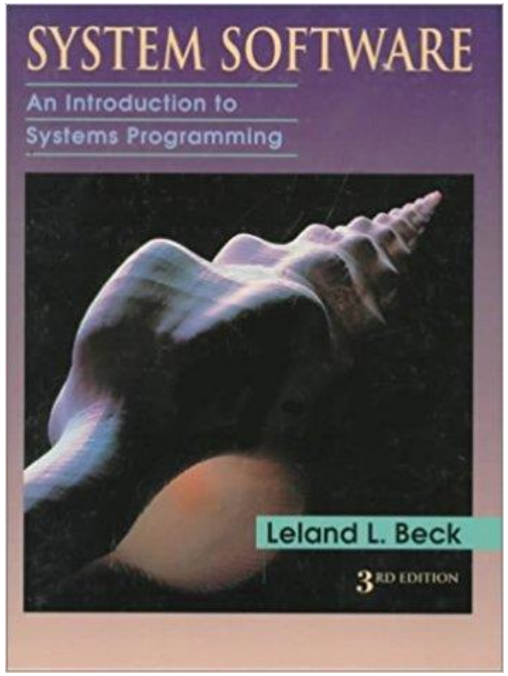
CSCI 30000
Systems Programming
Course Project



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MW 12:30-1:30 SL228

Course Project: Introduction

- These slides will serve as a basic guide to help you get started on the course project
- This project will take a considerable amount of time to complete successfully
  - <u>If you have not already, please quickly make a plan with your group detailing how you will complete this project</u>
  - <u>There is no way you will be able to successfully complete this project if you put if off until the end of the semester</u>
- This project will enhance both your understanding of System Software and your skills as a programmer

Course Project: Goal

- **Design and Implementation Project:** implement an assembler using **Java**, **C++, Perl, Tcl/Tk, others** (any one is OK)
  - I would suggest Java or Python, but you may choose whatever language reflects your team members' strengths
  - Irrespective of choice, you will be responsible for clearly outlining the details of how to successfully compile and run your code
- You will implement an assembler which can process SIC/XE assembly programs and generate the corresponding object codes and object programs

Course Project: Overview

- You will implement an assembler which can process SIC/XE assembly programs and generate the corresponding object codes and object programs
  - What does this actually entail?
  - We will see some specific details in a few slides, but the overall challenge is to…
- In homework one we saw how use an object code to calculate the corresponding SIC/XE instruction’s target addresses, addressing modes, opcode and instruction format (object code -> instruction details)
- In this project you are tasked with discerning a SIC/XE program's instructions’ information and working to create the corresponding object codes (instruction details -> object code)

Course Project: First Steps

- You need to start by reading the first two chapters of the textbook
- Your ability to contribute to your team's effort will be extremely limited if you have not read and fully understand the first two chapters of the textbook
- These first two chapters outline many of the operations, considerations, data structures and implementation details that this project will require
- I will give a few details here, but you will need to review the text to clearly understand what you must do

Course Project: Implementation Details

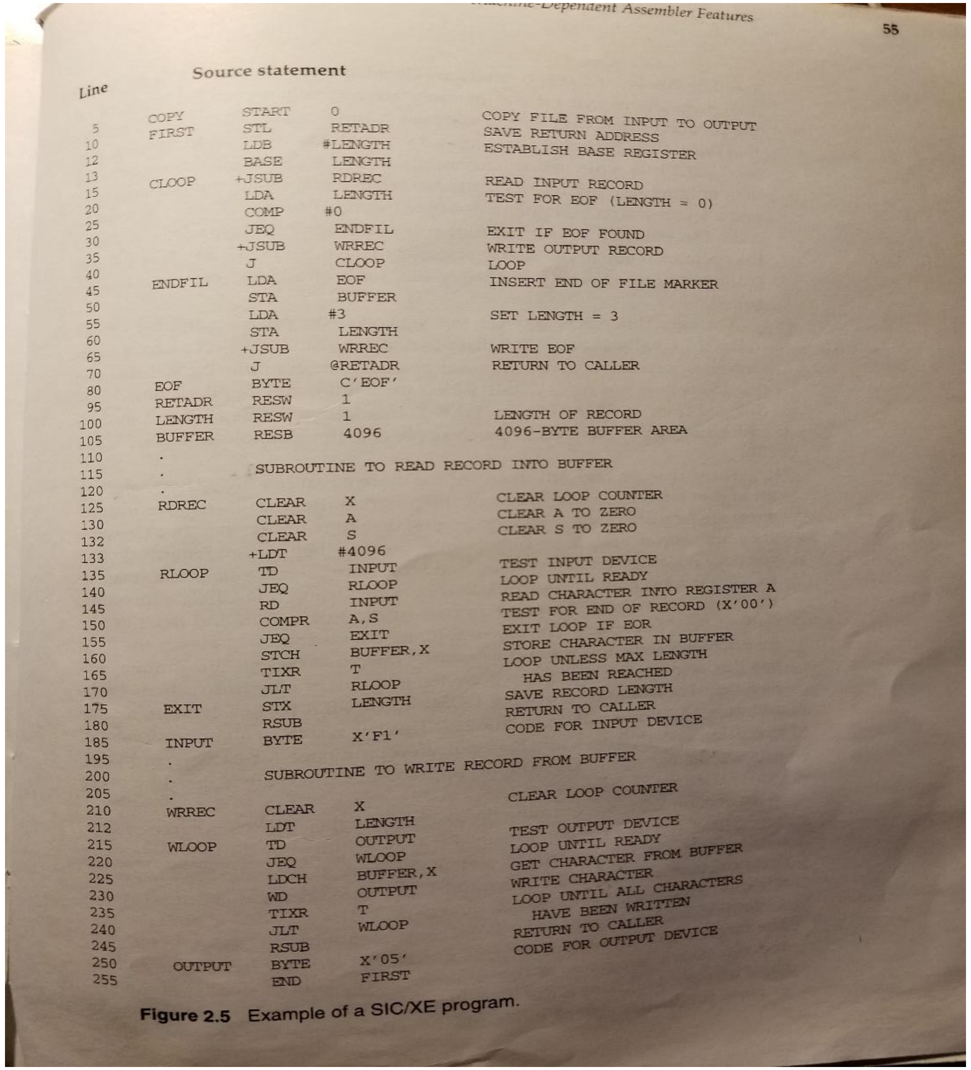
- Let us take a look at some assembler implementation details
- In an email you were given six sample SIC/XE assembly programs
  1. basic.txt
  2. functions.txt
  3. literals.txt
  4. program_blocks.txt
  5. control_sections.txt
  6. macros.txt
- You need to implement an assembler which can successfully process all these files
- Let us start by taking a closer look at functions.txt

Course Project: functions.txt

```
COPY            START       0               .copy the file form INPUT to OUTPUT
FIRST           STL         RETADR          .Save Return address
                LDB         #LENGTH         .establish base register
                BASE        LENGTH
CLOOP           +JSUB       RDREC           .Read INPUT Record
                LDA         LENGTH          .Test for EOF (Length = 0)
                COMP        #0
                JEQ         ENDFIL          .Exit if EOF found
                +JSUB       WRREC           .Write OUTPUT Record
                J           CLOOP           .Loop
ENDFIL          LDA         EOF             .Insert End Of File Marker
                STA         BUFFER
                LDA         #3              .Set LENGTH = 3
                STA         LENGTH
                +JSUB       WRREC           .write EOF
                J           @RETADR         .Return to Caller
EOF             BYTE        C'EOF'
RETADR          RESW        1
LENGTH          RESW        1               .LENGTH of Record
BUFFER          RESB        4096            .4096-BYTE Buffer area
.
.               SUBROUTINE TO READ RECORD INTO BUFFER
.
RDREC           CLEAR       X               .Clear Loop counter
                CLEAR       A               .Clear A to Zero
                CLEAR       S               .Clear S to Zero
                +LDT        #4096
RLOOP           TD          INPUT           .Test INPUT device
                JEQ         RLOOP           .LOOP until ready
                RD          INPUT           .READ character into Register A
                COMPR       A,S             .TEST for End Of Record (X'00')
                JEQ         EXIT            .EXIT loop if EOR
                STCH        BUFFER,X        .STORE character in BUFFER
                TIXR        T               .LOOP unless max Length has been reached
                JLT         RLOOP
EXIT            STX         LENGTH          .SAVE record length
                RSUB                        .Return to caller
INPUT           BYTE        X'F1'           .CODE for Input device
.
.               SUBROUTINE TO WRITE RECORD FROM BUFFER
.
WRREC           CLEAR       X               .CLEAR loop counter
                LDT         LENGTH
WLOOP           TD          OUTPUT          .Test OUTPUT Device
                JEQ         WLOOP           .Loop Until Ready
                LDCH        BUFFER,X        .GET character form BUFFER
                WD          OUTPUT          .WRITE character
                TIXR        T               .LOOP until all characters have been written
                JLT         WLOOP
                RSUB                        .Return to caller
OUTPUT          BYTE        X'05'           .CODE for OUPUT device
                END         FIRST
```

- This SIX/XE program should look familiar, it is from you book!

Course Project: functions.txt



Source statement

```
COPY      START   0            COPY FILE FROM INPUT TO OUTPUT
FIRST     STL     RETADR       SAVE RETURN ADDRESS
          LDB     #LENGTH      ESTABLISH BASE REGISTER
          BASE    LENGTH
CLOOP    +JSUB    RDREC        READ INPUT RECORD
          LDA     LENGTH       TEST FOR EOF (LENGTH = 0)
          COMP    #0
          JEQ     ENDFIL       EXIT IF EOF FOUND
         +JSUB    WRREC        WRITE OUTPUT RECORD
          J       CLOOP        LOOP
ENDFIL    LDA     EOF          INSERT END OF FILE MARKER
          STA     BUFFER
          LDA     #3           SET LENGTH = 3
          STA     LENGTH
         +JSUB    WRREC        WRITE EOF
          J       @RETADR      RETURN TO CALLER
EOF       BYTE    C'EOF'
RETADR    RESW    1
LENGTH    RESW    1            LENGTH OF RECORD
BUFFER    RESB    4096         4096-BYTE BUFFER AREA
.
.         SUBROUTINE TO READ RECORD INTO BUFFER
.
RDREC     CLEAR   X            CLEAR LOOP COUNTER
          CLEAR   A            CLEAR A TO ZERO
          CLEAR   S            CLEAR S TO ZERO
         +LDT     #4096
RLOOP     TD      INPUT        TEST INPUT DEVICE
          JEQ     RLOOP        LOOP UNTIL READY
          RD      INPUT        READ CHARACTER INTO REGISTER A
          COMPR   A,S          TEST FOR END OF RECORD (X'00')
          JEQ     EXIT         EXIT LOOP IF EOR
          STCH    BUFFER,X     STORE CHARACTER IN BUFFER
          TIXR    T            LOOP UNLESS MAX LENGTH
          JLT     RLOOP          HAS BEEN REACHED
EXIT      STX     LENGTH       SAVE RECORD LENGTH
          RSUB                 RETURN TO CALLER
INPUT     BYTE    X'F1'        CODE FOR INPUT DEVICE
.
.         SUBROUTINE TO WRITE RECORD FROM BUFFER
.
WRREC     CLEAR   X            CLEAR LOOP COUNTER
          LDT     LENGTH
WLOOP     TD      OUTPUT       TEST OUTPUT DEVICE
          JEQ     WLOOP        LOOP UNTIL READY
          LDCH    BUFFER,X     GET CHARACTER FROM BUFFER
          WD      OUTPUT       WRITE CHARACTER
          TIXR    T            LOOP UNTIL ALL CHARACTERS
          JLT     WLOOP          HAVE BEEN WRITTEN
          RSUB                 RETURN TO CALLER
OUTPUT    BYTE    X'05'        CODE FOR OUTPUT DEVICE
          END     FIRST
```

Figure 2.5 Example of a SIC/XE program.

- functions.txt (pg. 55)

Course Project: functions.txt

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	17202D
12	0003		LDB	#LENGTH	69202D
13			BASE	LENGTH	
15	0006	CLOOP	+JSUB	RDREC	4B101036
20	000A		LDA	LENGTH	032026
25	000D		COMP	#0	290000
30	0010		JEQ	ENDFIL	332007
35	0013		+JSUB	WRREC	4B10105D
40	0017		J	CLOOP	3F2FEC
45	001A	ENDFIL	LDA	EOF	032010
50	001D		STA	BUFFER	0F2016
55	0020		LDA	#3	010003
60	0023		STA	LENGTH	0F200D
65	0026		+JSUB	WRREC	4B10105D
70	002A		J	@RETADR	3E2003
80	002D	EOF	BYTE	C'EOF'	454F46
95	0030	RETADR	RESW	1	
100	0033	LENGTH	RESW	1	
105	0036	BUFFER	RESB	4096	
110		.			
115		.	SUBROUTINE TO READ RECORD INTO BUFFER		
120		.			
125	1036	RDREC	CLEAR	X	B410
130	1038		CLEAR	A	B400
132	103A		CLEAR	S	B440
133	103C		+LDT	#4096	75101000
135	1040	RLOOP	TD	INPUT	E32019
140	1043		JEQ	RLOOP	332FFA
145	1046		RD	INPUT	DB2013
150	1049		COMPR	A,S	A004
155	104B		JEQ	EXIT	332008
160	104E		STCH	BUFFER,X	57C003
165	1051		TIXR	T	B850
170	1053		JLT	RLOOP	3B2FEA
175	1056	EXIT	STX	LENGTH	134000
180	1059		RSUB		4F0000
185	105C	INPUT	BYTE	X'F1'	F1
195		.			
200		.	SUBROUTINE TO WRITE RECORD FROM BUFFER		
205		.			
210	105D	WRREC	CLEAR	X	B410
212	105F		LDT	LENGTH	774000
215	1062	WLOOP	TD	OUTPUT	E32011
220	1065		JEQ	WLOOP	332FFA
225	1068		LDCH	BUFFER,X	53C003
230	106B		WD	OUTPUT	DF2008
235	106E		TIXR	T	B850
240	1070		JLT	WLOOP	3B2FEF
245	1073		RSUB		4F0000
250	1076	OUTPUT	BYTE	X'05'	05
255			END	FIRST	

Figure 2.6 Program from Fig. 2.5 with object code.

- functions.txt solution (pg. 58)
- Loc and Object Code columns now present!

Course Project: functions.txt

```
H^COPY  ^000000^001077
T^000000^1D^17202D^69202D^4B101036^032026^290000^332007^4B10105D^3F2FEC^032010
T^00001D^13^0F2016^010003^0F200D^4B10105D^3E2003^454F46
T^001036^1D^B410^B400^B440^75101000^E32019^332FFA^DB2013^A004^332008^57C003^B850
T^001053^1D^3B2FEA^134000^4F0000^F1^B410^774000^E32011^332FFA^53C003^DF2008^B850
T^001070^07^3B2FEF^4F0000^05
M^000007^05
M^000014^05
M^000027^05
E^000000
```

Figure 2.8 Object program corresponding to Fig. 2.6.

- functions.txt object program solution (pg. 65)

Course Project: Implementation Details

- Cool! We can already see the answers ☺
- For many of the sample programs the solutions are given in the book
- As you implement your assembler and add functionalities to successfully process each of the six sample programs, you can reference these solutions to see if you are on the right track

- This still doesn't tell us much about how to actually generate the displayed object code or location columns though ☹
- Let us try to figure out

Course Project: Implementation Details

- Our given functions.txt file has four tab delimited columns
  - Symbol Column, Operation Column, Operand Column and Comments Column
- Comments are indicated with a '.'
- In the solution a Loc Coulmn and Object Code Column are added

Line	Source statement			
5	COPY	START	0	COPY FILE FROM INPUT TO OUTPUT
10	FIRST	STL	RETADR	SAVE RETURN ADDRESS
12		LDB	#LENGTH	ESTABLISH BASE REGISTER
13		BASE	LENGTH	
15	CLOOP	+JSUB	RDREC	READ INPUT RECORD
20		LDA	LENGTH	TEST FOR EOF (LENGTH = 0)
25		COMP	#0	
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	#3	SET LENGTH = 3
60		STA	LENGTH	
65		+JSUB	WRREC	WRITE EOF
70		J	@RETADR	RETURN TO CALLER
80	EOF	BYTE	C'EOF'	
95	RETADR	RESW	1	
100	LENGTH	RESW	1	LENGTH OF RECORD
105	BUFFER	RESB	4096	4096-BYTE BUFFER AREA

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	17202D
12	0003		LDB	#LENGTH	69202D
13			BASE	LENGTH	
15	0006	CLOOP	+JSUB	RDREC	4B101036
20	000A		LDA	LENGTH	032026
25	000D		COMP	#0	290000
30	0010		JEQ	ENDFIL	332007
35	0013		+JSUB	WRREC	4B10105D
40	0017		J	CLOOP	3F2FEC
45	001A	ENDFIL	LDA	EOF	032010
50	001D		STA	BUFFER	0F2016
55	0020		LDA	#3	010003
60	0023		STA	LENGTH	0F200D
65	0026		+JSUB	WRREC	4B10105D
70	002A		J	@RETADR	3E2003
80	002D	EOF	BYTE	C'EOF'	454F46
95	0030	RETADR	RESW	1	
100	0033	LENGTH	RESW	1	
105	0036	BUFFER	RESB	4096	

Course Project: Implementation Details

- First we need to perform our assembler's first pass which will serve mainly to create the Loc Column and Symbol Table (SYMTAB)
- The Loc (Location) Column can be created by simply finding the program's starting address and tracking the amount of bytes that have been used by instructions
  - How many bytes per instruction?
  - We will need to use our OPTAB
    (we will see what this is in the next slide)
- The SYMTAB will keep track of the values in the Loc Column corresponding to each symbol in the Symbol Column

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	17202D
12	0003		LDB	#LENGTH	69202D
13			BASE	LENGTH	
15	0006	CLOOP	+JSUB	RDREC	4B101036
20	000A		LDA	LENGTH	032026
25	000D		COMP	#0	290000
30	0010		JEQ	ENDFIL	332007
35	0013		+JSUB	WRREC	4B10105D
40	0017		J	CLOOP	3F2FEC
45	001A	ENDFIL	LDA	EOF	032010
50	001D		STA	BUFFER	0F2016
55	0020		LDA	#3	010003
60	0023		STA	LENGTH	0F200D
65	0026		+JSUB	WRREC	4B10105D
70	002A		J	@RETADR	3E2003
80	002D	EOF	BYTE	C'EOF'	454F46
95	0030	RETADR	RESW	1	
100	0033	LENGTH	RESW	1	
105	0036	BUFFER	RESB	4096	

Course Project: Implementation Details

- Next, we need to perform our second pass in which we generate the Object Code column
- Take a second to re-read (or read ☹) 2.2.1 Instruction Formats and Addressing Modes (pg. 57-61) to get an idea of what we will need to do
- First we should create an Operation Table (OPTAB)
  - The OPTAB will contain an entry for each instruction belonging to the SIC/XE instruction set
  - Each entry should contain the instruction’s corresponding mnemonic, opcode, and format(s)
  - This information is all given in the back of the book

Course Project: Implementation Details

- Once we have the OPTAB, we will use it to determine an instruction’s opcode and format
- Then (if necessary) we need to calculate the addressing mode information (nixbpe bits)
- Finally (if necessary) we need to calculate the disp/target address information based on the addressing mode information
- All this information will be used to calculate the instructions object code
- Let us see a few examples

Course Project: Implementation Details

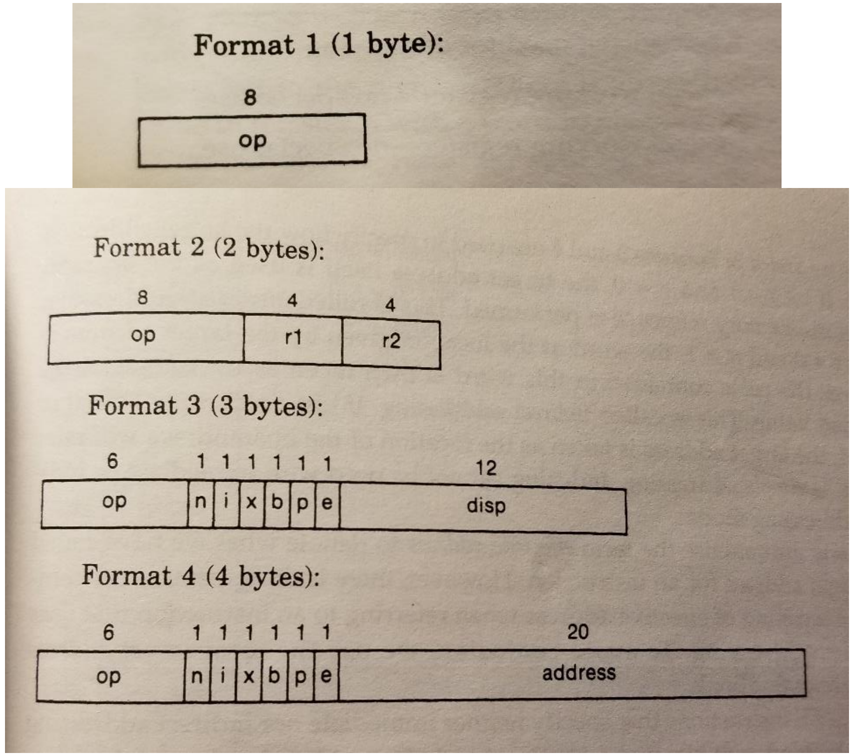
- Take a look in functions.txt at this line:

  FIRST STL RETADR .SAVE RETURN ADDRESS

- First, from our OPTAB we can see STL has an opcode of 14 (hexadecimal) and has a format of 3/4 (3 or 4)
- This means the first byte of our opcode will contain the value 14 (0001 0100) plus the n and i bit values we find
- This also means we will either have a format 3 or 4 instruction

Course Project: Implementation Details

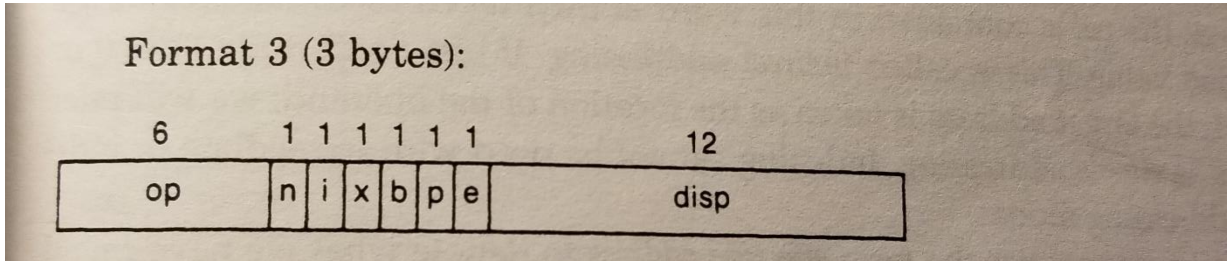
- Remember our SIC/XE addressing modes? (pg. 8 and 9)



- How can we tell if it is format 3 or 4?

Course Project: Implementation Details

- To indicate an instruction is format 4, the instruction will be preceded by a '+'
  - For example, in functions.txt take a look at the +JSUB WRECC line
- Since STL has no preceding '+' it must be format 3
- So we have the first six bits opcode of our 3 byte format 3 instruction, what about the rest?



Course Project: Implementation Details

- Next we need to calculate the nixbpe bits
- Remember:
  - n=1, i=1 indicates simple addressing
    - We have this by default if we don’t have indirect or immediate addressing
  - n=1, i=0 indicates indirect addressing
    - This will be signaled by an operand preceded by a ‘@’
    - For example, in functions.txt find the J @RETADR line
  - n=0, i=1 indicates immediate addressing
    - This will be signaled by an operand preceded by a ‘#’
    - For example, in functions.txt find the LDB #LENGTH line
  - x=1 indicates indexed addressing
    - This will be signaled by an operand followed by ‘, X’
    - For example, in functions.txt find the STCH BUFFER, X line
  - b=1, p=0 indicates for base relative addressing
  - b=0, p=1 indicates for program-counter relative addressing
  - e=1 indicates a format 4 instruction (e=0 indicates format 3 instruction)

Course Project: Implementation Details

- The base relative vs. program-counter relative distinction is a bit harder to discern
- In the reading we learned program-counter relative is used by default, but, if the displacement (disp) we calculate is out of range, we resort to base relative

Mode	Indication	Target address calculation	
Base relative	b = 1, p = 0	TA = (B) + disp	$(0 \le \text{disp} \le 4095)$
Program-counter relative	b = 0, p = 1	TA = (PC) + disp	$(-2048 \le \text{disp} \le 2047)$

Course Project: Implementation Details

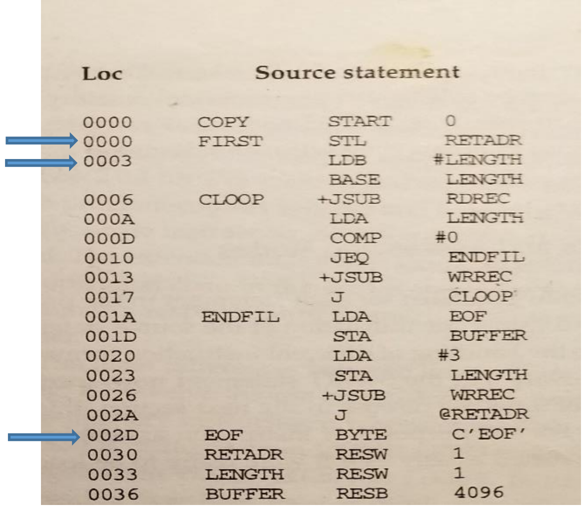
- So, in order to see whether we should use program-counter relative or base relative we need to calculate the displacement (disp)
- Its been a few slides, remember we are looking at the line:

  FIRST STL RETADR .SAVE RETURN ADDRESS
- From out first pass, we know this line's corresponding Loc Column value is 0000
- From the reading, we know that the PC register will

  contain the next Loc Column value (0003)
- We also know from our first pass-generated SYMTAB that the

  value corresponding to RETADR is 0030

  (this is the target address (TA))



Loc	Source statement		
0000	COPY	START	0
0000	FIRST	STL	RETADR
0003		LDB	#LENGTH
		BASE	LENGTH
0006	CLOOP	+JSUB	RDREC
000A		LDA	LENGTH
000D		COMP	#0
0010		JEQ	ENDFIL
0013		+JSUB	WRREC
0017		J	CLOOP
001A	ENDFIL	LDA	EOF
001D		STA	BUFFER
0020		LDA	#3
0023		STA	LENGTH
0026		+JSUB	WRREC
002A		J	@RETADR
002D	EOF	BYTE	C'EOF'
0030	RETADR	RESW	1
0033	LENGTH	RESW	1
0036	BUFFER	RESB	4096

Course Project: Implementation Details

- From the book we see, for pc-relative addressing:

  TA=(PC)+disp -> disp=TA-(PC)
- This means our disp=0030-0003, disp=002D (hexadecimal values)
- This is within our program-counter relative disp bounds

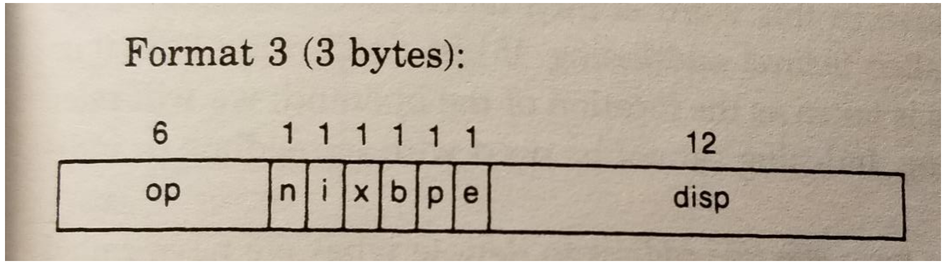
  (-2048 <= disp <= 2047) (decimal values)

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

Course Project: Implementation Details

- We finally have all the information we need to form the object code for line:

  FIRST STL RETADR .SAVE RETURN ADDRESS
- op (opcode)=14 or 0001 0100
- n=1,i=1,x=0,b=0,p=1,e=0 or 11 0010
  - We have simple addressing because we didn’t have immediate or indirect addressing!
- disp=02D or 0000 0011 1101



Course Project: Implementation Details

FIRST   STL   RETADR   .SAVE RETURN ADDRESS

- Object Code Generation:
  - First byte = opcode + ni -> 0001 0100 + 11 (or 14 + 3) -> 0001 0111 (or 17)

    So, our first byte = 0001 0111 (or 17)
  - Second byte first half = xbpe -> 0010 (or 2)

    So, our second byte first half = 0010 (or 2)
  - Second byte second half and third byte = disp -> 0000 0011 1101 (or 02D)

    So, our second byte second half and third byte = 0000 0011 1101 (or 02D)
  - Altogether, our 3-byte format 3 instruction is:

    0001 0111 0010 0000 0011 1101 (or 17202D)

Course Project: Implementation Details

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	17202D
12	0003		LDB	#LENGTH	69202D
13			BASE	LENGTH	
15	0006	CLOOP	+JSUB	RDREC	4B101036
20	000A		LDA	LENGTH	032026
25	000D		COMP	#0	290000
30	0010		JEQ	ENDFIL	332007
35	0013		+JSUB	WRREC	4B10105D
40	0017		J	CLOOP	3F2FEC
45	001A	ENDFIL	LDA	EOF	032010
50	001D		STA	BUFFER	0F2016
55	0020		LDA	#3	010003
60	0023		STA	LENGTH	0F200D
65	0026		+JSUB	WRREC	4B10105D
70	002A		J	@RETADR	3E2003
80	002D	EOF	BYTE	C'EOF'	454F46
95	0030	RETADR	RESW	1	
100	0033	LENGTH	RESW	1	
105	0036	BUFFER	RESB	4096	
110		.			
115		.	SUBROUTINE TO READ RECORD INTO BUFFER		
120		.			
125	1036	RDREC	CLEAR	X	B410
130	1038		CLEAR	A	B400
132	103A		CLEAR	S	B440
133	103C		+LDT	#4096	75101000
135	1040	RLOOP	TD	INPUT	E32019
140	1043		JEQ	RLOOP	332FFA
145	1046		RD	INPUT	DB2013
150	1049		COMPR	A,S	A004
155	104B		JEQ	EXIT	332008
160	104E		STCH	BUFFER,X	57C003
165	1051		TIXR	T	B850
170	1053		JLT	RLOOP	3B2FEA
175	1056	EXIT	STX	LENGTH	134000
180	1059		RSUB		4F0000
185	105C	INPUT	BYTE	X'F1'	F1
195		.			
200		.	SUBROUTINE TO WRITE RECORD FROM BUFFER		
205		.			
210	105D	WRREC	CLEAR	X	B410
212	105F		LDT	LENGTH	774000
215	1062	WLOOP	TD	OUTPUT	E32011
220	1065		JEQ	WLOOP	332FFA
225	1068		LDCH	BUFFER,X	53C003
230	106B		WD	OUTPUT	DF2008
235	106E		TIXR	T	B850
240	1070		JLT	WLOOP	3B2FEF
245	1073		RSUB		4F0000
250	1076	OUTPUT	BYTE	X'05'	05
255			END	FIRST	

Figure 2.6 Program from Fig. 2.5 with object code.

Course Project: Implementation Details

- The overall process will be quite similar for format 4 instructions
- This process will differ slightly with the different addressing modes
- Base relative addressing will require you to keep track of what is loaded into the B register for use in your disp calculation
- Immediate and indirect addressing effects also need to be considered!

Course Project: Implementation Details

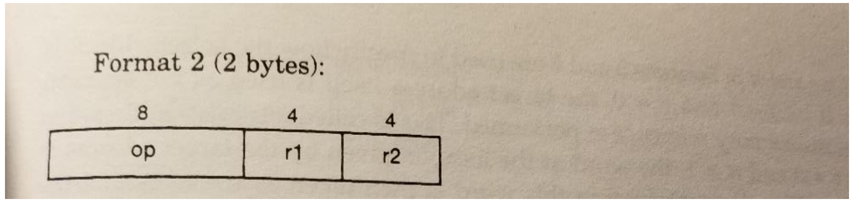
- Let us take a look at a format 2 instruction
- Look at functions.txt and find the line:

```
COMPR    A,S    .TEST for End Of Record (X'00')
```

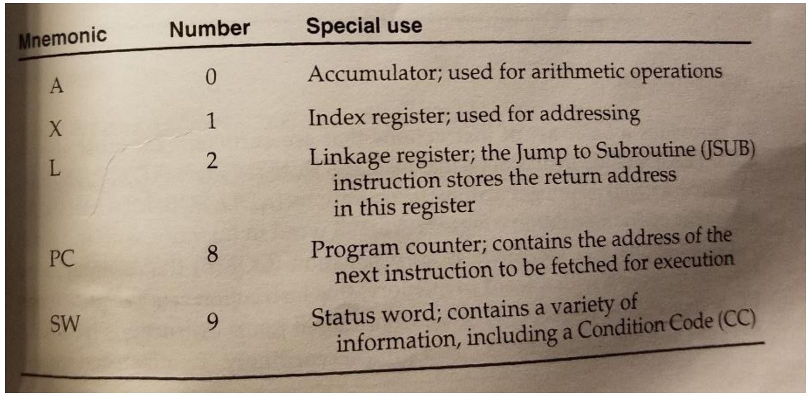
- From our OPTAB we see COMPR has opcode of A0 (hexadecimal value) and that it is a format 2 instruction

Course Project: Implementation Details

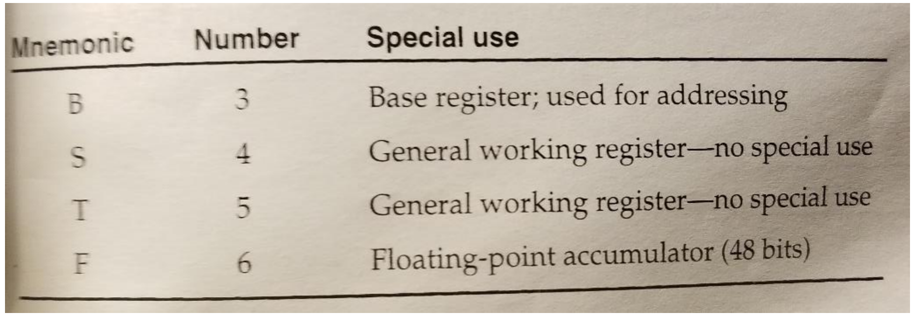
- So, we already have the op section ready (A0 or 1010 0000) for the first byte
- We need to get the r1 and r2 values for the second byte



- The book lists all the register values for us in the first chapter



Mnemonic	Number	Special use
A	0	Accumulator; used for arithmetic operations
X	1	Index register; used for addressing
L	2	Linkage register; the Jump to Subroutine (JSUB) instruction stores the return address in this register
PC	8	Program counter; contains the address of the next instruction to be fetched for execution
SW	9	Status word; contains a variety of information, including a Condition Code (CC)



Mnemonic	Number	Special use
B	3	Base register; used for addressing
S	4	General working register—no special use
T	5	General working register—no special use
F	6	Floating-point accumulator (48 bits)

Course Project: Implementation Details

COMPR   A,S   .TEST for End Of Record (X'00')

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- We need the A (0 hexadecimal) and S (4 hexadecimal) register values for r1 and r2 respectively

Format 2 (2 bytes):

8	4	4
op	r1	r2

Course Project: Implementation Details

COMPR   A,S   .TEST for End Of Record (X'00')

- Object Code Generation:
  - First byte = opcode -> 1010 0000 (or A0)

    So, our first byte = 1010 0000 (or A0)
  - Second byte first half = r1 -> A -> 0000 (or 0)

    So, the second byte first half = 0000 (or 0)
  - Second byte second half = r2 -> S -> 0100 (or 4)

    So, the second byte second half = 0100 (or 4)
  - Altogether, our 2-byte format 2 instruction is:

    1010 0000 0000 0100 (or A004)

Course Project: Implementation Details

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	17202D
12	0003		LDB	#LENGTH	69202D
13			BASE	LENGTH	
15	0006	CLOOP	+JSUB	RDREC	4B101036
20	000A		LDA	LENGTH	032026
25	000D		COMP	#0	290000
30	0010		JEQ	ENDFIL	332007
35	0013		+JSUB	WRREC	4B10105D
40	0017		J	CLOOP	3F2FEC
45	001A	ENDFIL	LDA	EOF	032010
50	001D		STA	BUFFER	0F2016
55	0020		LDA	#3	010003
60	0023		STA	LENGTH	0F200D
65	0026		+JSUB	WRREC	4B10105D
70	002A		J	@RETADR	3E2003
80	002D	EOF	BYTE	C'EOF'	454F46
95	0030	RETADR	RESW	1	
100	0033	LENGTH	RESW	1	
105	0036	BUFFER	RESB	4096	
110		.			
115		.	SUBROUTINE TO READ RECORD INTO BUFFER		
120		.			
125	1036	RDREC	CLEAR	X	B410
130	1038		CLEAR	A	B400
132	103A		CLEAR	S	B440
133	103C		+LDT	#4096	75101000
135	1040	RLOOP	TD	INPUT	E32019
140	1043		JEQ	RLOOP	332FFA
145	1046		RD	INPUT	DB2013
150	1049		COMPR	A,S	A004
155	104B		JEQ	EXIT	332008
160	104E		STCH	BUFFER,X	57C003
165	1051		TIXR	T	B850
170	1053		JLT	RLOOP	3B2FEA
175	1056	EXIT	STX	LENGTH	134000
180	1059		RSUB		4F0000
185	105C	INPUT	BYTE	X'F1'	F1
195		.			
200		.	SUBROUTINE TO WRITE RECORD FROM BUFFER		
205		.			
210	105D	WRREC	CLEAR	X	B410
212	105F		LDT	LENGTH	774000
215	1062	WLOOP	TD	OUTPUT	E32011
220	1065		JEQ	WLOOP	332FFA
225	1068		LDCH	BUFFER,X	53C003
230	106B		WD	OUTPUT	DF2008
235	106E		TIXR	T	B850
240	1070		JLT	WLOOP	3B2FEF
245	1073		RSUB		4F0000
250	1076	OUTPUT	BYTE	X'05'	05
255			END	FIRST	

Figure 2.6 Program from Fig. 2.5 with object code.

Course Project: Implementation Details

- With each of the sample programs there will need to be added functionality your assembler will need to support
  - literals.txt adds literals
  - program-blocks.txt adds program blocks
  - etc.
- You also should create object programs using the object code you generate
  - I would suggest leaving this part until you can support all six test files
- I will leave figuring out these parts to you
- Your book is very straightforward and will be your friend as you are figuring out these details
- You can come to my office hours and ask me questions

Course Project: Testing

- Your assembler should support the six test programs
- To test for robustness, your assembler will be tested using files you do not have access to

- Good luck and have fun!
- Email: phillity@iu.edu
- Office Hour: MW 12:30-1:30 SL228