# ECE 471 – Embedded Systems
# Lecture 6

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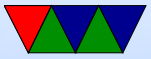
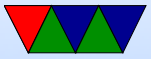
# Announcements

- HW#2 was posted, it is due Friday



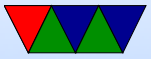
# Using git

- Not using gitlab like ECE271, was huge hassle
- Still idea to use some sort of source control management (SCM)
- There are actually worse than git out there
- Who invented git? Linus Torvalds



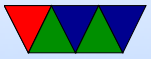
# Homework #1 Review

- Be sure to put your name in the assignment.
- Characteristics of embedded system
  - embedded inside – sometimes hard to know. Is a raw pi one? Pi used as desktop? Pi used as retro-pi? Pi controlling a 3D printer?
  - resource constrained
  - dedicated purpose
  - real-time
- Embedded System Question



- Toothbrush is actual specs I came across
- Real-Time Confusion: we will discuss this more in future.

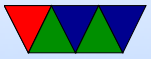
- Toothbrush: Just turning off the motor, and it takes an extra 1/2s is not really considered a real time thing. No one dies, no hardware destroyed, just mild annoyance if noticed at all. Now if somehow it had to keep the waveform to H-bridge exact within 1ms or the motor would overheat and catch on fire, that could be a real-time issue.



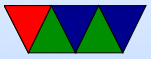
- Limited Hardware

  bitness of processor: while 8 or 16 bit probably embedded these days, 32 vs 64 bit not necessarily a sure sign.
- Low-cost is complicated. Something like a desktop might be optimized for cost extremely, while a one-off embedded system might not, and in fact might be over-engineered (like a space probe) because has to operate in tough conditions.

- Operating system?

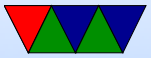


Can have an OS and still be considered embedded.
  - Be strong in your convictions!
- ASIC
  - cost/power. Depends a lot on numbers made, process, and how well designed it is.
  - Extra hardware overhead? ASIC mostly just flip flops and gates. SoC internally a lot more, but these days not much else is needed.
  - More secure? Can you reverse engineer an ASIC?



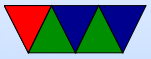
# How Executables are Made

- Compiler generates ASM (Cross-compiler)
- Assembler generates machine language objects
- Linker creates Executable (out of objects)



# Tools

- compiler: takes code, usually (but not always) generates assembly
- assembler: GNU Assembler as (others: tasm, nasm, masm, etc.)
  creates object files
- linker: ld
  creates executable files. resolves addresses of symbols. shared libraries.

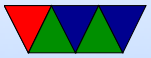


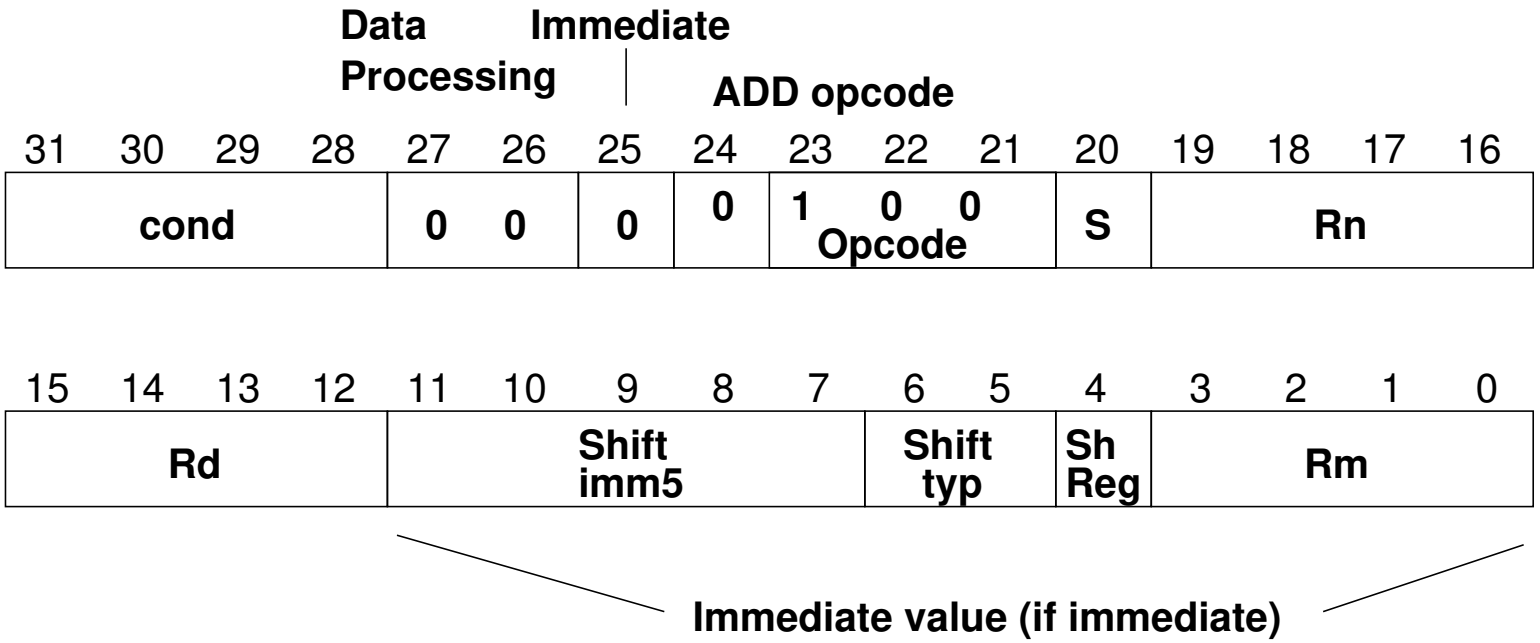
# Converting Assembly to Machine Language

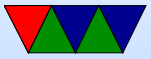
Thankfully the assembler does this for you.

ARM32 ADD instruction – `0xe0803080` == `add r3, r0, r0, lsl #1`

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



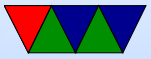

Data Processing
Immediate
ADD opcode
31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16
cond
0 0
0
0
1 0 0
Opcode
S
Rn
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Rd
Shift imm5
Shift typ
Sh Reg
Rm
Immediate value (if immediate)



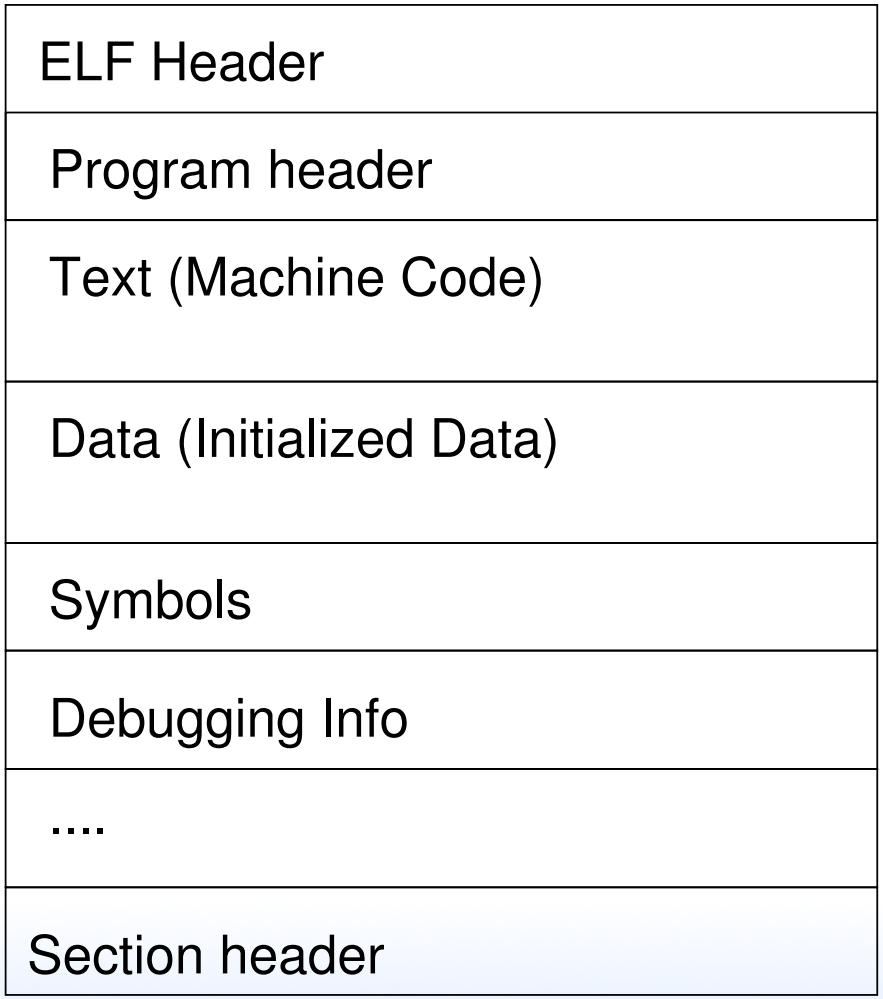
# Executable Format

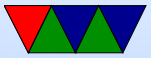
- ELF (Executable and Linkable Format, Extensible Linking Format)
  Default for Linux and some other similar OSes
  header, then header table describing chunks and where they go

- Other executable formats: a.out, COFF, binary blob



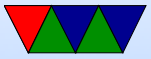
# ELF Layout


ELF Header
Program header
Text (Machine Code)
Data (Initialized Data)
Symbols
Debugging Info
....
Section header



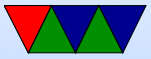
# ELF Description

- ELF Header includes a "magic number" saying it's 0x7f,ELF, architecture type, OS type, etc. Also location of program header and section header and entry point.
- Program Header, used for execution:
  has info telling the OS what parts to load, how, and where (address, permission, size, alignment)
- Program Data follows, describes data actually loaded into memory: machine code, initialized data

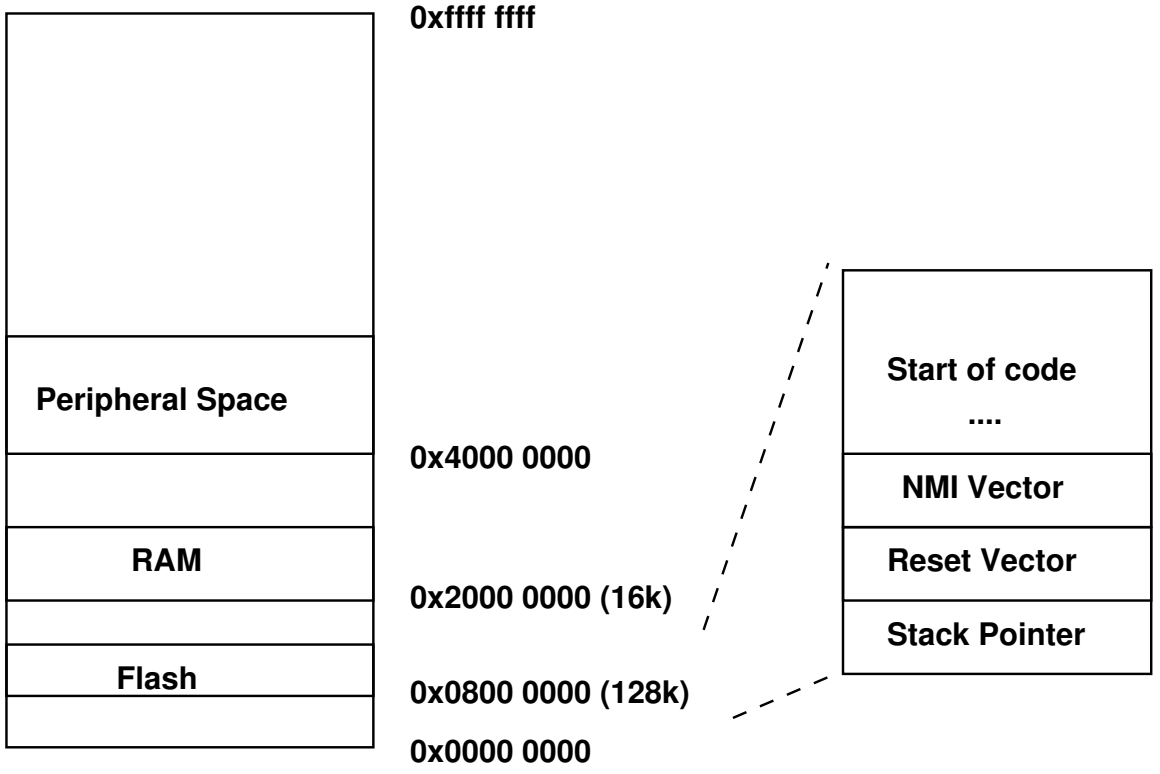


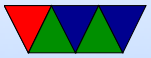
- Other data: things like symbol names, debugging info (DWARF), etc.
  DWARF backronym = "Debugging with Attributed Record Formats"

- Section Header, used when linking:
  has info on the additional segments in code that aren't loaded into memory, such as debugging, symbols, etc.

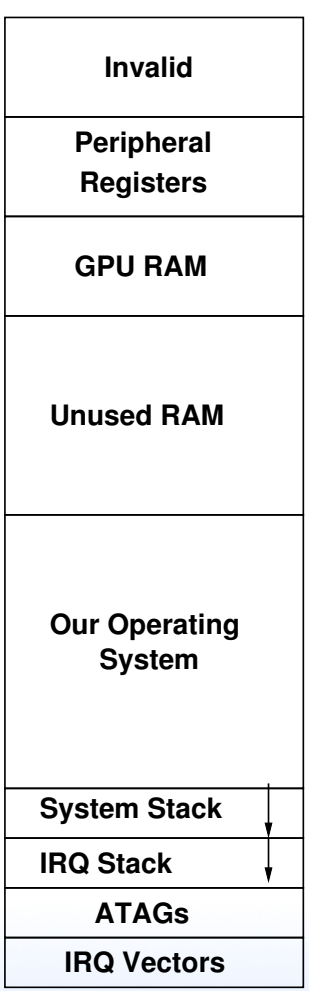


# STM32L-Discovery Physical Memory Layout



# Raspberry Pi Layout




0xffff ffff (4GB)

0x2100 0000 (528MB)

0x2000 0000 (512MB)

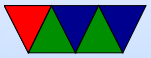
0x1c00 0000 (448MB)

0x0000 8000 (32k)

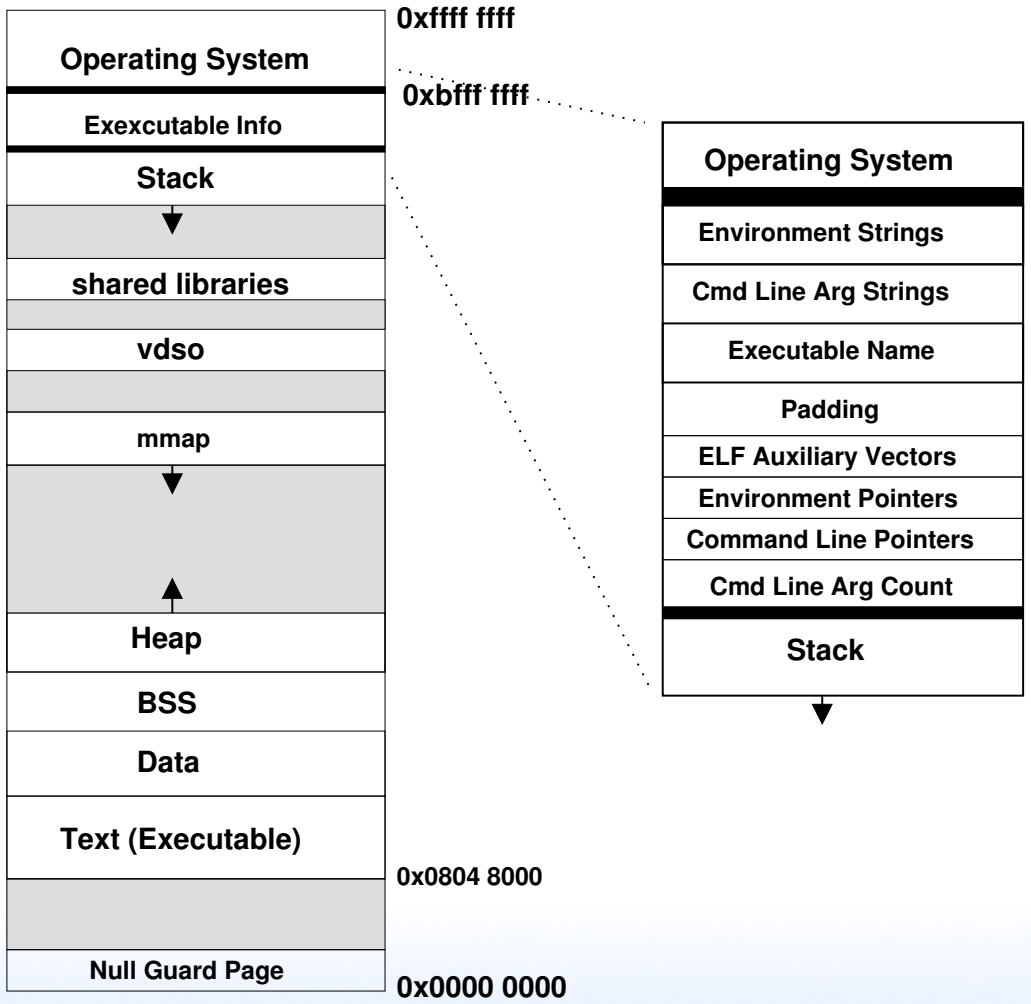
0x0000 4000 (16k)

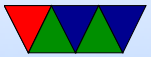
0x0000 0100 (256)

0x0000 0000



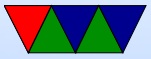
# Linux Virtual Memory Map



# Program Memory Layout on Linux

- Text: the program's raw machine code
- Data: Initialized data
- BSS: uninitialized data; on Linux this is all set to 0.
- Heap: dynamic memory. `malloc()` (`brk()` syscall) and C++ `new()`. Grows up.
- Stack: LIFO memory structure. Grows down.



# Program Layout

- Kernel: is mapped into top of address space, for performance reasons
- Command Line arguments, Environment, AUX vectors, etc., available above stack
- For security reasons "ASLR" (Address Space Layout Randomization) is often enabled. From run to run the exact addresses of all the sections is randomized, to make it harder for hackers to compromise your system.