# Introduction to Firmware Design

*or*

"Firmware: harder than software."

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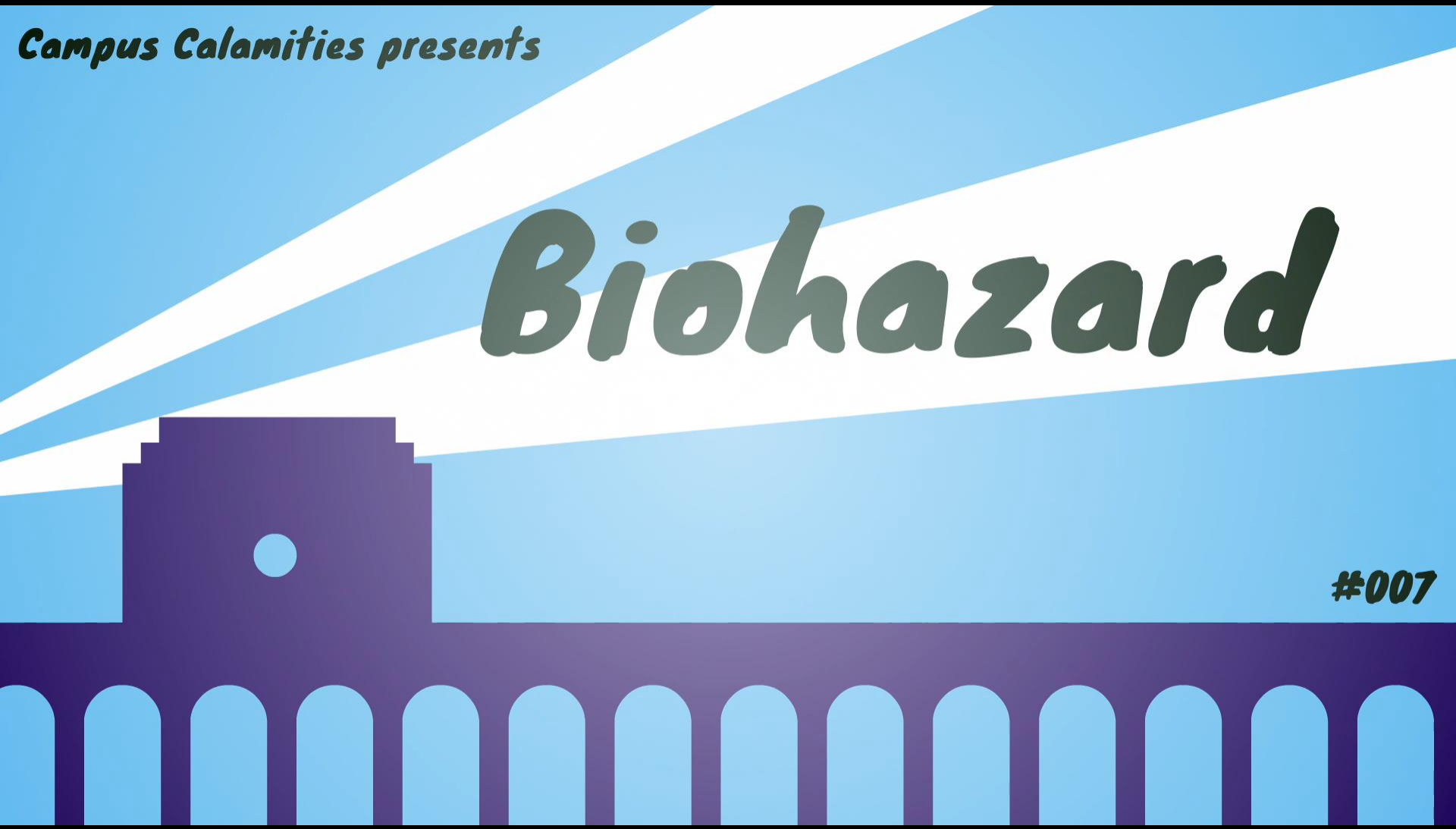
16 April 2019

University of Queensland

# But first…

**A valuable message about safety…**


Campus Calamities presents
Biohazard
#007

# But secondly…

Some house keeping

# Calendar at a glance

| Week | Dates | Lecture | Reviews | Demos | Assessment submissions |
|---|---|---|---|---|---|
| 1 | 25/2 – 1/3 | Introduction | | | |
| 2 | 4/3 – 8/3 | Principles of Mechatronic Systems design | | | Problem analysis |
| 3 | 11/3 – 15/3 | Previous years deconstruction case studies | | | |
| 4 | 18/3 – 22/3 | Professional Engineering Topics | Progress review 1 | | |
| 5 | 25/3 – 29/3 | PCB design tips | | | |
| 6 | 1/4 – 5/4 | Your soldering is (probably) terrible | | | |
| 7 | 8/4 – 12/4 | ~~Introduction to mechatronic design~~ Military-industrial complex | Progress seminar | 25% demo | |
| **8** | 15/4 – 19/4 | Introduction to firmware design | | | |
| **Break** | 22/4 – 26/4 | | | | |
| **9** | 29/4 – 3/5 | Q and A sessions | | 50% demo | |
| **10** | 6/5 – 10/5 | No lecture | Progress review | | |
| **11** | 13/5 – 17/5 | Q and A sessions | | 75% demo | Preliminary report |
| **12** | 20/5 – 24/5 | Monday lecture!! | | | |
| **13** | 27/5 – 31/5 | Closing lecture | | Final testing | Final report and reflection |

You are here

# Progress seminars

- All done! Nobody failed! Yay!
- Please make sure you fill out your PAFs and return them before you leave
- If you haven't yet returned your PAF sheet from Progress Review 1, then do so immediately – I AM COMING FOR YOU

# PAF 1 results

- I also now have complete PAF 1 results
  - If you are getting less than “C” from your peers, that’s a fair sign that they are unhappy with you…
  - If your PAF 2 is also <C, I’ll probably want to talk to you to see if there is a problem
- No PAF 1 result on Blackboard?
  - Let me know!

# Seminar and PAF 2 results

- Normally I have a histogram here, but I'm still waiting on Iain Rudge to send marks
  - C'mon, Iain! ಠ_ಠ
  - I'll put them in the online version when finished
- Instead, some general comments:
  - OMG, keep to time! 10 mins means 10 mins
  - Analysis, analysis, analysis.
  - I'm not kidding about this – seriously!

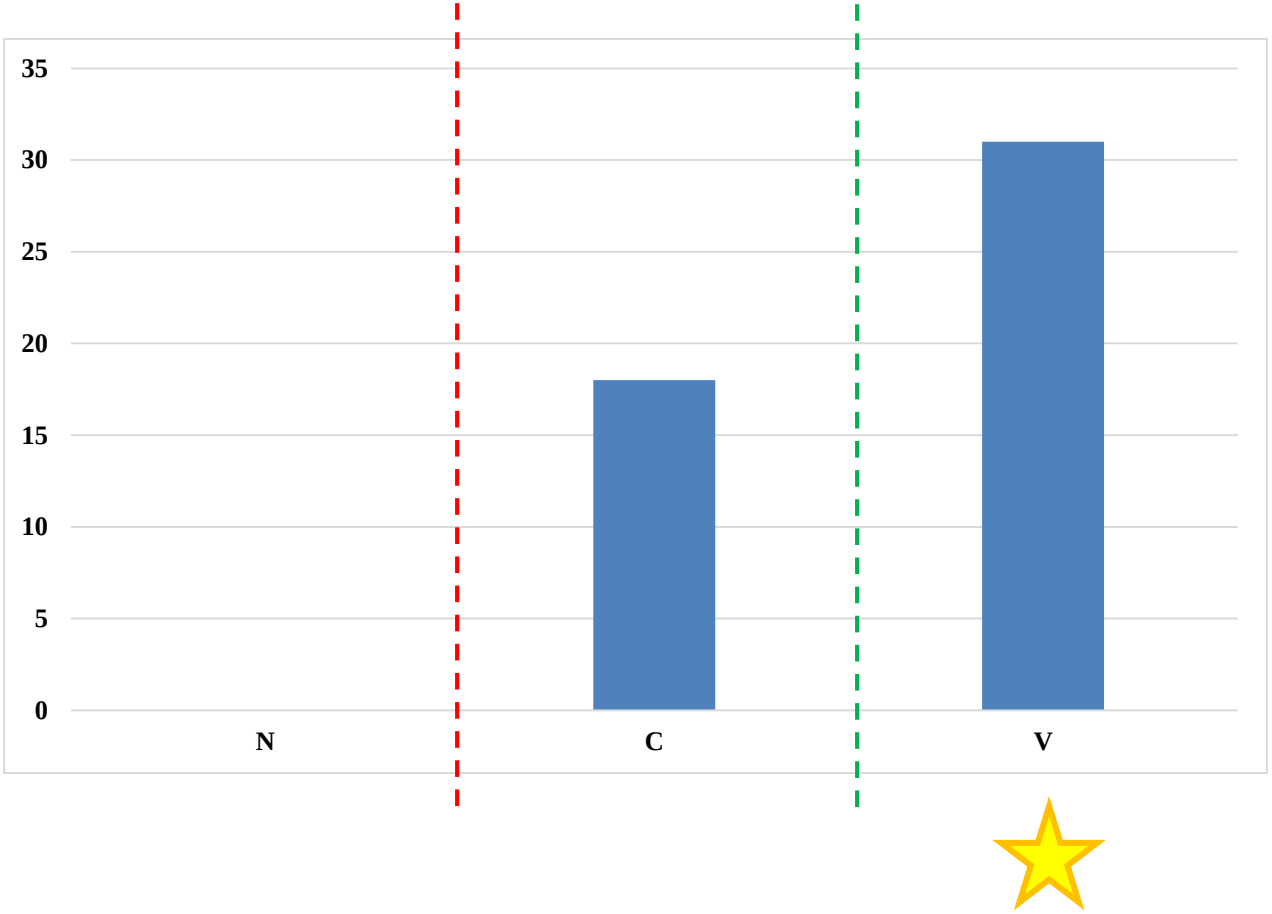
# Marks should all be updated

- People have been asking for PAF results and other marks
  - Happy to oblige!

- With only a few exceptions, all your marks to-date should be online for your viewing pleasure
  - If not, you and/or someone probably owe me an assessment or PAF

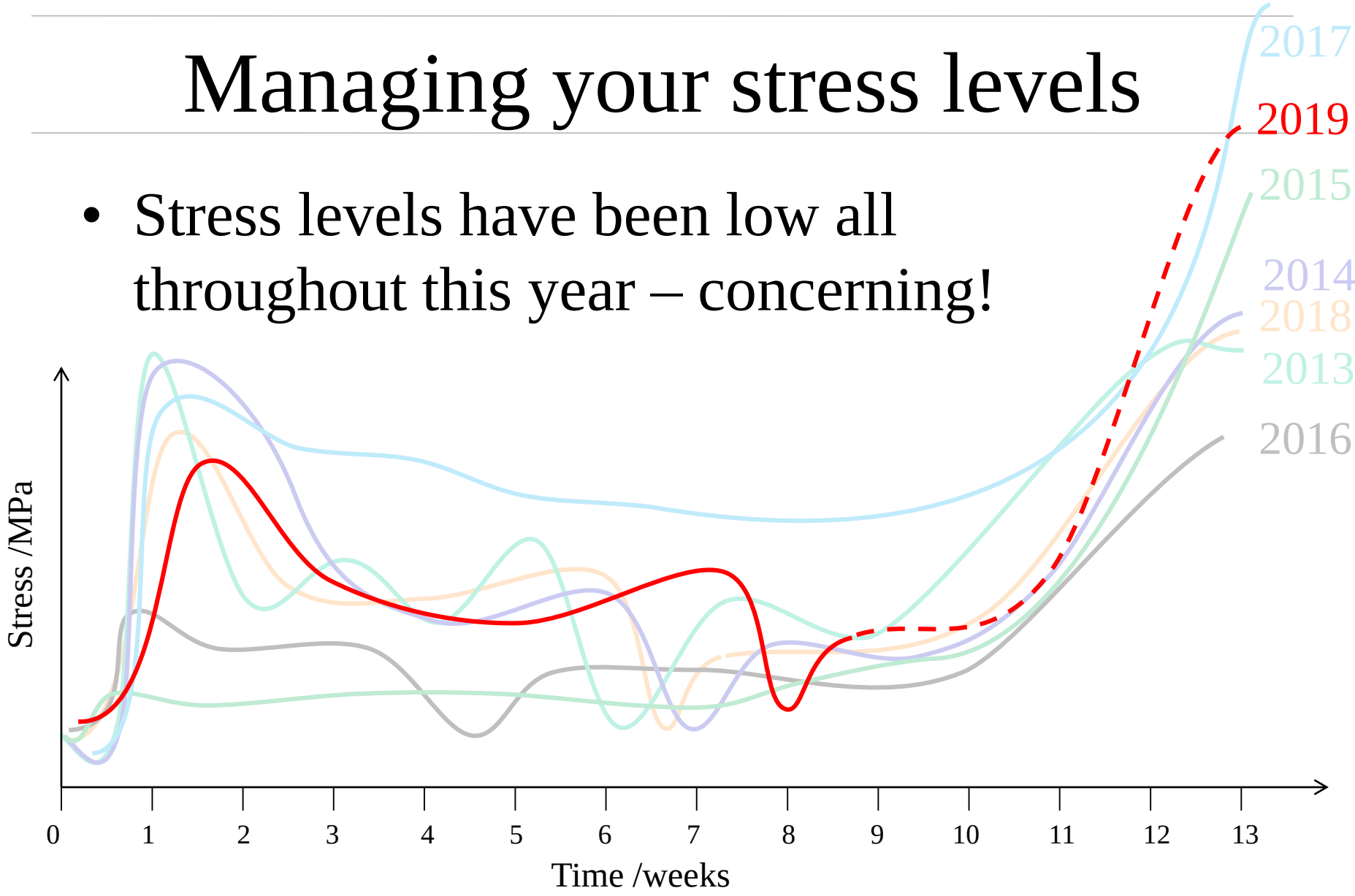
# Seminar Results

Results available via Blackboard right now!



# Managing your stress levels

- Stress levels have been low all throughout this year – concerning!



# FAQ Roundup

- **Can you look at my part design and give me feedback?**
  - Hell yeah! That's what I'm here for! Bring it!
- **How much will this part cost?**
  - Uhh... ask Jason Herriot?
- **Does "wall plug power pack" include power packs with cables to the wall, like ATX supplies, laptop power bricks and such?**
  - No. "Wall plug power pack" means power supplies where the transformer is integrated into the module that plugs into the wall. This is a safety compliance thing. Previously students have brought downright dangerous power supplies into the lab and it was a big problem.

# STC sessions

- More STC sessions have been added for this week and during the break!
  - Hooray!
- You need to book them through URite as usual
  - Hooray?

# Foam extraction

- It has been brought to my attention that foam dust is Probably Not Great™
  - You should avoid inhaling it or rubbing it into your eyes and mucus membranes.
- Not yet sure how much of a problem it will be, but I'm going to do the following:
  - Provide you with goggles
  - Provide you with a mini dust sucker to suck dust
  - Ask you to please keep your mucus membranes to yourself

# Onwards!

To firmware and beyond!

# Firmware: OMG what is it?

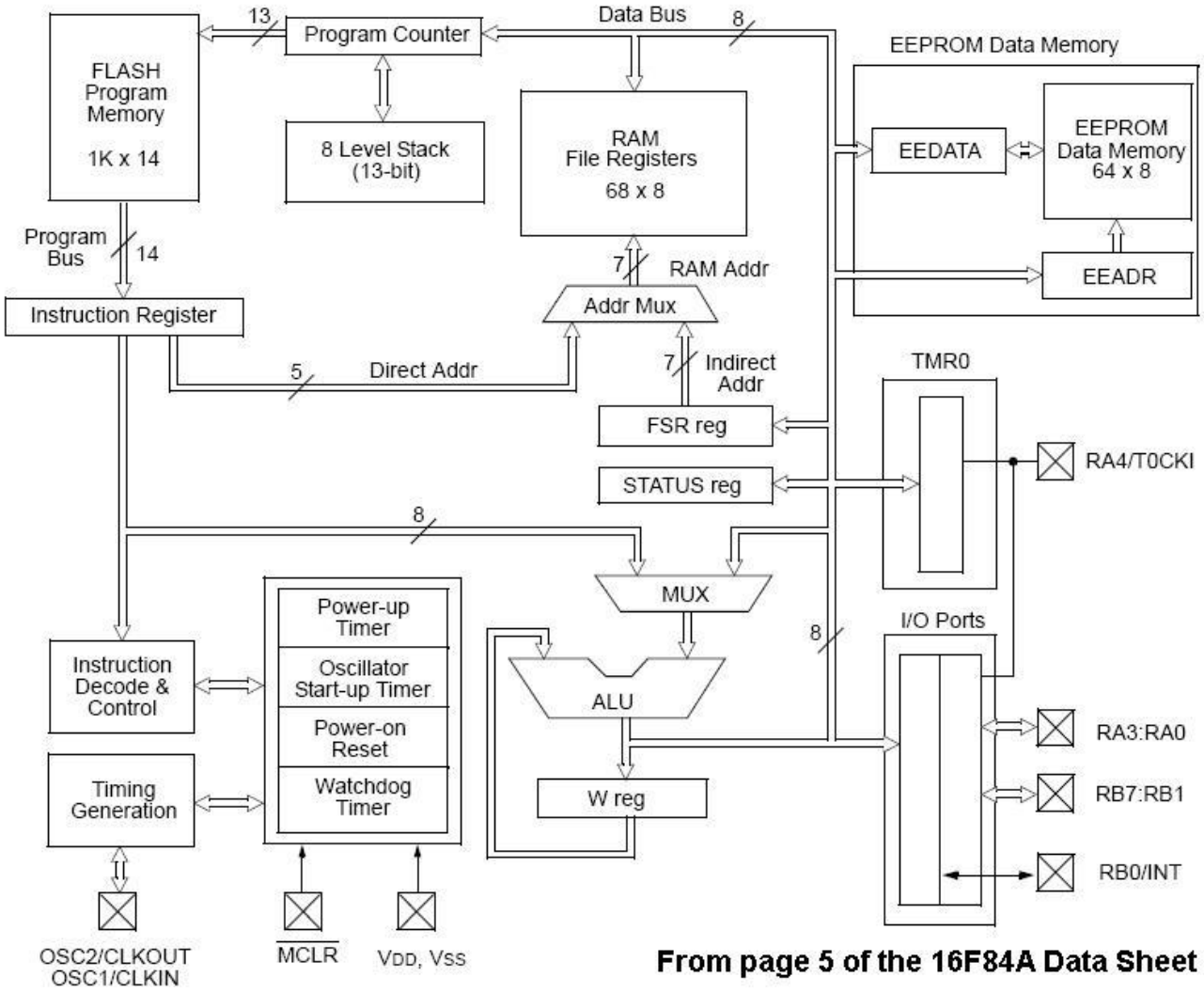
- The embedded machine code inside a microcontroller
  - Like software, only closer to hardware… so "firm"-ware
- Unique from software, in that it can write directly to device physical outputs
  - Straight from 'The Matrix' to the "Real World"

Let's talk about microcontrollers…

# Key elements

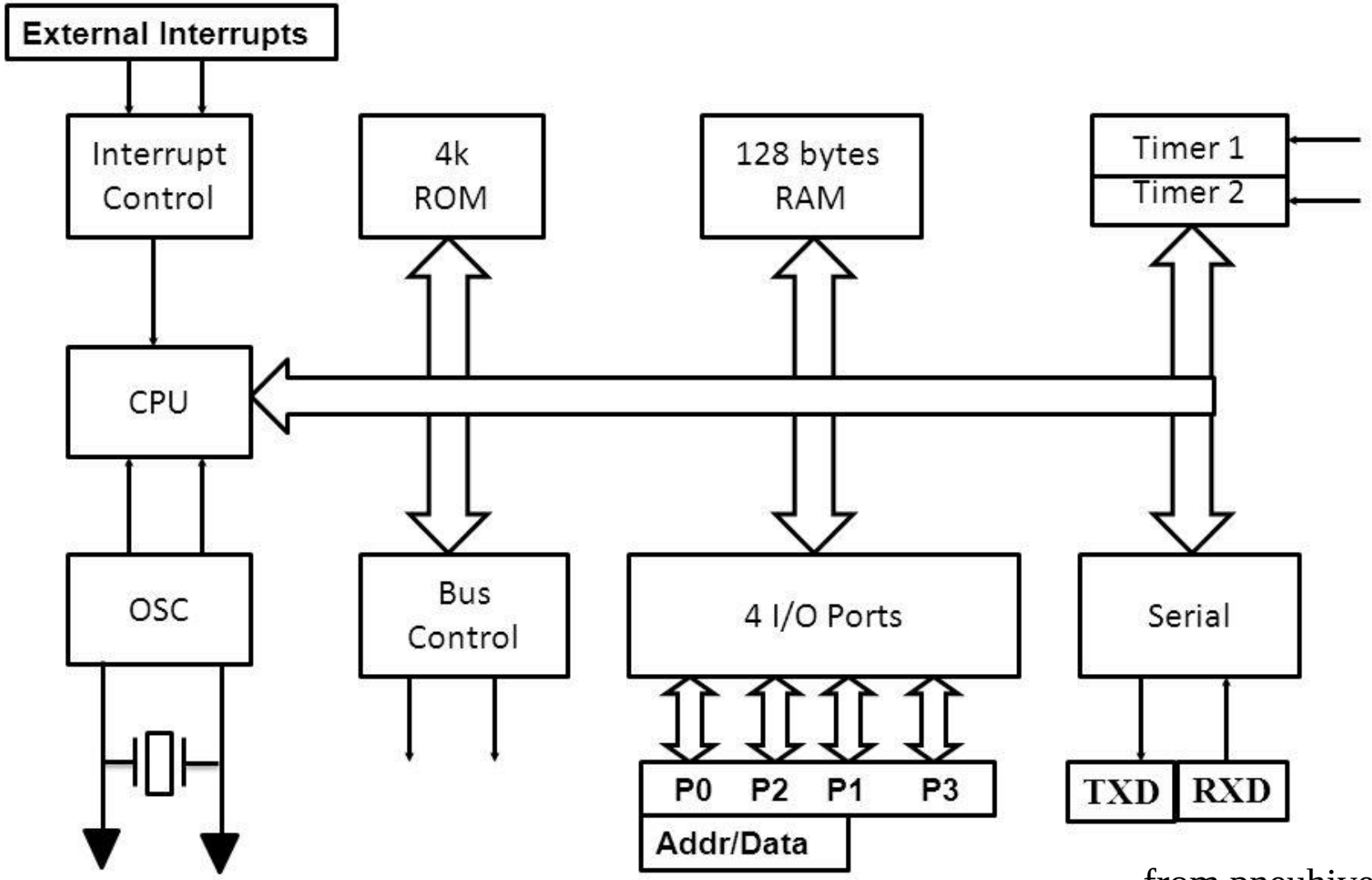
- Microcontrollers behave like a whole computer on a chip:
  1. Co-locate RAM with working memory
  2. Integrated data bus
  3. Internal clock sources and timing
  4. Input/output hardware (PWM, SPI, CCP, etc)
  5. Specialised hardware (graphics/audio/RF/etc)

# The legendary PIC 16F84A




From page 5 of the 16F84A Data Sheet

# Block diagram that thing…




from pneuhiver.info

# So, what about it?

- Firmware is necessarily low level
  - Yes, IDEs help, but if it shields you from the details, it also shields you from TRUE POWER
  - In order of least to most abstracted:

Opcodes > ASM > C > Python > I dunno, Matlab, maybe?

- "Teach me, Sensei – teach me this power!"
  - "Grasshopper, the longest code starts with a single #define"

# Some principles

- Structure everything
  - Structure is a lifestyle
- Modularise
  - Yes, even into separate files
- Use C
  - It’ll make it easier
- No, really: use C (or maybe Python).
  - You’ll thank me when you’re older

# Structure is a lifestyle

- Don’t do ANYTHING without structure

  “Code without structure is chaos”

  – a really smart person, probably Dijkstra

- Comments help you understand code, but good code makes comments less important

# Structure is a lifestyle

Major moving parts

- Front matter
  - All the nuts-and-bolts stuff, plus globals
- Main(){}
  - Your high-level structure should be visible here
  - Your program shouldn’t live in a function (although this is debatable)
- Client functions
  - All the stuff commonly reused, outside of loops

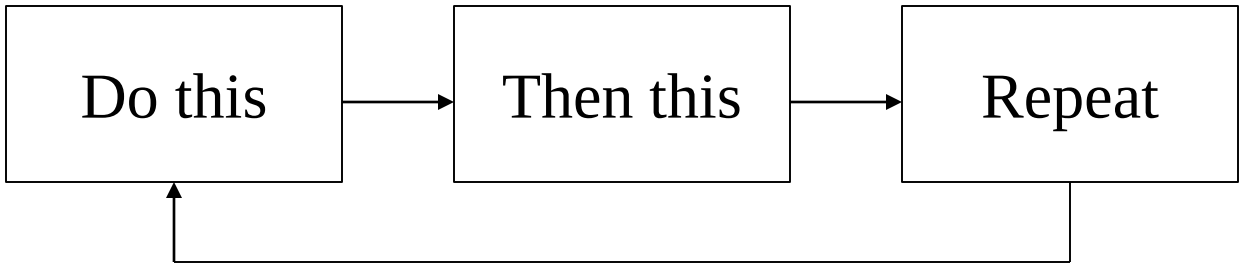
# Structure is a lifestyle

- One some level, you write code like a report
  - Start with a “skeleton” outline of what the program must do
  - Flesh out the details incrementally
- Of course, you want to be testing each functional block of code as you go…

# Structure is a lifestyle

- Start broad and work your way down
  1. Main/functions first (high level)
  2. loops/switches (intermediate level)
  3. Conditionals/function calls (low level)
  4. Operations (details)

This is all the “block diagram stuff”



# Structure is a lifestyle

- Begin with pseudocode
  - Write it out in words, then add details

Eg.:

```
Get the next value;
If the value passes the test;
 Store it for use later;
```

Then:

```
read(var); //Get next value
if(var > foo){ //Test value
 buf = var; //Store for reuse
}
```

# Structure is a lifestyle

- If you do it right, you get complete code with integrated comments for free!
- Also check out “Literate programming”
  - Natural language explanation of process flow intertwined with code
  - Easy to read, easy to write

# Modular Me

- Code reuse is made of God and Win
  - A lazy programmer is an efficient programmer
- Modular code is also easier to manage
  - Easy to “drop in” new functionality
  - Especially important for firmware, where porting from one processor to another is an all-too-common chore

# Modular Me

- Consider:
  - A specific header file for each particular microprocessor you use (almost mandatory!)
  - A separate source file and header file for each peripheral IC
  - A separate source file for each common major hardware function (eg. can.c, spi.c)

A source map isn't a bad idea after a while…

# Modular Me

## Example:

```
#ifndef PIC18F14K22_H
#define             PIC18F14K22_H

#define TMR0IF      (INTCON.F2)
#define TMR0IE      (INTCON.F5)
#define PEIE        (INTCON.F6)
#define GIEL        (INTCON.F6)
#define GIE         (INTCON.F7)
#define GIEH        (INTCON.F7)

#define INTEDG0     (INTCON2.F6)
#define INTEDG1     (INTCON2.F5)
#define INTEDG2     (INTCON2.F4)
```

# Use C

- C is the screwdriver of firmware languages
  - The number of things it's good for vastly outnumber the things it isn't good for
- Almost everything compiles C
  - Everything embedded DOES compile C
- If your firmware needs something C can't do, you're probably doing it wrong

# Use C

- If you are not using C, it's because:
  - A. You're doing something very specialised that uses arcane language extensions that C simply cannot support
  - B. Your boss/manager is a moron who insists on using the latest Agile-Cloud-Based-Buzzword-On-Rails mumbo jumbo
  - C. You're just scared of it and need to step up to the challenge?

# Kernels

- Kernels mediate between hardware processes and application software layers

- Most embedded tasks are on-going, continuous, repeating processes
  - A simple kernel makes program flow really straight-forward to manage
  - Ideally suitable for dynamic control

# Kernels

- A really small kernel is a snap to write:

```
interrupt(){/**interrupt handling, asynchronous stuff**/}
main(){
   hardware_setup();
   while(1){
        if(timing_flag){ //Regulate process loop rate
              service_routines(); //Reset timers, flags
              io_process(); //Read/write ports, flush buffers
              application_process1();
              application_process2(); //etc; can be dynamic
        }
        whenever_routines(); //Quick stuff, eg. poll loops
   }
}
```

# Rules for beginners (and everybody)

- Keep it simple – r*eally* simple!
  - Short routines, broken out into files by function
- Be one with your micro
  - Understand it and the circuit around it, totally
- Use a reliable toolchain – IDE is life
- Start with the biggest micro
  - Once it works, *then* you can optimise/downscale
- Document *everything*
  - Code comments are mandatory!



Based on the “15 rules” by 123Jack

# What about the Powah?

"But… I was promised TRUE POWER!

This sucks…"

Ok, with well-crafted

firmware and hardware…

# What about the Powah?

- You can get precision instruction timing that can be accurate down to *picoseconds*
  - I designed a nano-second timer for GPS in C
- You can build a drone from $10 of parts, in a circuit the size of a 10c coin.
- You can build a remote sensor that works for five years on a single coin cell.

# Join ussss

- So yeah… firmware is important

- Embrace structure
- Embrace C
- Embrace TRUE POWER

# Questions

# Tune-in next time for…

Questions and Answers Vol. 1

*or*

"The quick and the decaf"

Fun fact: Boeing writes avionics code in C.