO REGISTER A
        ADDR    S,A         ADD THE VALUE OF INCR
        SUB     #1          SUBTRACT 1
        STA     DELTA       STORE IN DELTA
        .
        .
        .
.                           ONE WORD VARIABLES
ALPHA   RESW    1
BETA    RESW    1
GAMMA   RESW    1
DELTA   RESW    1
INCR    RESW    1
```

1.3.3 SIC Programming Examples

- **String copy**

```
        LDX     ZERO            INITIALIZE INDEX REGISTER TO 0
MOVECH  LDCH    STR1,X          LOAD CHARACTER FROM STR1 INTO REG A
        STCH    STR2,X          STORE CHARACTER INTO STR2
        TIX     ELEVEN          ADD 1 TO INDEX, COMPARE RESULT TO 11
        JLT     MOVECH          LOOP IF INDEX IS LESS THAN 11
        .
        .
        .
STR1    BYTE    C'TEST STRING'  11-BYTE STRING CONSTANT
STR2    RESB    11              11-BYTE VARIABLE
.                               ONE-WORD CONSTANTS
ZERO    WORD    0
ELEVEN  WORD    11
```

1.3.3 SIC Programming Examples

```
            LDT     #11             INITIALIZE REGISTER T TO 11
            LDX     #0              INITIALIZE INDEX REGISTER TO 0
MOVECH      LDCH    STR1,X          LOAD CHARACTER FROM STR1 INTO REG A
            STCH    STR2,X          STORE CHARACTER INTO STR2
            TIXR    T               ADD 1 TO INDEX, COMPARE RESULT TO 11
            JLT     MOVECH          LOOP IF INDEX IS LESS THAN 11
            .
            .
            .
STR1        BYTE    C'TEST STRING'  11-BYTE STRING CONSTANT
STR2        RESB    11              11-BYTE VARIABLE
```

1.3.3 SIC Programming Examples

```
            LDA     ZERO        INITIALIZE INDEX VALUE TO 0
            STA     INDEX
ADDLP       LDX     INDEX       LOAD INDEX VALUE INTO REGISTER X
            LDA     ALPHA,X     LOAD WORD FROM ALPHA INTO REGISTER A
            ADD     BETA,X      ADD WORD FROM BETA
            STA     GAMMA,X     STORE THE RESULT IN A WORD IN GAMMA
            LDA     INDEX       ADD 3 TO INDEX VALUE
            ADD     THREE
            STA     INDEX
            COMP    K300        COMPARE NEW INDEX VALUE TO 300
            JLT     ADDLP       LOOP IF INDEX IS LESS THAN 300
            .
            .
            .
INDEX       RESW    1           ONE-WORD VARIABLE FOR INDEX VALUE
.                               ARRAY VARIABLES--100 WORDS EACH
ALPHA       RESW    100
BETA        RESW    100
GAMMA       RESW    100
.                               ONE-WORD CONSTANTS
ZERO        WORD    0
K300        WORD    300
```

1.3.3 SIC Programming Examples

```
        LDS     #3          INITIALIZE REGISTER S TO 3
        LDT     #300        INITIALIZE REGISTER T TO 300
        LDX     #0          INITIALIZE INDEX REGISTER TO 0
ADDLP   LDA     ALPHA,X     LOAD WORD FROM ALPHA INTO REGISTER A
        ADD     BETA,X      ADD WORD FROM BETA
        STA     GAMMA,X     STORE THE RESULT IN A WORD IN GAMMA
        ADDR    S,X         ADD 3 TO INDEX VALUE
        COMPR   X,T         COMPARE NEW INDEX VALUE TO 300
        JLT     ADDLP       LOOP IF INDEX VALUE IS LESS THAN 300
        .
        .
        .
.                           ARRAY VARIABLES--100 WORDS EACH
ALPHA   RESW    100
BETA    RESW    100
GAMMA   RESW    100
```

(b)

Figure 1.5 Sample indexing and looping operations for (a) SIC and (b) SIC/XE.

1.3.3 SIC Programming Examples

```
INLOOP    TD      INDEV      TEST INPUT DEVICE
          JEQ     INLOOP     LOOP UNTIL DEVICE IS READY
          RD      INDEV      READ ONE BYTE INTO REGISTER A
          STCH    DATA       STORE BYTE THAT WAS READ
          .
          .
          .
OUTLP     TD      OUTDEV     TEST OUTPUT DEVICE
          JEQ     OUTLP      LOOP UNTIL DEVICE IS READY
          LDCH    DATA       LOAD DATA BYTE INTO REGISTER A
          WD      OUTDEV     WRITE ONE BYTE TO OUTPUT DEVICE
          .
          .
          .
INDEV     BYTE    X'F1'      INPUT DEVICE NUMBER
OUTDEV    BYTE    X'05'      OUTPUT DEVICE NUMBER
DATA      RESB    1          ONE-BYTE VARIABLE
```

Figure 1.6 Sample input and output operations for SIC.

1.3.3 SIC Programming Examples

```
            JSUB    READ            CALL READ SUBROUTINE
            .
            .
            .
.                                   SUBROUTINE TO READ 100-BYTE RECORD
READ        LDX     ZERO            INITIALIZE INDEX REGISTER TO 0
RLOOP       TD      INDEV           TEST INPUT DEVICE
            JEQ     RLOOP           LOOP IF DEVICE IS BUSY
            RD      INDEV           READ ONE BYTE INTO REGISTER A
            STCH    RECORD,X        STORE DATA BYTE INTO RECORD
            TIX     K100            ADD 1 TO INDEX AND COMPARE TO 100
            JLT     RLOOP           LOOP IF INDEX IS LESS THAN 100
            RSUB                    EXIT FROM SUBROUTINE
            .
            .
            .
INDEV       BYTE    X'F1'           INPUT DEVICE NUMBER
RECORD      RESB    100             100-BYTE BUFFER FOR INPUT RECORD
.                                   ONE-WORD CONSTANTS
ZERO        WORD    0
K100        WORD    100
```

1.3.3 SIC Programming Examples

```
            JSUB    READ            CALL READ SUBROUTINE
            .
            .
            .
.                                   SUBROUTINE TO READ 100-BYTE RECORD
READ        LDX     #0              INITIALIZE INDEX REGISTER TO 0
            LDT     #100            INITIALIZE REGISTER T TO 100
RLOOP       TD      INDEV           TEST INPUT DEVICE
            JEQ     RLOOP           LOOP IF DEVICE IS BUSY
            RD      INDEV           READ ONE BYTE INTO REGISTER A
            STCH    RECORD,X        STORE DATA BYTE INTO RECORD
            TIXR    T               ADD 1 TO INDEX AND COMPARE TO 100
            JLT     RLOOP           LOOP IF INDEX IS LESS THAN 100
            RSUB                    EXIT FROM SUBROUTINE
            .
            .
            .
INDEV       BYTE    X'F1'           INPUT DEVICE NUMBER
RECORD      RESB    100             100-BYTE BUFFER FOR INPUT RECORD
```

Traditional (CISC) Machines

- Complex Instruction Set Computers (CISC)
  - complicated instruction set
  - different instruction formats and lengths
  - many different addressing modes
  - e.g. VAX or PDP-11 from DEC
  - e.g. Intel x86 family
- Reduced Instruction Set Computer (RISC)

RISC Machines

- RISC system
  - instruction
    - standard, fixed instruction format
    - single-cycle execution of most instructions
    - memory access is available only for load and store instruction
    - other instructions are register-to-register operations
    - a small number of machine instructions, and instruction format
  - a large number of general-purpose registers
  - a small number of addressing modes
  - Three RISC machines
    - SPARC family
    - PowerPC family
    - Cray T3E