A New Role of Assembly Language in Computer Engineering/Science Curriculum

Afsaneh Minaie  Reza Sanati-Mehrizy
Assistant Professor  Associate Professor
minaieaf@uvsc.edu  sanatre@uvsc.edu
Computing and Networking Sciences Department
Utah Valley State College

Abstract:

A separate assembly language course in computer engineering/science curriculum is not required by curriculum guidelines anymore. This is because assembly language programmer is not needed in industry and the curriculum does not afford to include a separate course for assembly language programming. However, it is essential for students to be exposed to assembly language to understand the different concepts in computer engineering/science.

In our introductory computer architecture and assembly language course, we are teaching assembly language using 8086 architecture and Turbo Assembler’s Ideal mode for about seven weeks in order to introduce the basic concepts of computer architecture and organization. The students will benefit from knowledge of assembly language programming early in the curriculum not only for better understanding of computer organization and architecture, but it will help them with the concepts such as data representation, instruction interpretation, compiler design, system programming, cost of language abstractions and hardware/software tradeoffs. In this paper, we elaborate the detail content of our introductory computer architecture & assembly language course and the teaching strategies and analyze its outcome.

Introduction

Computer engineering and computer science fields are expanding in all directions. All the subject areas have grown and new subject areas have been added. Since, there are a limited number of courses that can be included in a curriculum model; some of the existing courses will have to be dropped to introduce new ones. As software applications become more complex, more industries use high level languages. The lack of need in industry makes assembly language programming to be a good candidate for elimination from the curriculum. The newer curriculum standards now
recommend the diminution of traditional assembly language programming to make way for a glut of new curriculum topics such as software engineering, object oriented programming, security, computer graphics, and the World Wide Web\(^1\). This paper argues that assembly language is a vital component of computer engineering/science; however, its role in the traditional curriculum should be evaluated. The assembly language can be used as a tool for better understanding computer architecture and to prepare students for abstract courses to come. The intention of teaching assembly language programming is not to make students experts in assembly language programming, however; to use it to understand abstract materials.

The Case for Assembly Language

Assembly language concepts are fundamental for the understanding of many areas of computer engineering/science. During a student’s career, he or she will encounter lots of abstract concepts in subjects ranging from programming languages, to operating systems, to real time programming, to artificial intelligence, to computer interfacing and to compiler design. The foundation of many of these concepts lies in assembly language programming and computer architecture. One might say that assembly language provides bottom-up support for the top-down methodology we teach in high-level languages\(^6\).

Some of the topics which can be explained further using assembly language concepts are: data representation, computer organization, instruction interpretation and encoding, compiler construction, system programming, overhead of data structures, overhead of parameter passing in procedure abstraction, space/time tradeoffs, hardware/software tradeoffs, input/output programming, interrupts, and etc.\(^7\). Krishnaprasad\(^7\) claims that the role of assembly language course is similar to that of the discrete structures course in computer science curriculum.

Teaching assembly language is going to help students learn the abstract computer engineering/science subjects easier. However, due to the lack of need in the industry for assembly programmers and the fact that the computer engineering/science is expanding every day, it will not be affordable to offer a separate course for teaching assembly language. It will be feasible and essential to teach assembly for few weeks in the introductory computer architecture class because it is a viable tool for understanding computer architecture.

Assembly Language and Computer Architecture at Utah Valley State College (UVSC)

Students at UVSC majoring in computer science or computer engineering take an introductory assembly language and computer architecture course after completing their first object oriented course in C++. The goal of this course is to use assembly language as a tool for better understanding computer architecture and to prepare them for abstract courses to come. The intention is not to make students experts in assembly language programming. The introductory course that we teach uses two text books. The primary text is Computer Organization and Architecture by William Stallings\(^7\). The second text is Mastering Turbo Assembler by Tom Swan\(^8\). The software package used is Borland’s Turbo Assembler for the PC.

We start teaching the course by introducing the number systems and data representation and integer arithmetic. Then, we introduce assembly language basics. Our students learn the basic organization and internal functioning of 8086 microprocessor by using Turbo Assembler. As students use the Turbo Debugger to step through an assembly language program, they will
observe the various changes in the registers and status flags. Important teaching points can be emphasized by having them step through an assembly language program while observing the various changes in the registers and status flags. Then, we move to the computer architecture part of the course and teach the structure and function of computers from a top down view. As the need comes for more assembly material, in order for students to do their programming assignments or to understand a computer architecture concept; we move back to the assembly part of the course. The organization of the course is that we mix assembly language concepts and computer architecture materials. Following is an outline for the course that we teach:

Course Outline:

- Number Systems
- Data Representation and Integer Arithmetic
- Introduction to Assembly Language
- 8086 architecture
- 8068 Assembly Language Features
- The History of Computer Architecture Technology
- Addressing Modes for 8086
- Stack
- Digital Logic
- A top-level View of Computer Function and Interconnection
- Subroutines and parameter passing
- Cache Memory
- Logical Instructions
- Internal Memory
- Finite State Machines
- Input / Output Techniques
- Interrupts and Interrupt handling
- Instruction Sets: Characteristics and Functions
- Instruction Sets: Addressing Modes and Formats
- CPU Structure and Function

At UVSC, we have six open computer labs which are open 7:00 a.m. – 10:00 p.m. This class is not held in the lab. However, in the beginning of the semester, we take students to the lab. The purpose of taking students to the lab is for them to become familiar with the turbo assembler environment and learn how to use the debugger. In the lab, the students will type in an assembly program and assemble and link it and use the debugger to step through the program. There is a tutor for the course that sits in the lab to help students with their programming assignments. The tutor-student relationship benefits the tutor as well. Tutor solidifies his/her knowledge while helping their peers. Laboratory programming assignments are given electronically. Assignments are submitted and graded electronically. Following a sample project is given:

Sample Laboratory Project
In this assignment, students will write an interrupt service routine to replace the existing ISR for Control - Break. Normally, the <ct rl-C> key press will terminate the currently running DOS program. Their assignment is to write a new ISR for the <ct rl-C> key. Their program should declare a global variable in their main program data segment where they will keep a count of the number of times the <ct rl-C> key is pressed. Each time <ct rl-C> is pressed their interrupt service routine will get the contents of this variable and add one, then return control to their main program. Their ISR must save the registers that it uses. The interrupt number for Control - Break is 23h, which is a software interrupt.

In their main routine, their program will first save the default interrupt vector then load the interrupt vector to their interrupt service routine. Once the interrupt is set up, they will display the following message:

    Enter a character from the keyboard:

Their program will enter a loop, inspects to see if it is a printable character then prints out the present character input with a space character. It will continue printing out the same character until a different printable character is inputted. If a non-printable character is inputted, stops printing and waits until a printable character is inputted then continues printing the new character. This will continue until an <!> character is entered. Their screen output should look something like this:

Enter a character from the keyboard: a
a a a a a a a a a a a a a a a a a a ^c a a a a a a a a a a a a a a a a a
a a a a a a b b b b b b b b b b b b b b b b b b b b b b b ^c b b b b b b b b b b b b b b b b b b !

<ctrl-C> was pressed 02 times

The characters input in this example were in this order:
<a> <^c> <b> <^c> <^z> <x> <!>

When a <ct rl-C> is pressed their ISR will be called automatically, and the count updated.

When an <!> is pressed, their program should exit the loop and print out the number of times <ct rl-C> was pressed. This count is a byte count and should print out at least 2 ASCII digits in a message something like

<ct rl-C> was pressed 13 times

Their program should then restore the original interrupt that they saved and then exit to DOS.

A student’s implementation of the assignment follows:

```plaintext
%TITLE "CNS 1380 Programming Project #7"
;-----------------------------------------------------------
```

Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition Copyright © 2003, American Society for Engineering Education
; Replace Interrupt Routines for ctrl-c with my own.
; Display prompt, accept input from keyboard.

;-----------------------------------------------------------

IDEAL ; Turbo Assembler mode
MODEL small ; Program model
STACK 100h ; Stack size

;-----------------------------------------------------------

DOS EQU 21h ; DOS interrupt code
KEY EQU 01h ; KEY reads keyboard
WRITE EQU 02h ; WRITE for video display
CR EQU 13 ; ASCII number for carriage return
LF EQU 10 ; ASCII for line feed
STR_WRITE EQU 09h ; Used to write out a string
ENTER_KEY EQU 0Dh ; value for Enter Key
CTRLC EQU 23h ; value for CTRL-C

;-----------------------------------------------------------

DATASEG

exCode DW 04C00h ; return code
msg1 DB 'Enter a character from the keyboard: $'
quitmsg DB '<ctrl-c> was pressed $'
quitmsg2 DB ' times$' ; quit message
charIn DB ? ; used to save input character
vStore1 DW ? ; used to store bx of original vector
vStore2 DW ? ; used to store es of original vector
ctrlcount1 DB '0' ; used to count how many times ctrl-c was pressed
ctrlcount2 DB '0' ; used to count how many times ctrl-c was pressed
keyFlag DB 0FFh ; value returned if key has been pressed

;-----------------------------------------------------------

CODESEG

Main:
    mov ax, @data ; get ds
    mov ds, ax ; initialize ds

; Used to save interrupt vector

;    mov ah, 35h ; get interrupt vector
    mov al, CTRLC ; for INT 23 for CTRL-C
    int 21h ; call DOS
    mov [vStore1], bx ; Store the offset
    mov [vStore2], es ; Store the segment

; Used to set new interrupt vector

;    push ds ; save ds
    push cs ; store cs
    pop ds ; put cs in ds
    mov dx, OFFSET ISRoutine
    mov ah, 25h ; Set interrupt vector
    mov al, CTRLC ; for INT 23 for CTRL-C
    int DOS ; call DOS
    pop ds ; restore ds

Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition Copyright © 2003, American Society for Engineering Education
mov dx, OFFSET msg1  ; prepares msg1 to be displayed
call PutStr  ; calls subroutine to display string
jmp Start

;----------------------------------
; New interrupt code
ISRoutine:
cmp [ctrlcount1], '9'  ; jumps to increment 10's spot
je Count10s
inc [ctrlcount1]  ; increments ctrlcount1 by 1
iret
Count10s:
mov [ctrlcount1], '0'  ; resets ctrlcount1 back to 0
inc [ctrlcount2]  ; increments ctrlcount2 by 1
iret

; Displays prompt, waits for character input
; Goes to first of new line, outputs character that was input
Start:
call GetChar  ; calls routine to accept input character
pop bp  ; pops value for character input from stack
mov ax, bp  ; moves content of bp to ax
mov [charIn], al  ; copies input character to memory
cmp [charIn], '!'  ; if ! is entered then exit
je exitIn  ; jumps to exitIn
je Start  ; if key was pressed goes back to start
mov dl, " "  ; used for spacer
call PutChar  ; puts spacer on screen
call Ischar  ; checks to see if al is a printable character
jz Loopy  ; jumps to Loopy
jmp Start  ; jumps back to Start if an invalid key was pressed
Loopy:
mov ah, 0Bh  ; used to see if there has been a key press
int DOS  ; call DOS
cmp al, [keyFlag]  ; sees if key was pressed
je Start  ; if key was pressed goes back to start
mov dl, [charIn]  ; used for PutChar when displaying prompt
call PutChar  ; calls routine to display character
mov dl, " "  ; used for PutChar when displaying prompt
call PutChar  ; calls routine to display character
jmp Loopy
exitIn:
call NewLine  ; used to exit when ! is entered
mov dx, OFFSET quitmsg  ; used for first part of exit message
call PutStr
mov dl, [ctrlcount2]  ; displays 10's location of number
call PutChar
mov dl, [ctrlcount1]  ; displays 0-9 for times ctrl-c pressed
call PutChar
mov dx, OFFSET quitmsg2  ; end of exit message
call PutStr
push dx  ; pushes current dx register
push ds  ; pushes current ds register
mov dx, [vStore1]  ; used to restore original vector
mov ds, [vStore2]  ; used to restore original vector
mov ah, 25h  ; Set interrupt vector
mov al, CTRL C ; for INT 23
int DOS ; call DOS
pop ds ; pop ds from stack
jmp Exit ; exits

Exit:
mov ax, [exCode] ; return code
int DOS ; function call to DOS

PutStr:
mov ah, STR_WRITE
int DOS
ret

GetChar:
push bp ; used to input character from keyboard
push bp ; used to store future input character
push ax ; used to store updated pointer
mov bp, sp ; backs up old ax
mov bp, sp ; movs sp to bp
mov ax, [bp+6] ; movs old bp into ax
mov [bp+4], ax ; mov ax into new bp stack location
mov ah, KEY ; dos command to key input
int DOS ; calls dos
mov [bp+6], ax ; saves character input onto stack
pop ax ; pops old ax
pop bp ; pops updated bp
ret

PutChar: ; used to move to new line and display character
push bp ; stores old bp
push dx ; stores old dx
mov bp, sp ; mov sp to bp
mov dx, [bp] ; moves the old dx info into dx reg
mov ah, WRITE ; dos call to write character
int DOS ; calls dos
pop dx ; pops old dx content
pop bp ; pops old bp content
ret

NewLine: ; used for carriage return
mov dl, CR
mov ah, WRITE ; dos call to write character
int DOS ; calls dos
mov dl, LF ; used for line feed
mov ah, WRITE ; dos call to write character
int DOS ; calls dos
ret

Ischar:
cmp [charIn], '!' ; used to see if character value is ASCII
jb A1
cmp [charIn], '~'
ja A1
test ax,0
A1:
ret

END Main ; end of program

The course material is available at ftp://cseftp.uvsc.edu/csn/minaieaf/CNS%201380

Conclusion:
Assembly language concepts are fundamental to understanding many fields of computer engineering/science. Since we cannot afford to offer a stand alone course in assembly language, in our introductory course in computer architecture, we teach assembly language for less than half of the semester. By teaching assembly language in that course, our students can understand the computer architecture concepts better and it will also prepare them for abstract courses to come.

Bibliography:


AFSANEH MINAIE is an assistant professor in the Computing and Networking Sciences Department at Utah Valley State College. She received a B.S., M.S. and Ph.D. all in Electrical Engineering from University of Oklahoma in 1981, 1984 and 1989 respectively. Her current interests are in computer architecture, digital design, and computer interfacing.

REZA SANATI MEHRIZY is an associate professor of the Computing and Networking Sciences Dept. at Utah Valley State College, Orem, Utah. He received his MS and PhD in Computer Science from University of Oklahoma, Norman, Oklahoma. His research focuses on diverse areas such as: Database Design, Data Structures, Artificial Intelligence, Robotics, and Computer Integrated Manufacturing.