ECE 471 – Embedded Systems
Lecture 10

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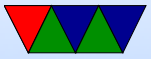
20 September 2017

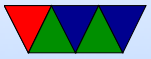
Announcements

- How is HW#3 going?



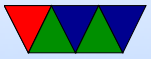
HW2 Review

- Everyone seems to be accessing the Pi OK
  If UK keyboard/etc run raspi-config
  One benefit of a pi, is lots of people using it so google very helpful.
- Be sure to follow directions!
- Comment your code!
- Also watch out for compiler warnings! (Though each compiler version might have different warnings)
- Error handling!



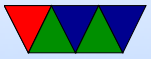
- Most C code OK.
  Be sure if it says print 20 lines that you do, not 21.
  Colors seem not to be a problem.

- more info on ls. Looking for man. "info" or `ls --help`
- ls -a shows hidden files. Hidden files on UNIX
- Why use Linux? open-source, because it's free. Not a bad operating system overall.



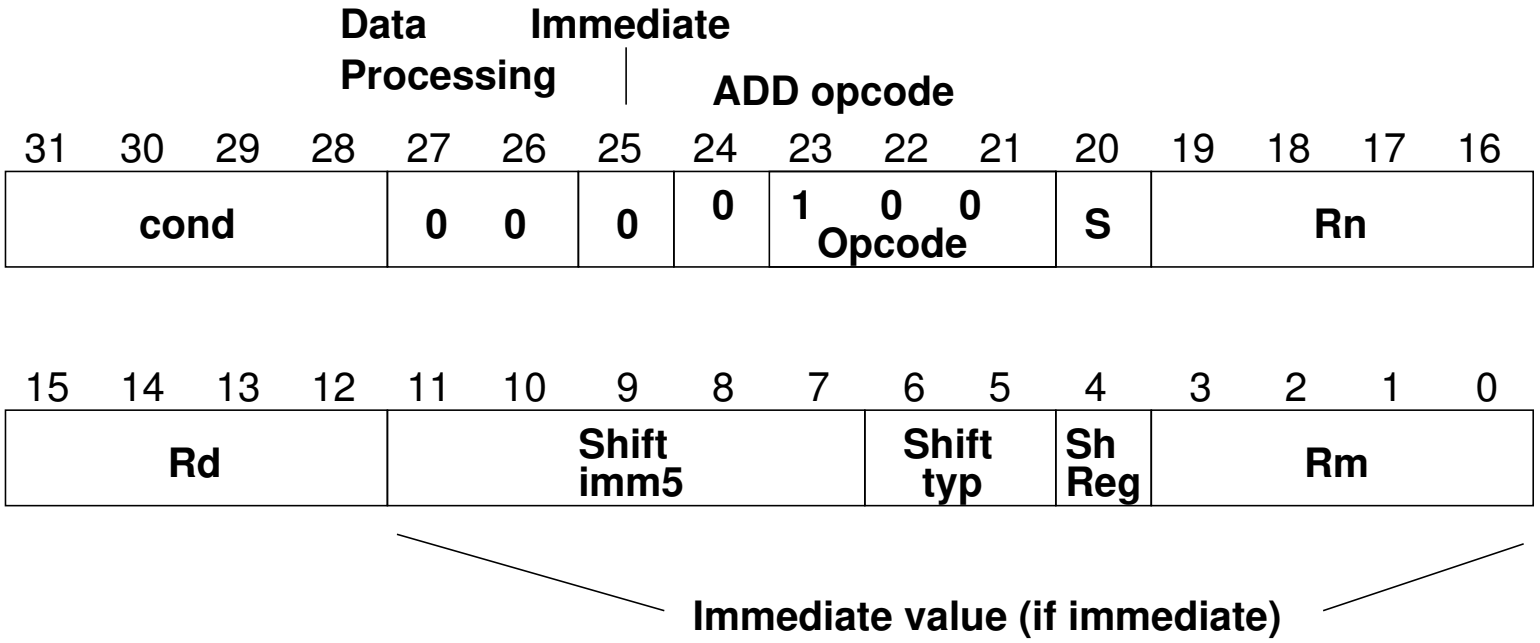
ARM Instruction Set Encodings

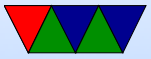
- ARM – 32 bit encoding
- THUMB – 16 bit encoding
- THUMB-2 – THUMB extended with 32-bit instructions
  - STM32L *only* has THUMB2
  - Original Raspberry Pis *do not* have THUMB2
  - Raspberry Pi 2/3 *does* have THUMB2
- THUMB-EE – extensions for running in JIT runtime
- AARCH64 – 64 bit. Relatively new. Completely different from ARM32



Recall the ARM32 encoding

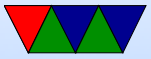
```
ADD{S}<c> <Rd>,<Rn>,<Rm>{,<shift>}
```



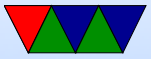


THUMB

- Most instructions length 16-bit (a few 32-bit)
- Only r0-r7 accessible normally
  `add`, `cmp`, `mov` can access high regs
- Some operands (sp, lr, pc) implicit
  Can't always update sp or pc anymore.
- No prefix/conditional execution
- Only two arguments to opcodes
  (some exceptions for small constants: `add r0,r1,#1`)
- 8-bit constants rather than 12-bit

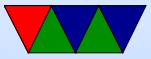


- Limited addressing modes: [rn,rm], [rn,#imm], [pc|sp,#imm]
- No shift parameter ALU instructions
- Makes assumptions about "S" setting flags
  (gas doesn't let you superfluously set it, causing problems if you naively move code to THUMB-2)
- new push/pop instructions (subset of ldm/stm), neg (to negate), asr,lsl,lsr,ror, bic (logic bit clear)

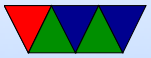


THUMB/ARM interworking

- See `print_string_armthumb.s`
- BX/BLX instruction to switch mode.
  Sets/clears the T (thumb) flag in status register
  If target is a label, *always* switchmode
  If target is a register, low bit of 1 means THUMB, 0 means ARM
- Can also switch modes with `ldrm`, `ldm`, or `pop` with PC as a destination
  (on armv7 can enter with ALU op with PC destination)

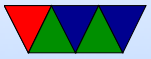


- Can use `.thumb` directive, `.arm` for 32-bit.



THUMB-2

- Extension of THUMB to have both 16-bit and 32-bit instructions
- The 32-bit instructions are *not* the standard 32-bit ARM instructions.
- Most 32-bit ARM instructions have 32-bit THUMB-2 equivalents *except* ones that use conditional execution. The `it` instruction was added to handle this.
- `rsc` (reverse subtract with carry) removed
- Most cannot have PC as src/dest



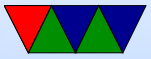
- Shifts in ALU instructions are by constant, cannot shift by register like in arm32
- THUMB-2 code can assemble to either ARM-32 or THUMB2

  The assembly language is compatible.

  Common code can be written and output changed at time of assembly.
- Instructions have “wide” and “narrow” encoding.

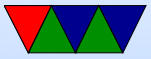
  Can force this (`add.w` vs `add.n`).
- Need to properly indicate “s” (set flags).

  On regular THUMB this is assumed.



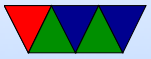
THUMB-2 Coding

- See `test_thumb2.s`
- Use `.syntax unified` at beginning of code
- Use `.arm` or `.thumb` to specify mode



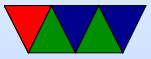
New THUMB-2 Instructions

- BFI – bit field insert
- RBIT – reverse bits
- movw/movt – 16 bit immediate loads
- TB – table branch
- IT (if/then)
- cbz – compare and branch if zero; only jumps forward



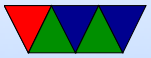
Thumb-2 12-bit immediates

```
top 4 bits 0000 -- 00000000 00000000 00000000 abcdefgh
           0001 -- 00000000 abcdefgh 00000000 abcdefgh
           0010 -- abcdefgh 00000000 abcdefgh 00000000
           0011 -- abcdefgh abcdefgh abcdefgh abcdefgh
rotate bottom 7 bits|0x80 right by top 5 bits
           01000 -- 1bcdefgh 00000000 00000000 00000000
            ...
           11111 -- 00000000 00000000 00000001 bcdefgh0
```



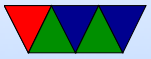
Compiler

- Original RASPBERRY PI DOES NOT SUPPORT THUMB2
- `gcc -S hello_world.c`
  By default is arm32
- `gcc -S -march=armv5t -mthumb hello_world.c`
  Creates THUMB (won't work on Raspberry Pi due to HARDFP arch)
- `-mthumb -march=armv7-a` Creates THUMB2



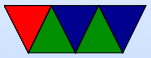
IT (If/Then) Instruction

- Allows limited conditional execution in THUMB-2 mode.
- The directive is optional (and ignored in ARM32)
  the assembler can (in-theory) auto-generate the IT instruction
- Limit of 4 instructions



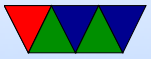
Example Code

```
it cc
addcc r1,r2

itete cc
addcc r1,r2
addcs r1,r2
addcc r1,r2
addcs r1,r2
```



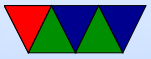
`ll` Example Code

```
        ittt cs @ If CS Then Next plus CS for next 3
discrete_char:
        ldrbcs  r4,[r3]       @ load a byte
        addcs   r3,#1         @ increment pointer
        movcs   r6,#1         @ we set r6 to one so byte
        bcs.n   store_byte    @ and store it
offset_length:
```



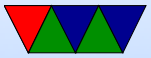
AARCH64

- 32-bit fixed instruction encoding
- 31 64-bit GP registers (x0-x30), zero register (x30)
- PC is not a GP register
- only branches conditional
- no load/store multiple
- No thumb

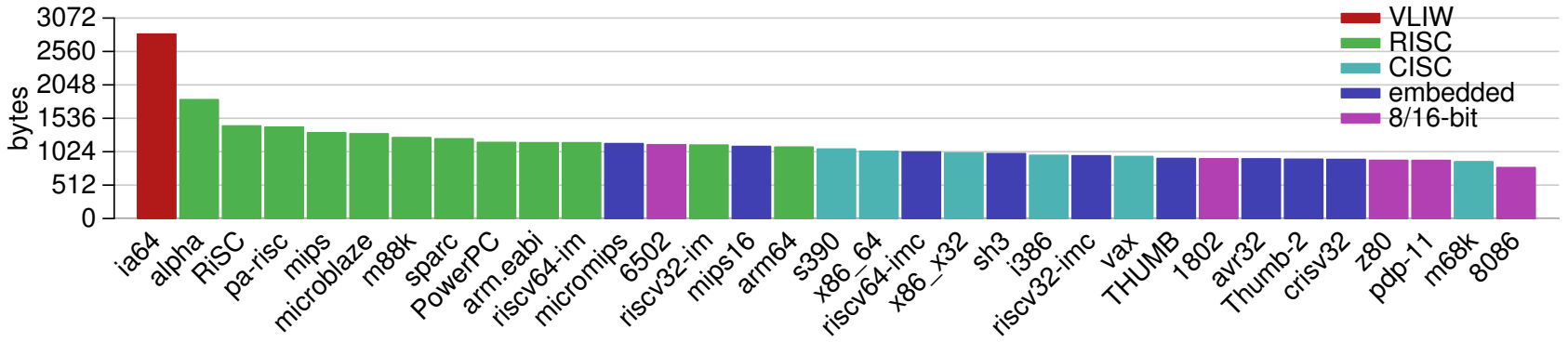


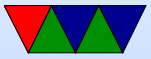
Code Density

- Overview from my `ll` ICCD'09 paper
- Show code density for variety of architectures, recently added Thumb-2 support.
- Shows overall size, though not a fair comparison due to operating system differences on non-Linux machines



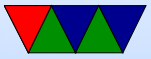
Code Density – overall



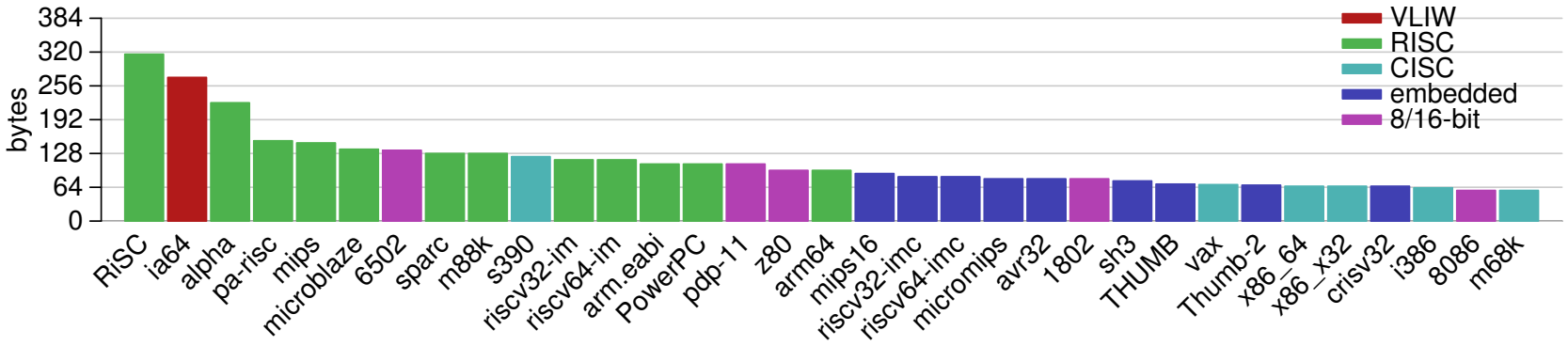


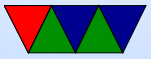
lzss compression

- Printing routine uses lzss compression
- Might be more representative of potential code density



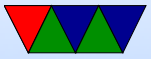
Code Density – lzss



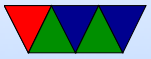


Put string example

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

        .globl _start
_start:
        ldr     r1,=hello
        bl      print_string            @ Print Hello World
        ldr     r1,=mystery
        bl      print_string            @
        ldr     r1,=goodbye
        bl      print_string            /* Print Goodbye */

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



```
        #====================
        # print string
        #====================
        # Null-terminated string to print pointed to by r1
        # r1 is trashed by this routine

print_string:
        push    {r0,r2,r7,r10}          @ Save r0,r2,r7,r10 on stack

        mov     r2,#0                   @ Clear Count

count_loop:
        add     r2,r2,#1                @ increment count
        ldrb    r10,[r1,r2]             @ load byte from address r1+r2
        cmp     r10,#0                  @ Compare against 0
        bne     count_loop              @ if not 0, loop

        mov     r0,#STDOUT              @ Print to stdout
        mov     r7,#SYSCALL_WRITE       @ Load syscall number
        swi     0x0                     @ System call

        pop     {r0,r2,r7,r10}          @ pop r0,r2,r7,r10 from stack

        mov     pc,lr                   @ Return to address stored in
```



```
                                        @ Link register

.data
hello:          .string "Hello World!\n"    @ includes null at end
mystery:        .byte 63,0x3f,63,10,0       @ mystery string
goodbye:        .string "Goodbye!\n"        @ includes null at end
```