ECE 471 – Embedded Systems
Lecture 8

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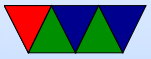
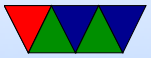
Announcements

- HW#3 will be posted
- Pick up parts! An e-mail was sent out! If you need them mailed, let me know as soon as possible!

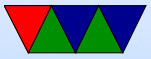


Stuff from Last Time

- Are there executable formats other than ELF?
- VM layout for Linux vs Physical

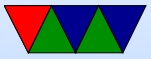


Low-Level ARM Linux Assembly

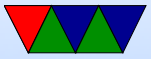


Linux C (ABI)

- Application Binary Interface
- The rules an executable needs to follow in order to talk to other code/libraries on the system
- A software agreement, this is not enforced at all by hardware
- r0-r3 are first 4 arguments/scratch (extra go on stack) (caller saved)
- r0-r1 are return value
- r4-r11 are general purpose, callee saved

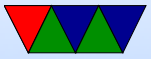


- r12-r15 are special
- Things are more complex than this. Passing arrays and structs? 64-bit values? Floating point values? etc.



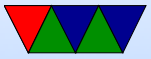
Kernel Programming ABIs

- OABI – "old" original ABI (arm). Being phased out. slightly different syscall mechanism, different alignment restrictions
- EABI – new "embedded" ABI (armel)
- hard float – EABI compiled with ARMv7 and VFP (vector floating point) support (armhf). Raspberry Pi (raspbian) is compiled for ARMv6 armhf.



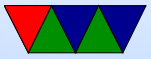
System Calls (EABI/armhf)

- System call number in r7
- Arguments in r0 - r6
- Return value in r0 (-1 if error, errno in -4096 - 0)
- Call `swi 0x0`
- System call numbers can be found in `/usr/include/arm-linux-gnueabihf/asm/unistd.h` They are similar to the 32-bit x86 ones.



System Calls (OABI)

- The previous implementation had the same system call numbers, but instead of r7 the number was the argument to `swi`.
- This was very slow, as there is no way to determine that value without having the kernel backtrace the callstack and disassemble the instruction.

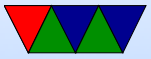


Manpage

The easiest place to get system call documentation.

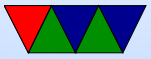
`man open 2`

Finds the documentation for "open". The 2 means look for system call documentation (which is type 2).



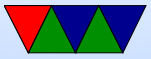
A first ARM assembly program: hello_exit

```
.equ SYSCALL_EXIT,     1

        .globl _start
_start:

        #=================================
        # Exit
        #=================================
exit:
        mov     r0,#5
        mov     r7,#SYSCALL_EXIT        @ put exit syscall number (1) in r7
        swi     0x0                     @ and exit
```



Some GNU assembler notes

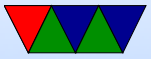
- Code comments
  - @ is the traditional comment character
  - # can be used on line by itself but will confuse assembler if on line with code.
  - Can also use /* */ and //
  - *Cannot* use ;
- Order is source, destination
- Constant value indicated by # or $
- .equ is equivalent to a C #define



`hello_exit` example

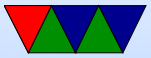
Assembling/Linking using `make`, running, and checking the output.

```
lecture6$ make hello_exit_arm
as -o hello_exit_arm.o hello_exit_arm.s
ld -o hello_exit_arm hello_exit_arm.o
lecture6$ ./hello_exit_arm
lecture6$ echo $?
5
```



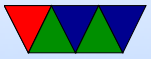
Let's look at our executable

- `ls -la ./hello_exit_arm`
  Check the size
- `readelf -a ./hello_exit_arm`
  Look at the ELF executable layout
- `objdump --disassemble-all ./hello_exit_arm`
  See the machine code we generated
- `strace ./hello_exit_arm`
  Trace the system calls as they happen.



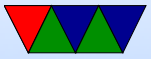
hello_world example

```
.equ SYSCALL_EXIT,      1
.equ SYSCALL_WRITE,     4
.equ STDOUT,            1

        .globl _start
_start:
        mov     r0,#STDOUT              /* stdout */
        ldr     r1,=hello
        mov     r2,#13                  @ length
        mov     r7,#SYSCALL_WRITE
        swi     0x0

        # Exit
exit:
        mov     r0,#5
        mov     r7,#SYSCALL_EXIT        @ put exit syscall number in r7
        swi     0x0                     @ and exit

.data
hello:          .ascii "Hello World!\n"
```



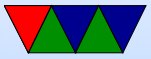
New things to note in `hello_world`

- The fixed-length 32-bit ARM cannot hold a full 32-bit immediate
- Therefore a 32-bit address cannot be loaded in a single instruction
- In this case the "=" is used to request the address be stored in a "literal" pool which can be reached by PC-offset, with an extra layer of indirection.
- Data can be declared with .ascii, .word, .byte
- BSS can be declared with .lcomm



simple loop example

```
        # for(i=0;i<10;i++) do_something();

        mov     r0,#0           # set loop index to zero
loop:
        push    {r0}            # save r0 on stack
        bl      do_something    # branch to subroutine, saving
                                # return address in link register
        pop     {r0}            # restore r0 from stack

        add     r0,r0,#1        # increment loop counter
        cmp     r0,#10          # have we reached 10 yet?
        bne     loop            # if not, loop
```



string count example

Count the number of chars in a string until we hit a space.

```
        mov     r1,=hello       # load pointer to hello string into r1
        mov     r2,#0           # initialize count to zero
loop:
        ldrb    r0,[r1]         # load byte pointed by r1 into r0
        cmp     r0,#'␣'         # compare r0 to space character
                                # this updates the status flags
        beq     done            # if it was equal, we are done
        add     r2,r2,#1        # increment our count
        add     r1,r1,#1        # increment our pointer
        b       loop            # branch (unconditionally) to loop
done:
```