CSCI131

Introduction to Computer Systems

Task Group 2: Assembly language programming

Complete the exercises, and try to get them marked, before attempting the assignment!

There are several exercise tasks in this task group as detailed below. At the end of this document there is a link to the assignment. You should try to complete all the exercise tasks before attempting the assignment task.

Some tasks require that you simply run a supplied assembly language program on the simulator. When running the program on the simulator, you are supposed to be following how the program works by reference to the lecture notes. For these tasks, you need only take a couple of screenshots to prove completion. Other tasks require that you enter and run code.

When you have completed all the tasks, show your results to a tutor to be credited with marks.

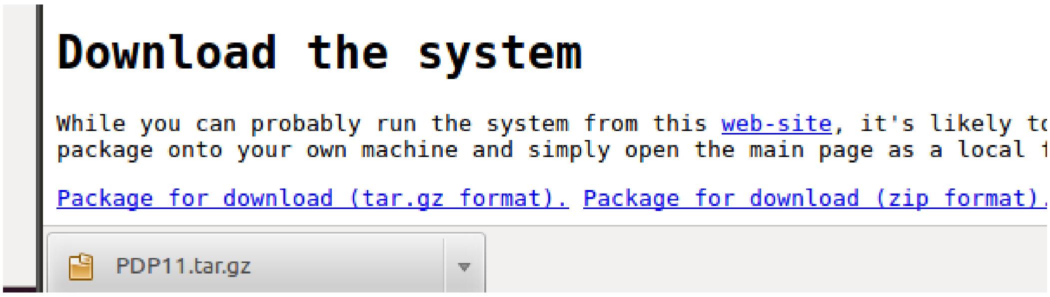
You will be writing and running PDP11 code.

Your PDP11 computer is actually a Javascript program written by [Julius Schmidt](), a German physics student who had an interest in computing and Unix. On a good modern PC, when run with a decent Javascript interpreter such as that in the Chrome browser, Schmidt's simulator runs at close to the speed of the original hardware! (Challenge: Schmidt, a physics student, wrote his Javascript simulator using the PDP11-40 system manual as a guide; can you, a computer science student, write another version in Python/Java/C/C++ without peeking too much at Schmidt's code?)

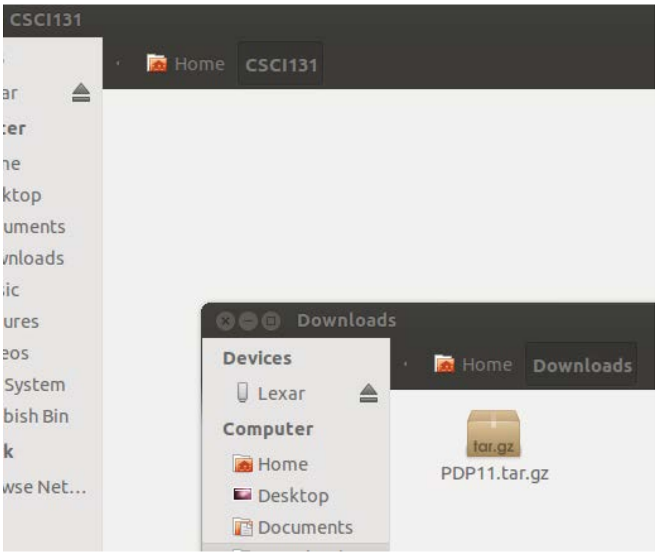
Because the simulator is in Javascript, it is run as a web application. You can use it over the Internet by connecting to http://www.uow.edu.au/~nabg/131/PDP11/Page1.html; but it will probably be easier for you to download the entire application and run it locally on your own machine.

Task 1: Copying a string and counting the characters: 2 marks

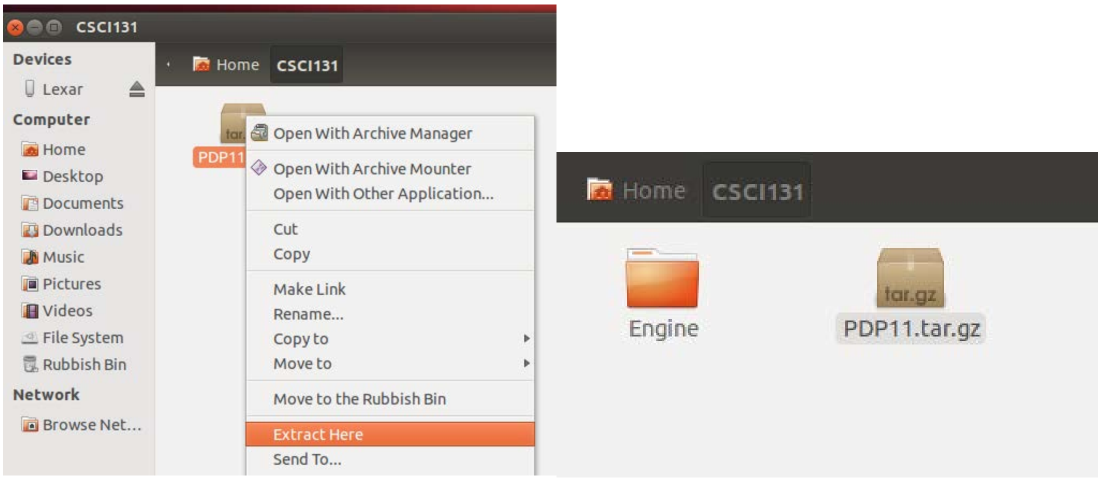
Create a sub-directory for you work on this task group. Connect to the UOW server with the code (www.uow.edu.au/~nabg/PDP11/) and download the system.



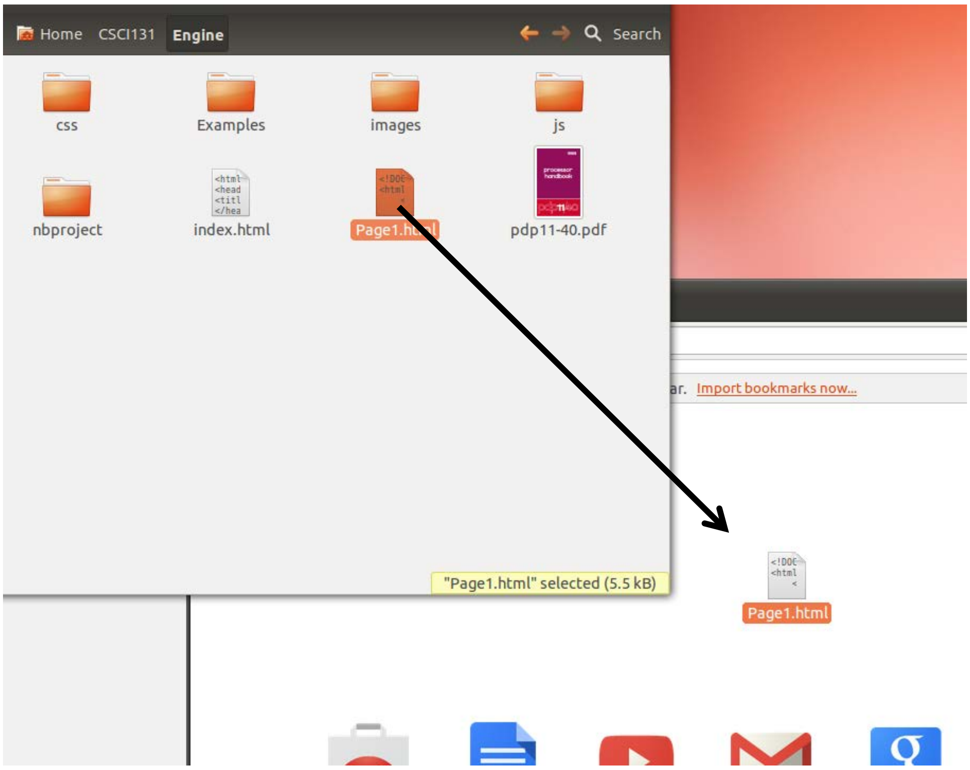
The code is provided as a "tar.gz" Unix archive (or a zip file for Microsofties).



Unpack the file

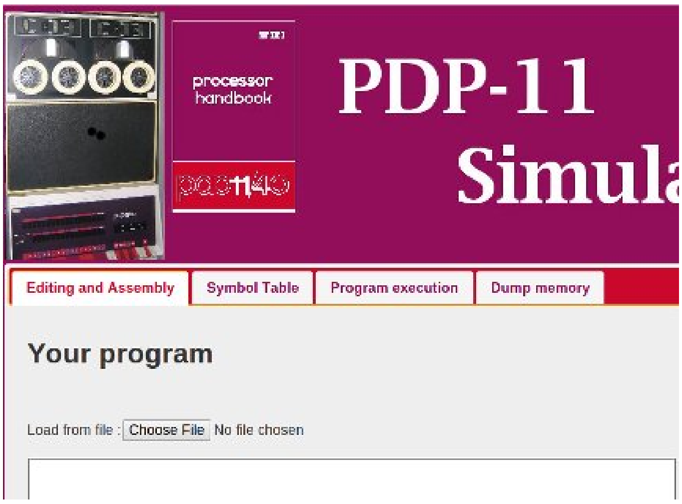


You run it by using a browser to open the HTML page that contains the Javascript code (“Page1.html”). For the Chrome browser in the labs, you drag the file into a Chrome window:



The HTML page consists of four tabs:

- Editing and Assembly
- Symbol table
- Program execution
- Dump memory

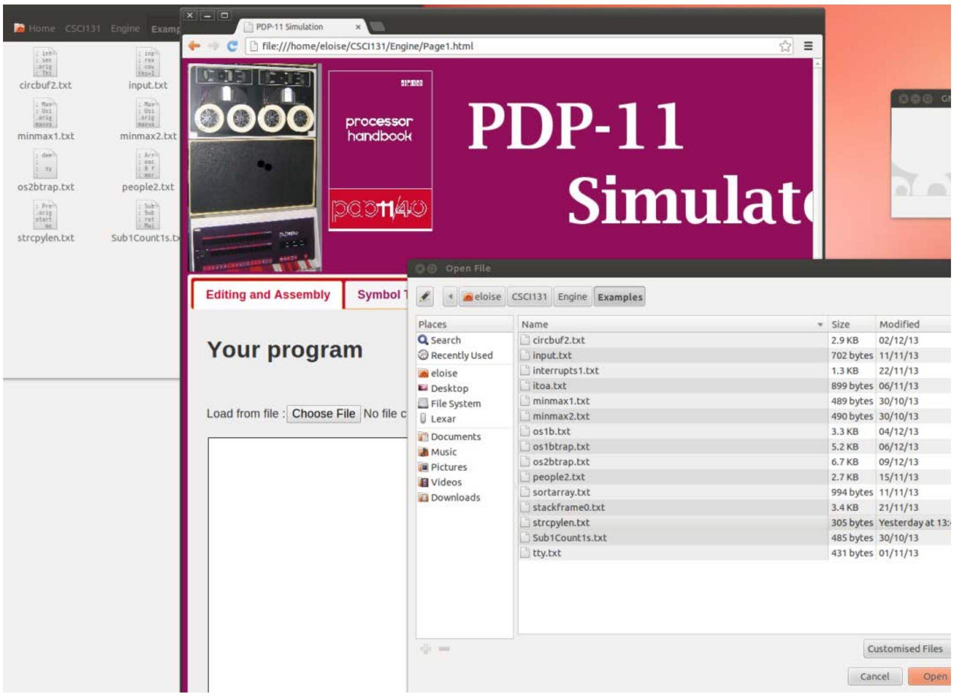


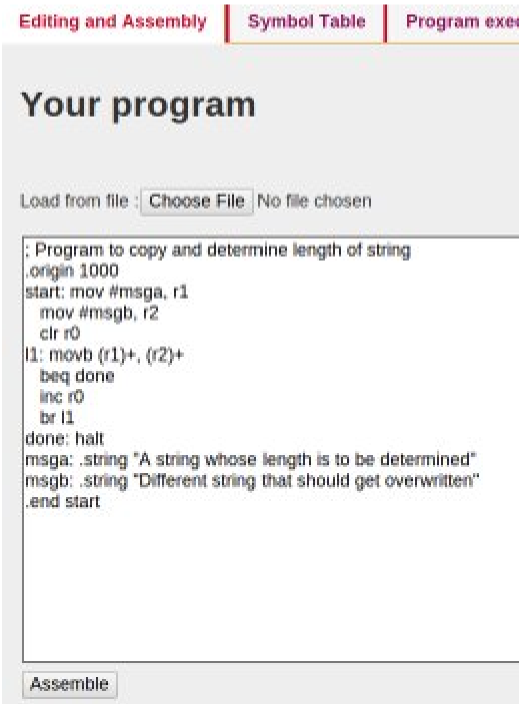
For this first task, you will run the lecture example of a program that copies a string and counts the number of characters. A roughly equivalent C++ program is:

```
 * Author: nabg
 *
 * Created on 29 May 2013, 3:48 PM
 */

#include <cstdlib>

using namespace std;

/*
 *
 */
int main(int argc, char** argv) {
    int r0; // count of characters
    char msga[] = "A string whose length is to be determined";
    char msgb[100]; // Place for a copy of the string
    char *r1 = msga; // Set pointers appropriately
    char *r2 = msgb;
    r0 = 0; // zero out count
    while(*r1) {
        *r2 = *r1;
        r1++;
        r2++;
        r0++;
    }
    // Need to put null at end of msgb
    *r2 = 0;
    return 0;
}
```

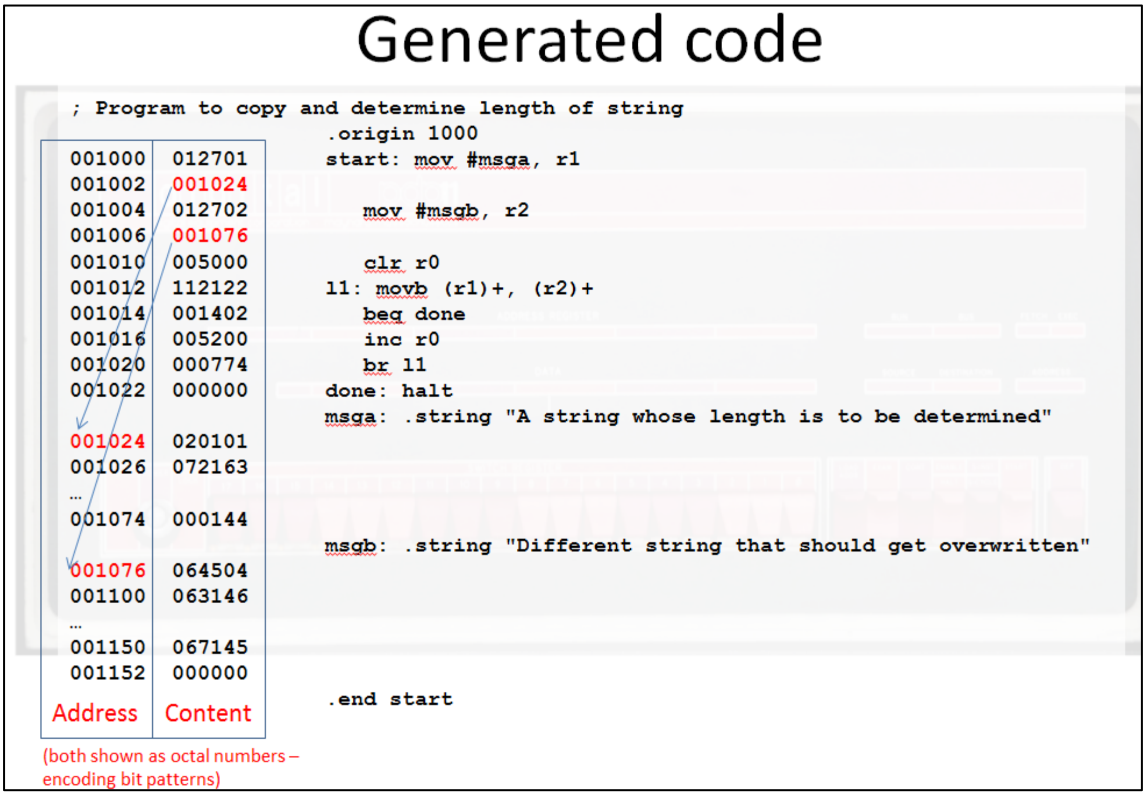
(You could try creating a C++ NetBeans project for that code and use "Debug" to run the C++ under control of gdb. You should see that it operates almost exactly likely the assembly language version.)

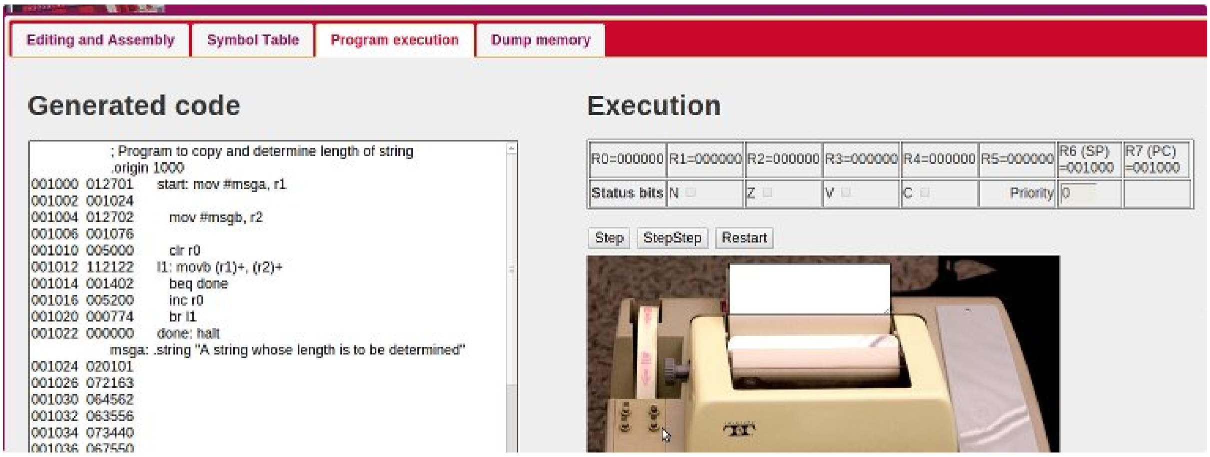
The source for the assembly language code is included in the Engine/Examples folder. You can open the file from the displayed HTML page, or just type in the assembly language code:





Assemble the code and switch to the program execution window.





Use "Step" to single step through the execution of the program (not the whole way, just for two or three cycles of the loop after which you can switch to "Step Step" continuous execution to let the program finish). You can switch back from "StepStep" to single step mode by clicking the Step button.

As the program executes, the line with the last executed instruction is highlighted in the "Generated code" text area:

Generated code

```
                ; Program to copy and determine length of string
                .origin 1000
001000  012701      start: mov #msga, r1
001002  001024
001004  012702          mov #msgb, r2
001006  001076
001010  005000          clr r0
001012  112122      l1: movb (r1)+, (r2)+
001014  001402          beq done
001016  005200          inc r0
001020  000774          br l1
001022  000000      done: halt
                msga: .string "A string whose length is to be determined"
001024  020101
```

The registers, status flags, and priority settings are updated as each instruction is executed.

Execution

R0=000000	R1=001025	R2=001077	R3=000000	R4=000000	R5=000000	R6 (SP) =001000	R7 (PC) =001014
Status bits	N ☐	Z ☐	V ☐	C ☐	Priority	0	

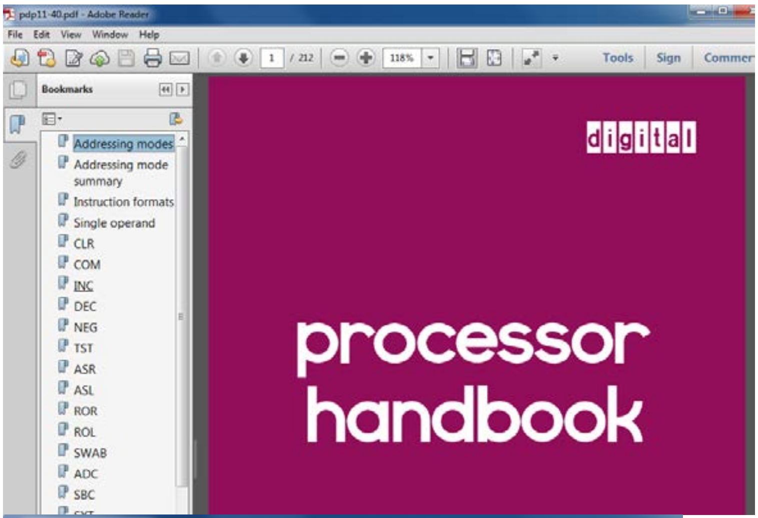
Run the program to completion. (Step-step mode slows down Schmidt's simulator greatly to allow the steps to be observed.)

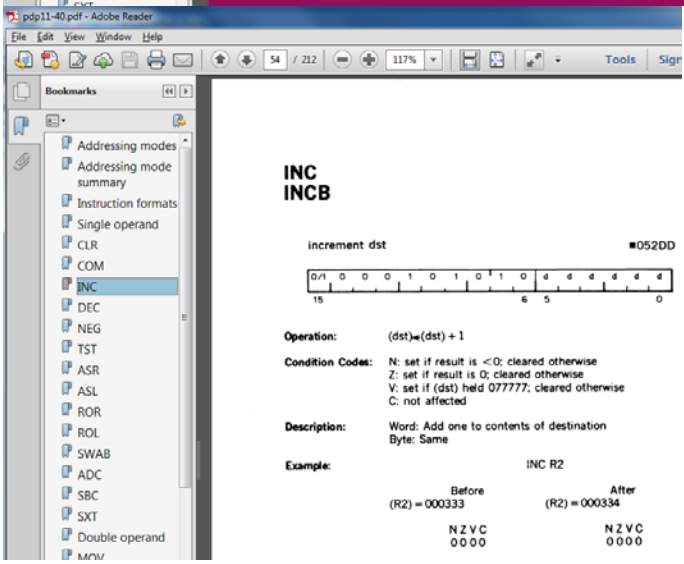
Check the results. The length of the string will be shown as the final value in register r0 (remember it is displayed in octal, work out the length and check that it is correct for the message string).

Dump the memory. Inspect the memory dump and confirm that the characters from msga have been used to overwrite those originally in msgb.

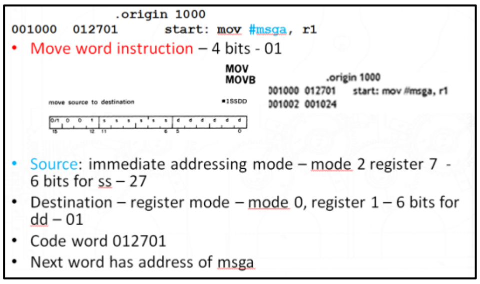
Check that you understand the assembly directives `.origin`, `.string`, `.end` (see slide 45 in 05PDP11Details.pdf).

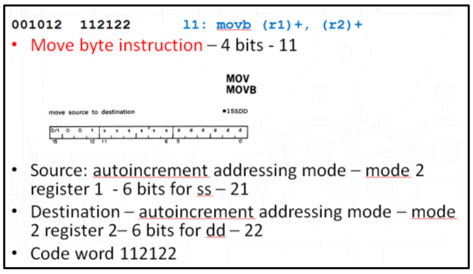
Look up the documentation on each of the instructions used in the program. (`mov`, `clr`, `movb`, `beq`, `inc`, `br`, `halt`) The PDP11-40 manual is included in your download:

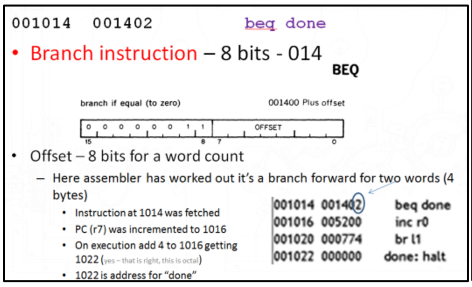


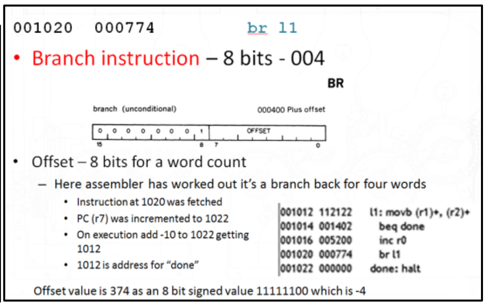


Use [the lecture notes](#) (slides around 50) to get an explanation of the addressing modes used when accessing data:

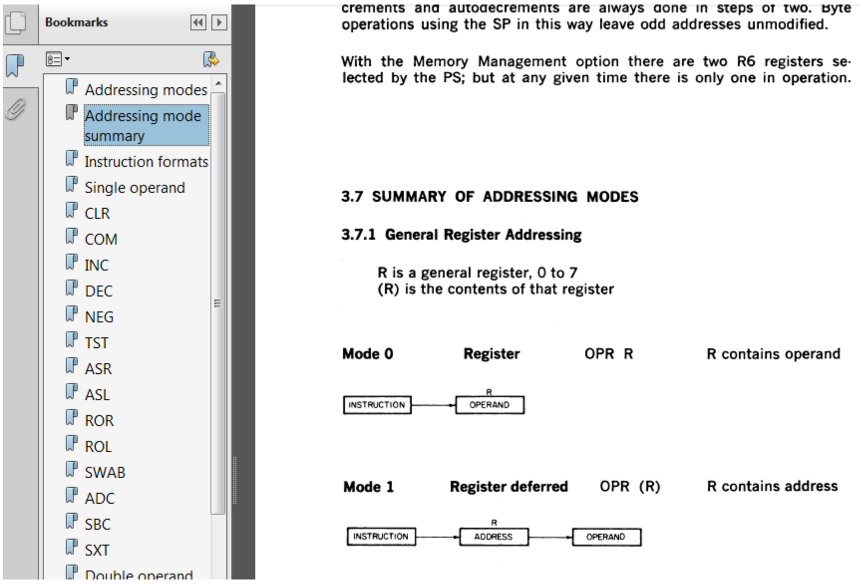








Read the explanations of addressing modes in the manual:



Task 2: Data processing examples: 1 mark

The lecture notes contain a number of examples that illustrate how familiar programming constructs in C/C++ work at the assembly language level. The examples include array access (both using pointers in classical C style, and using array indexing), subroutines (functions/procedures/methods/… whatever name you prefer), recursive functions, and structs.

Pick one of the following examples from the lectures:

minmax1.txt

Example from [04PDP11.pdf](04PDP11.pdf), about slide 47, finding minimum and maximum values in an array. Loops through array using address pointer style code (like C/C++ `int data[16]; int* ptr = data: - int val = *ptr;`.)

minmax2.txt

Example from [04PDP11.pdf](04PDP11.pdf), about slide 59, finding minimum and maximum values in an array. Loops through array using indexed addressing (like C/C++ `int data[16]; int ndx=0; int val = data[ndx] array subscripting code.`)

Sub1sCount1s.txt

Example from [04PDP11.pdf](04PDP11.pdf), about slide 70, that illustrates call to a subroutine (with return address placed on stack etc).

sortarray.txt

Example from 05PDP11Details.pdf, about slide 80, sorting array. Illustrates array access with indexed addressing mode.

itoa.txt

Example from 05PDP11Details.pdf, about slide 90, showing recursion (recursive implementation of integer to ascii string function).

people2.txt

Example from 05PDP11Details.pdf, about slide 120. Just illustrating how C structs, and access to fields of struct, might be handled in assembly. It's a different way of using indexed addressing mode

Run your chosen example in the simulator. Make sure that you understand (and could explain to the tutor) the different instructions and addressing modes used in the code.

Task 3: Examples relating to I/O: 1 mark

The lecture notes contain a number of examples that illustrate how input and output are handled using both naïve "wait-loop" mechanisms and more sophisticated interrupt-driven approaches that allow overlap of I/O tasks and continued computation.

Pick one of the following examples from the lectures:

tty.txt

Example from 04PDP11.pdf, about slide 78, showing wait loop I/O being used while printing a message.

input.txt

Example from 05PDP11Details.pdf, about slide 120, showing wait loop I/O being used reading and echoing characters.

Interrupts1.txt

Example from 05PDP11Details.pdf, about slide 160, that illustrates output of message using interrupts while supposedly completing some compute task.

Run your chosen example in the simulator. Make sure that you understand (and could explain to the tutor) how I/O can be handled by polling (wait loops) or by using interrupts and why interrupt driven mechanisms allow for more efficient use of a computer system.

Task 4: Proto operating systems: 1 mark

The lecture notes contain a series of examples that illustrate aspects of a primitive operating system including "supervisor calls" (trap/emt/svc/…) that provide I/O related services (possibly implemented using interrupts).

Pick one of the following examples from the lectures:

os1b.txt

> Example from 05PDP11Details.pdf, about slide 220, illustrating a simple non-interrupt driven "operating system".
> The earliest operating systems incorporated utility functions such as ascii<->integer conversion functions as well as more fundamental things like i/o handling. In later systems, utility functions became part of standard libraries that were linked with user code. Also, in early operating systems, OS functions were invoked with simple subroutine calls. This code mimics such an early OS.

os1btrap.txt

> Example from 05PDP11Details.pdf, about slide 260, illustrating "traps" or "supervisor calls". As operating systems became more sophisticated, extra instructions (emt/trap/svc/...) were added that were to be used in calls to the OS. This example is the same as the previous one but using "trap" instructions.

os2btrap.txt

> Example from 05PDP11Details.pdf, about slide 280, illustrating "traps" or "supervisor calls" and an interrupt driven "OS".

Run your chosen example in the simulator. Make sure that you understand (and could explain to the tutor) how supervisor calls work.

Task 5: Simple coding in assembly language: 1 mark

You can never have enough practice in manipulating bits with logical operations. You did it in C; now try in assembler.

You are to implement an assembly language version of a subset of the following C program:

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

/*
 *
 */
int main(int argc, char** argv) {
    unsigned short a, b;
    a  = (unsigned short) (getpid() % 65536);
    b = (unsigned short) (getuid() % 65536);
    printf("a %ho; b %ho\n", a, b);
    unsigned short c, d, e;
    c = a & b;
    d = a | b;
    e = a ^ b;
    printf("a & b %ho\n", c);
    printf("a | b %ho\n", d);
    printf("a ^ b %ho\n", e);
    return (EXIT_SUCCESS);
}
```

You should run the C code. Then you will have known data values, in octal, for ‘a’, ‘b’, ‘c’, ‘d’ and ‘e’.

```
Logic (Build, Run) ×   Logic (Run) ×
a 52350; b 1750
a & b 350
a | b 53750
a ^ b 53400
```

(Your data will differ.) This will help you check your assembly language code.

The assembly version will have the values of ‘a’ and ‘b’ defined using .word directives. It doesn’t use any input and output; you check the results in the “Dump memory” display.

Try to work out the code for the operations yourself. Inclusive or is essentially the PDP11’s “bit set” instruction – modify the destination by setting all those bits that are in the source. There is an XOR instruction. There isn’t an “AND”. But you can use “bit clear”. Instead of doing “AND” with a bit pattern, you complement the pattern and then do “bit clear” (try it on paper and convince yourself that that will work.)

Load from file : Choose File No file chosen

```
.origin 1000
; and - there is no and instruction
; but can get there using bic (bit clear)
; c = a & b;
start: mov a, c
  mov b, r0
  com r0
  bic r0, c
; or - well that is really just bit set
; d = a | b;
  mov a, d
  bis b, d
; and xor - well do have an xor
  mov a,e
  mov b, r0
  xor r0,e
  halt
a: .word 52350
b: .word 1750
c: .word 0
```

Assemble

Symbol	Value
start	001000
a	001054
b	001056
c	001060
d	001062
e	001064

Dump memory

```
 ...     ...   ....
001000 016767 000050 000052 016700 000044 005100 040067 000040
001020 016767 000030 000034 056767 000024 000026 016767 000014
001040 000022 016700 000010 074067 000012 000000 052350 001750
001060 000350 053750 053400 000000 000000 000000 000000 000000
 ...     ...   ....
```

Look carefully in the dump; ‘c’ at 1060 contains 0350 – that’s correct. Others are correct as well.

Task 6: Processing some data: 2 marks

For this task, you will use the supplied “operating system” with its I/O handlers and utility functions for reading and writing strings and decimal integers.

A C version of the program that you are to implement is:

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
static char input[128];
static char output[128];

void createreverse() {
    char* r1 = input;

    while(*r1) r1++;

    char *r2 = output + (r1 - input) -1;
    r1=input;
    while(*r1) {
        *r2 = *r1;
        r1++;
        r2--;
    }

}
int main(int argc, char** argv) {
    memset(output,0, 128);
    gets(input);
    createreverse();
    puts(input);
    puts(output);
    return (EXIT_SUCCESS);
}
```

```
Output - ReverseApp (Run)
Hello World
Hello World
dlroW olleH
```

(The char[] will be in uninitialized memory; that is why it is necessary to clear at least the output array via memset().)

The functions gets() and puts() are defined in the stdio library. The function gets() reads in a line of characters from stdin, storing them in the array supplied (which is assumed to be of sufficient size). It reads until a newline character; this is not stored in the array. A nul byte is added to terminate the string. When working with stdin connected to a terminal, Unix/Linux automatically echoes input characters. The function puts() writes the contents of a character array to stdout; if connected to a terminal, it automatically appends a newline character. The gets() and puts() functions in stdio are part of “libc” – Linux’s standard library functions. Their implementation uses Linux’s read and write supervisor calls.

The function createreverse() reverses the string. You should make sure that you understand how the C code works. The use of pointers here is typical of C. You have probably been shown code like this, but you will have been encouraged to use a rather different style in your C++ coding.

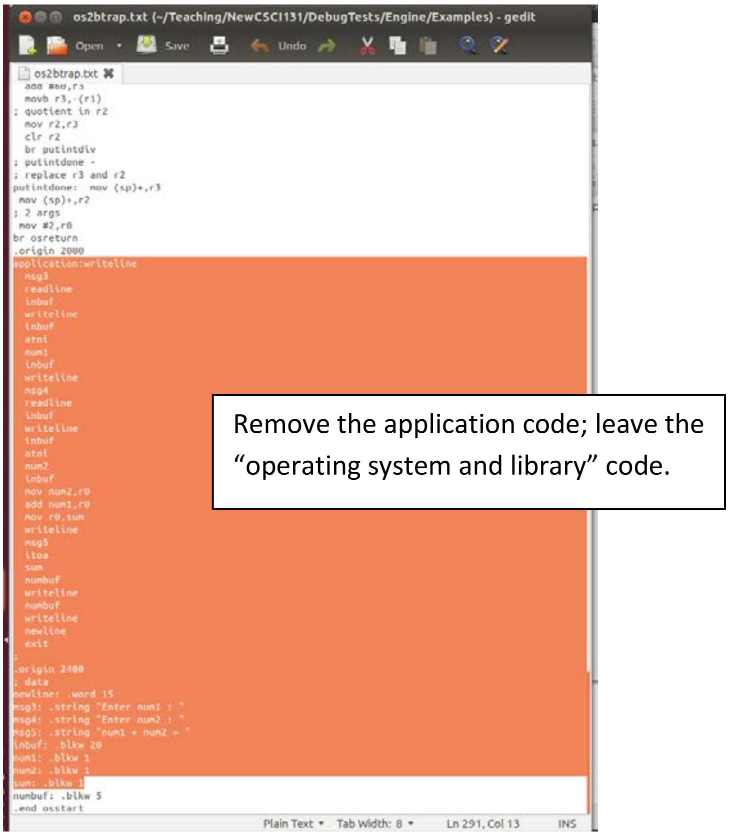
The first while loop in createreverse() is finding the end of the string (keep incrementing the pointer r1 until it is referencing a nul byte. The length of the string is the difference between the final value in r1 and the start address of the input buffer. The pointer r2 is then set to an appropriate offset position in the output buffer while r1 is reset to the start of the input. The second while loop copies the bytes, decrementing r2 and incrementing r1 as it goes.

The assembly language version will be closer to the following version of createreverse():

```
void createreverse() {
    char* r1 = input;

    while(*r1++) ;
    r1--;

    char *r2 = output + (r1 - input);
    r1=input;
    while(*(--r2)=*(r1++));

}
```

(Convince yourself that this code has the same effect as that shown previously.)

Start your assembly language version by taking the code of the example os2btrap.txt and cutting out the example application code to leave just the “operating system and library” components.



The operating system functions readline and writeline are similar to gets and puts. (The readline function differs from gets in that it does include the newline character in the input buffer.) Of course, input is NOT automatically echoed.

Create a new application:

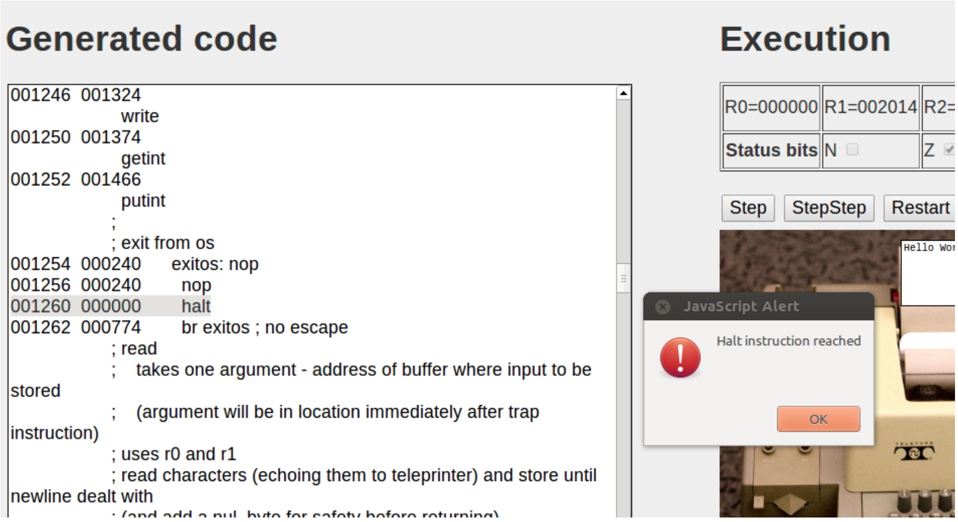
```
.origin 2000
application:readline
  input
  writeline
  input
; still to do
; call createreverse
; writeline
;output
  exit
.origin 3000
; data
input: .blkw 100
output: .blkw 100
.end osstart
```

Assemble

This has the input and output static arrays similar to the C code. It simply reads in a line of text, then outputs it. Run this part to make sure that you have correctly copied the code from os2btrap.txt.

Remember to click in the input text area before attempting to provide input to the program:

This part should run.



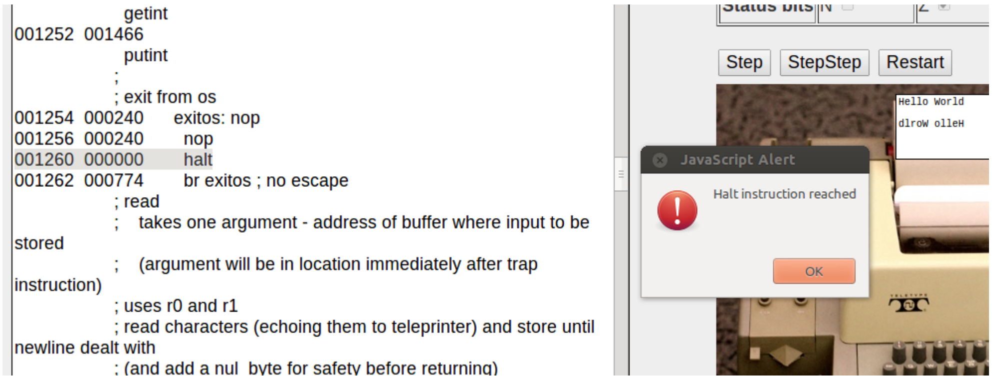
Now implement the createreverse function:

```
application:readline
   input
   writeline
   input
   call createreverse
   writeline
  output
  exit
createreverse: mov #input,r1
   strlen:tstb (r1)+
   bne strlen
   dec r1
   mov #output,r2
   add r1,r2
   sub #input,r2
   mov #input,r1
cpy:movb (r1)+,-(r2)
   bne cpy
   return
.origin 3000
```

Check that you understand all the instructions and addressing modes used. Confirm that it does implement the second version of the C code.

Try running.

(**Hack**. Sometimes it is useful to be able to switch from "StepStep" to single step mode at a specific point in a program. One of the unused instruction op-codes has been usurped to allow this! It is the FADD instruction 075000. The simulator does not have the "floating point" hardware so this is an invalid op-code – it was floating point add. Just insert that value in your code where you want single-step to start. Apart from changing simulator execution mode, it is a "no-op".)



Exercises complete

Show the tutor that you have completed all the parts.

(That was 8 very easy marks wasn't it – just copy the code. Hopefully, you learnt a little about how assembly language works and how a primitive operating system can provide I/O and other services to applications.)

Assignment

The assignment: implement a little data processing program (using the supplied "operating system and library" to handle I/O).