UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

SE 423: Introduction to Mechatronics

Lecture 2: Peripherals

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Monday, January 26th, 2026

Questions?

How was the first lab? Enjoyed it?

Office Hours

Times:

- **Monday:** 4-6 PM**,** Samuel
- **Tuesday:** 11-1 PM**,** Lakshmi
- **Tuesday:** 1-3 PM**,** Neel
- **Tuesday:** 2-5 PM**,** Dan & Marius

- There to help with setting up CodeComposer (not necessary but helpful for homeworks), finishing the solder, getting checked off for the homeworks, labs or LabVIEW
- Close to deadlines it will be busy so be sure to come in early!

Due Dates

Lab:

- Starting Lab 1 this week, will be using C so be sure to be prepared!
- Do Exercise 1 of Homework 1 to get started in C.
  - You cannot use CodeComposer for that. You can just use an online C compile.
- Lab 1 is a 1-week lab, some are longer

Homeworks:

- All check-offs for homework 1 are due **February 3, 5PM**
  - Questions 2, 3, 5, 7, 8, 9 and 10 need to be checked-off by instructors / TAs
- Answers and code submissions for homework 1 are due **February 4, 9AM**
- No late acceptations, since these are individual!
- Soldering is Exercise 2 of Homework 1.

LabVIEW:

- All check-offs for LabVIEW 1 are due **February 5, 5PM**

Semester Project

Thursday May 14th, 11AM – 2PM

Last day of Finals!!!

(yes, I know that's annoying)

Attendance is mandatory!!

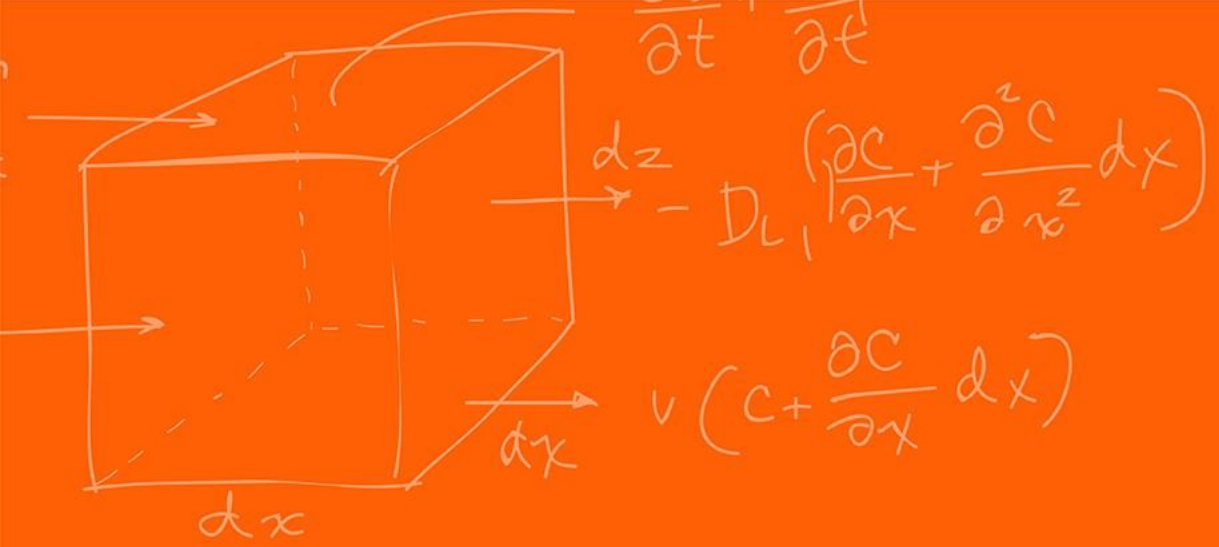
Semester Project

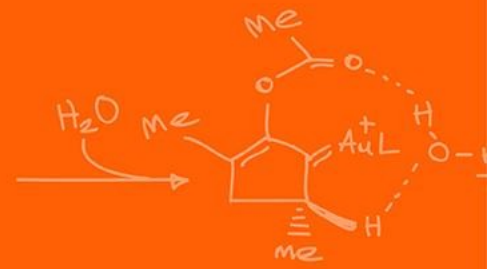
Website

You will be creating a Hackster.io website to show what you have done by the end of the semester to showcase to everyone.

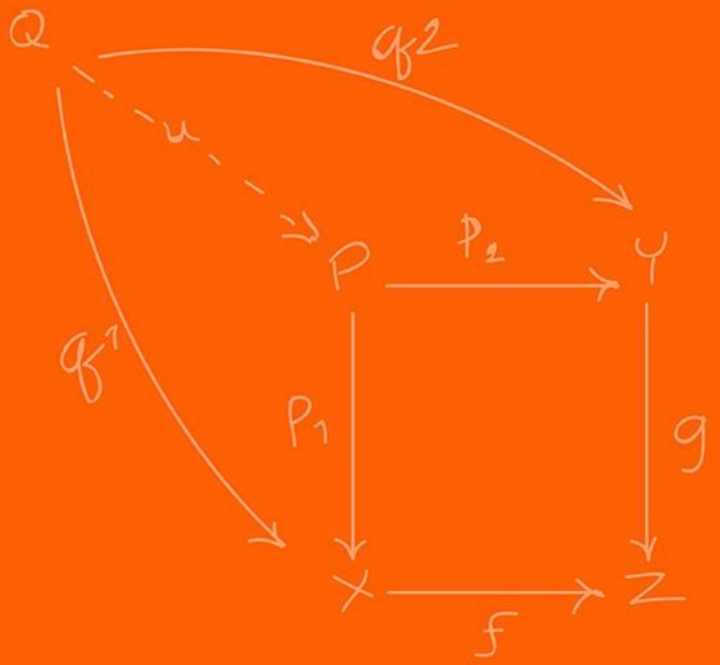
- Show the video working,
- Put code,
- **Show any other cool stuff you do!**

You are posting this to be publicly visible, so put your best effort in doing this. You can show the work for interviews, etc…





Registers



Memory-Mapped I/O

The CPU only knows one thing: **memory addresses**

On the TMS320F2837xD:

- RAM has addresses
- Flash has addresses
- Peripherals also have addresses

This is called Memory-Mapped I/O (**MMIO**)

A peripheral is a hardware module whose control and status registers are mapped to fixed memory addresses, allowing the CPU to configure and control hardware by reading from and writing to memory.

System and Peripheral Registers

Peripheral:

A **Peripheral** is a hardware device with a specific address in memory that it writes data to and/or reads data from.

All peripherals can be described by an offset from the **Peripheral Base Address.**

On the TMS320F2837xD, registers are typically **32-bits** or **16-bit** wide

Each bit usually represents to:

- A hardware switch (ON / OFF)
- A configuration option
- A hardware status flag (Error code, OK)

Peripheral Base Address

TI groups peripherals into address regions.

For example:

- GPIO register live in one address range
- Timers in another
- ePWM in another
- ADC (Analog to Digital Converters) in another
- Etc…

Each register is located at:

Peripheral Base Address + Register Offset

You do not need to calculate these addresses manually; TI provides C structures and header files that do this manually.

```
EPwm1Regs.TBCTL.bit.CLKDIV = 1;
```

System Peripheral

System registers control the *behavior of the CPU itself*

These registers affect the **entire chip.** These system registers are protected.

These can modify:

- Clock configuration
- Resets
- Peripheral interrupts
- Memory configuration
- Timer

Full list is available in Table 3-17 - System Control Base Address Table

EALLOW / EDIS

Some registers are protected to prevent accidental damage (most / all system peripherals).

Thus, an additional layer of protection is allowed for accidental writes (memory leaked code or otherwise).

- **EALLOW**: unlocks protected registers
- **EDIS:** locks them again

```
EALLOW;  // This is needed to write to EALLOW protected registers
PieVectTable.TIMER0_INT = &cpu_timer0_isr;
PieVectTable.TIMER1_INT = &cpu_timer1_isr;
PieVectTable.TIMER2_INT = &cpu_timer2_isr;
PieVectTable.EMIF_ERROR_INT = &SWI_isr;
EDIS;    // This is needed to disable write to EALLOW protected registers
```

Peripheral Registers

Peripheral registers control individual hardware modules. Usually do not have any write protection

Examples:
- GPIO (General Purpose Input-Output)
- Timers
- ADC (Analog-to-Digital Converter)
- PWM (Pulse Width Modulation)
- SPI (Serial Peripheral Interface)

Each peripheral has a Read (DAT), Write (SET), Clear (CLEAR) and Toggle (TOGGLE) register.

```
GpioDataRegs.GPBDAT.bit.GPIO37; // Do not use to set
GpioDataRegs.GPBSET.bit.GPIO37 = 1; // Sets GPIO37 to 1
GpioDataRegs.GPBCLEAR.bit.GPIO37 = 1; // Sets GPIO37 to 0
GpioDataRegs.GPBTOGGLE.bit.GPIO37 = 1; // Sets GPIO37 to 0->1
```

Using DAT

There are problems that arise from writing directly to DAT

Writing to DAT requires,

1. Read
2. Modify
3. Write

An interrupt (code that runs on certain events) can run between these steps and corrupt data

SET / CLEAR registers avoid this by being **atomic** hardware operations.

Atomic operations guarantee that a variable will be locked during the operations and cannot be modified by anyone else during that time.

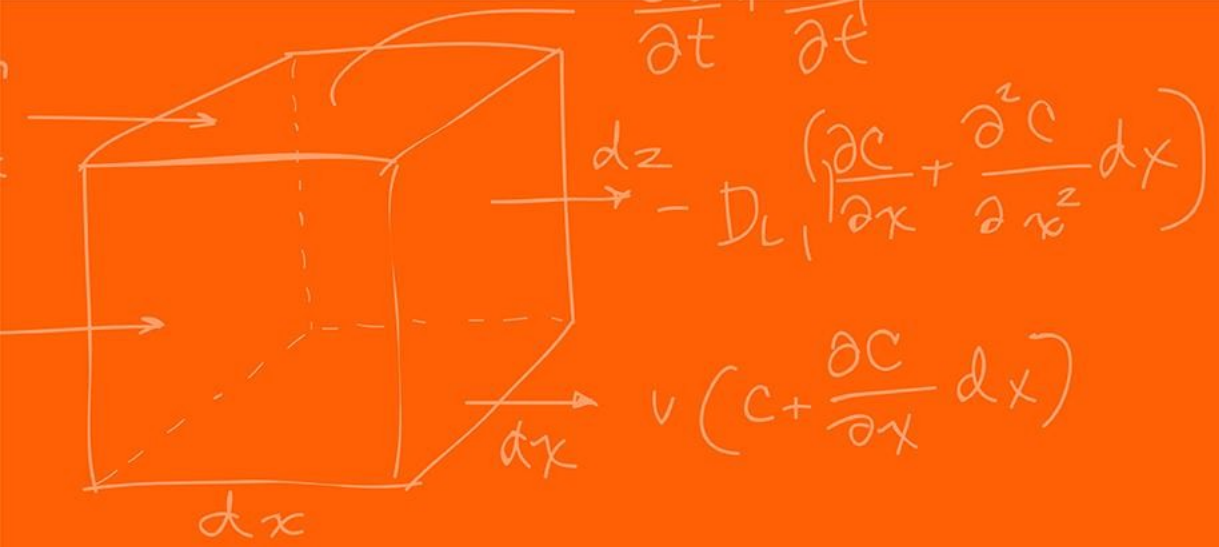
Digital I/O (GPIO)

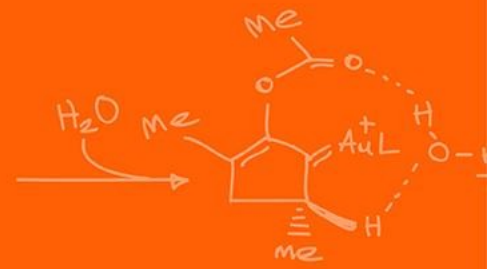
Each **physical** pin can serve **multiple functions**

- GPIO
- PWM
- SPI
- SCI
- CAN

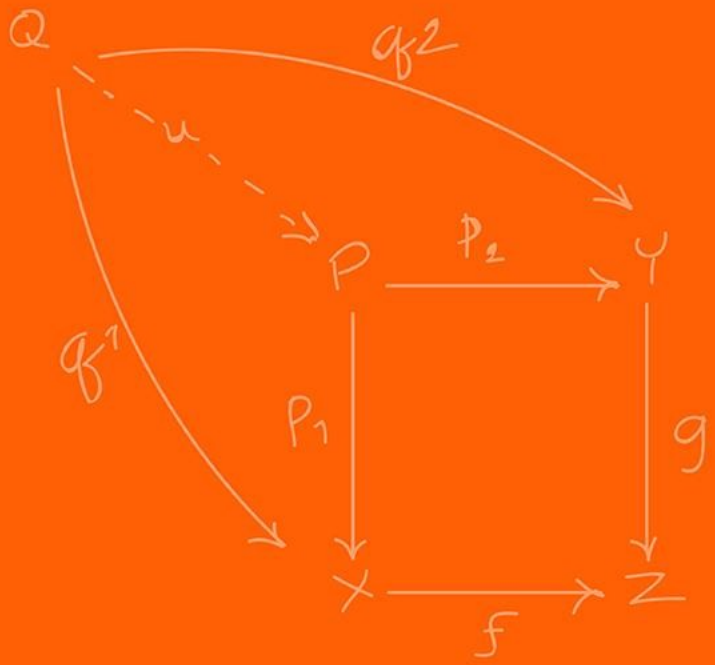
You must first select the function

```
GPIO_SetupPinMux(31, GPIO_MUX_CPU1, 0);
GPIO_SetupPinOptions(31, GPIO_OUTPUT, GPIO_PUSHPULL);
```





Bits



Binary

The CPU only reads binary, 1s or 0s; however, for humans it is difficult to understand long string of numbers.

A 32-bit register could be represented as such with 32 bits (unsigned 3,357,083,684):

```
int32_t x = 0b11001000000110010000010000100100;
```

What is a potential problem?

Prone to make mistakes if you need to manually type this out! For example, there are **33-bits** above, not 32!

Why not use Decimal system? Not as simple to convert from decimal to binary!

Hexadecimal

Instead of base 10, let's explore base 16, i.e., hexadecimal base system

Very easy to convert binary to hex (0-9 then A-F):

Binary	Hexidecimal	Decimal
0000	0	0
0001	1	1
1010	A	10
1111	F	15

Every 4-bits = 1 hex value, makes things much easier to compress, much easier to look at!

```
int32_t x = 0xC8190824;
int16_t x = 0x0824;
```

Windows Calculator set to programming mode can easily do the conversion!

Bits, Bit Positions and Masks

Bit number starts at 0

Bit 0 → 2^0
Bit 1 → 2^1
Bit 5 → 2^5 = 32 = 0x20

Creating a bit shifting:

- Left shifting: x << n, shifts bits in x to the left by n. `0b01 << 1 = 0b10`
- Right shifting: x >> n, shifts bits in x to the right by n. `0b10 >> 1 = 0b01`

Commonly used to create bit “masks”:

```
int32_t bit5Mask = 1 << 5; // 0x20, sets only bit 5 to 1!
```

What are masks? What are they used for?

Bitwise Operations

AND (&) – Masking

```
if (reg & (1 << 3)) {
    // Bit 3 is set
}
```

OR (|) – Setting Bits

```
reg |= (1 << 3);
```

REG	MASK	AND	OR	XOR
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	1	0

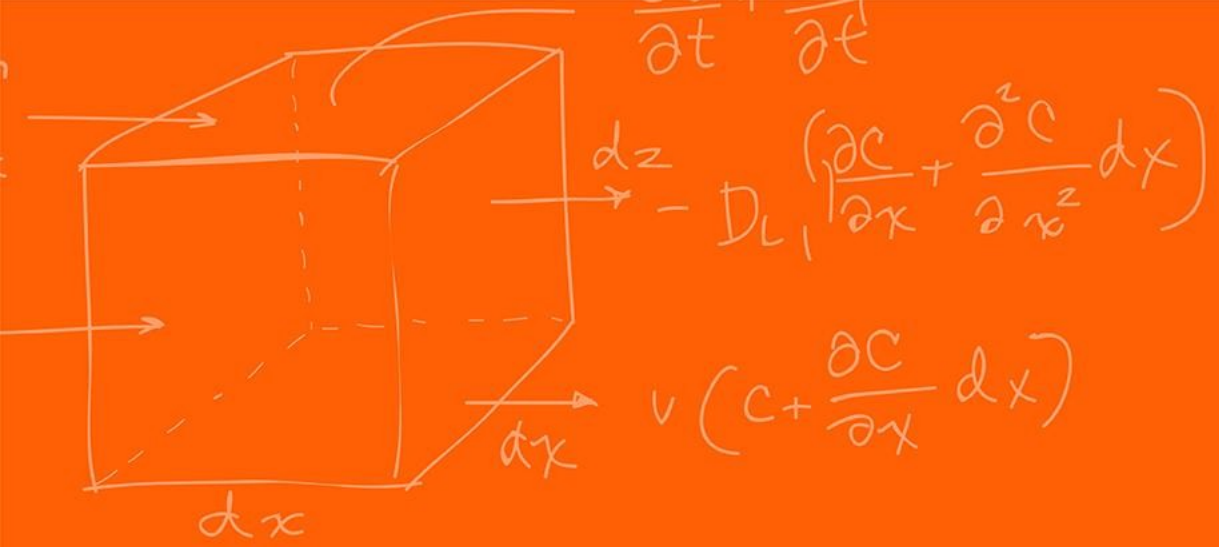
NOT (~) – Clearing Bits

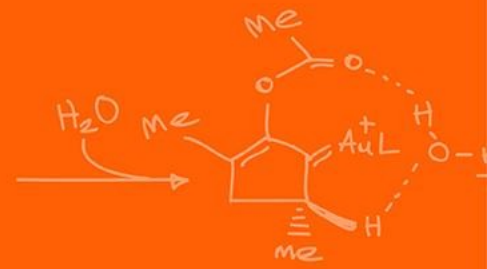
```
reg &= ~(1 << 3);
```

XOR (^) – Toggling Bits

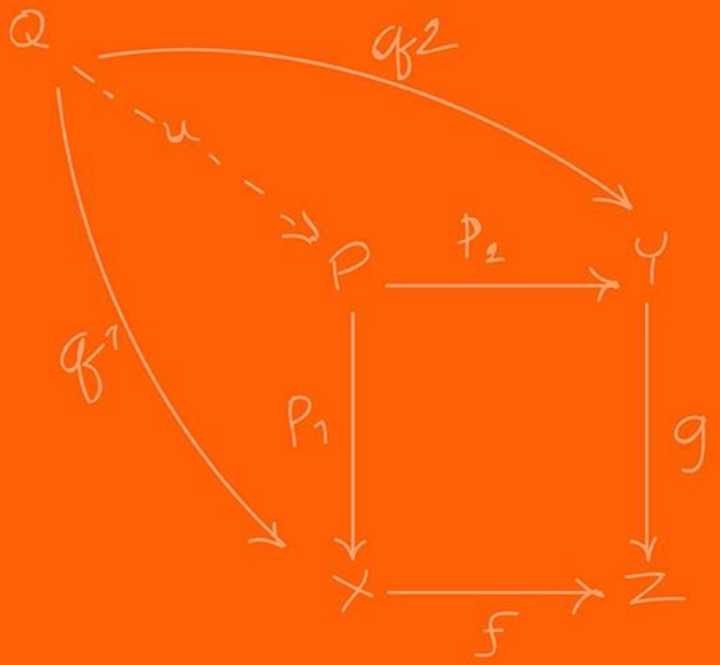
```
reg ^= (1 << 3);
```

MASK	NOT
0	1
1	0





Timers



What is a timer?

Just like a clock that you have; however, in hardware it is EXTREMELY important.

A **timer** is a hardware counter that:

- Counts clock cycles
- Triggers an interrupt when it reaches a specified condition

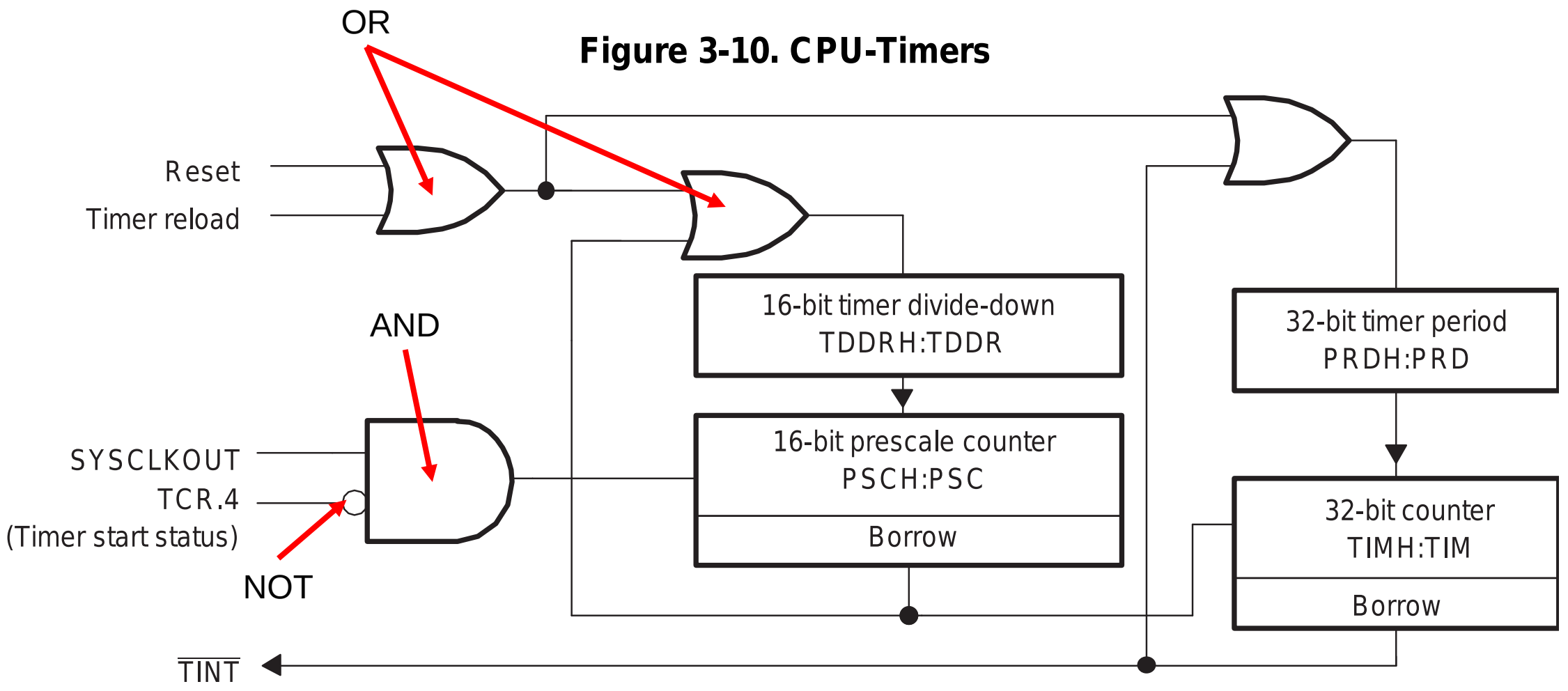
The TMS320F2837xD has **3** 32-bit CPU timers.

- CPU-Timer0 and CPU-Timer1 can be used in user applications
- CPU-Timer2 is reserved for real-time operating system uses (if not being uses in an operating system that uses this timer, it can used in the application).

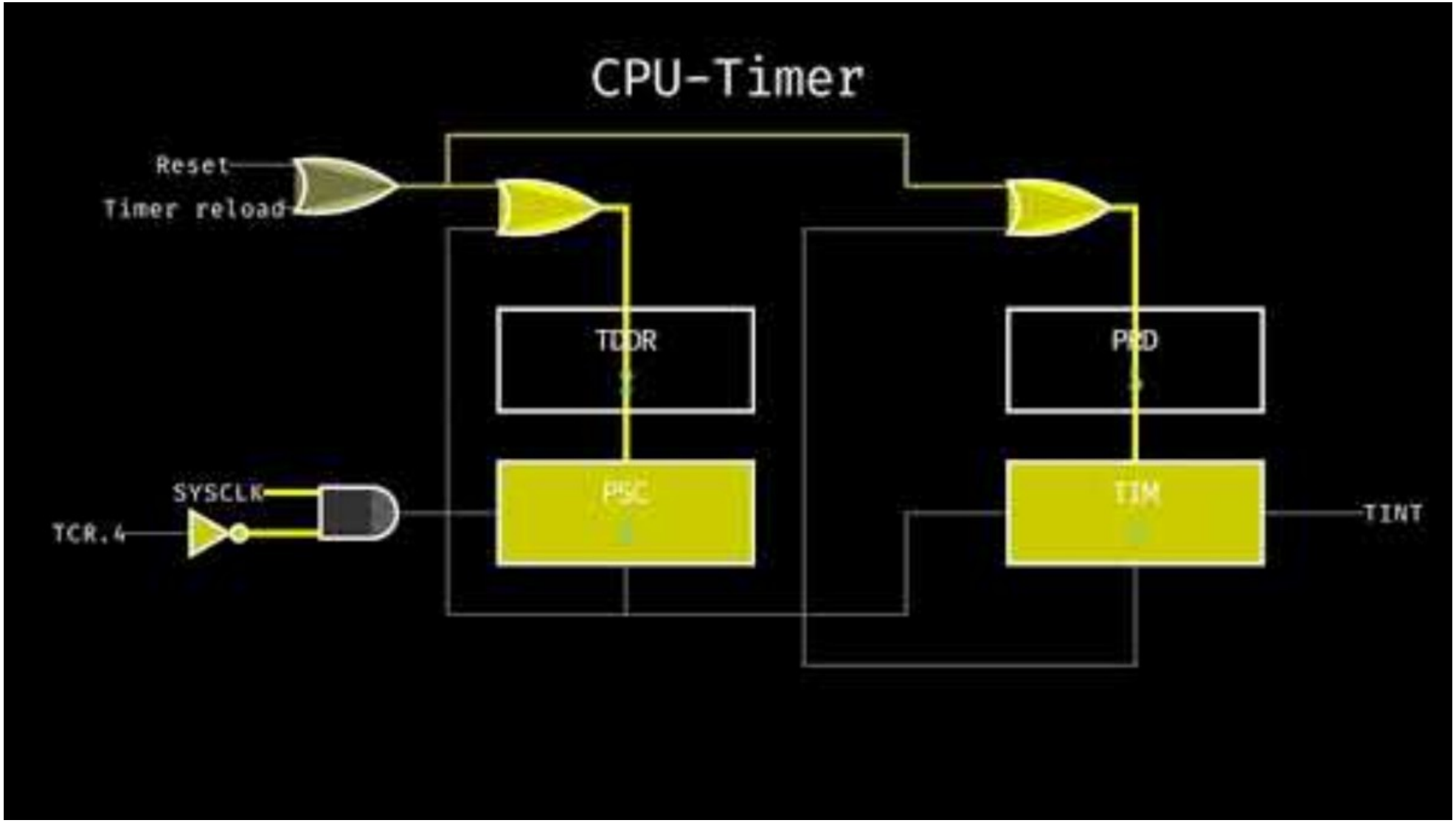
These clocks run off the system's internal clock (SYSCLK) (CPU-Timer2, has additional options)

System's internal clock runs at 200 MHz

What is a timer?



What is a timer?



What is a timer?

Why are there 2-counter blocks?

System clock: SYSCLKOUT = 200 MHz → T_{clk} = 2 ns

Problem is that the clock is too fast for software:

At 200 MHz:
- 1 ms requires: 200,000 clock ticks
- 10 ms requires: 2,000,000 clock ticks

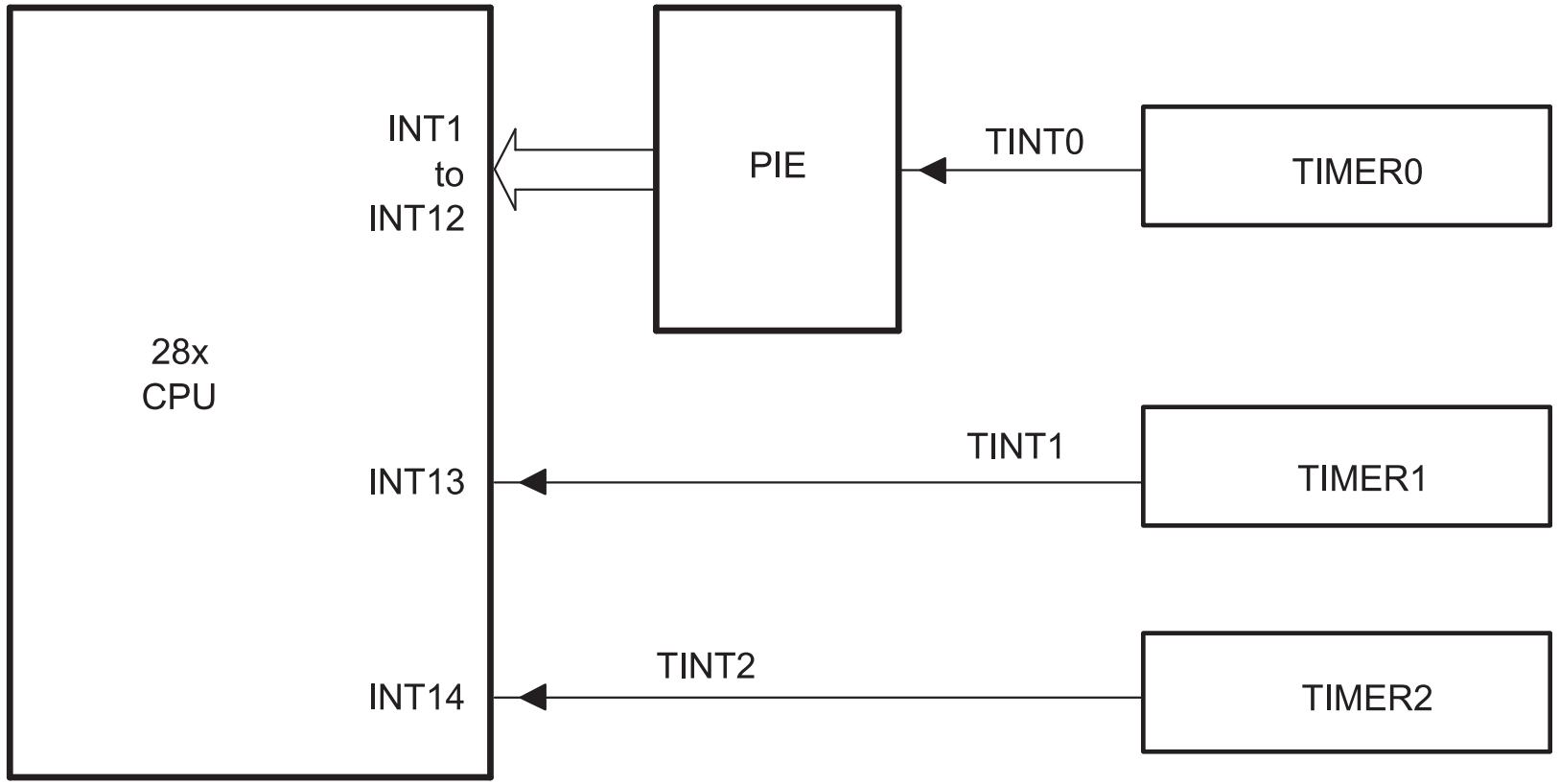
Split the job into 2 counters:
- Prescaler Counter (PSC, TDDR) – Controls speed, defines a unit of time
- Main Timer Counter (TIM, PRD) – Controls duration, how much time should pass

One counter decides how *fast time flows* and the other decides *how much time passes.*

With a prescaler set to TTDR=199 for example, you now have that a single tick for the main timer counter represents a clean 1 µs, thus, to ensure that your timer runs every 10 ms you can set PRD = 10,000! Much simpler!

What is a timer?

Figure 3-11. CPU-Timer Interrupts Signals and Output Signal



A The timer registers are connected to the memory bus of the C28x processor.

B The CPU Timers are synchronized to SYSCLKOUT.

What is a timer?

The timer controls:

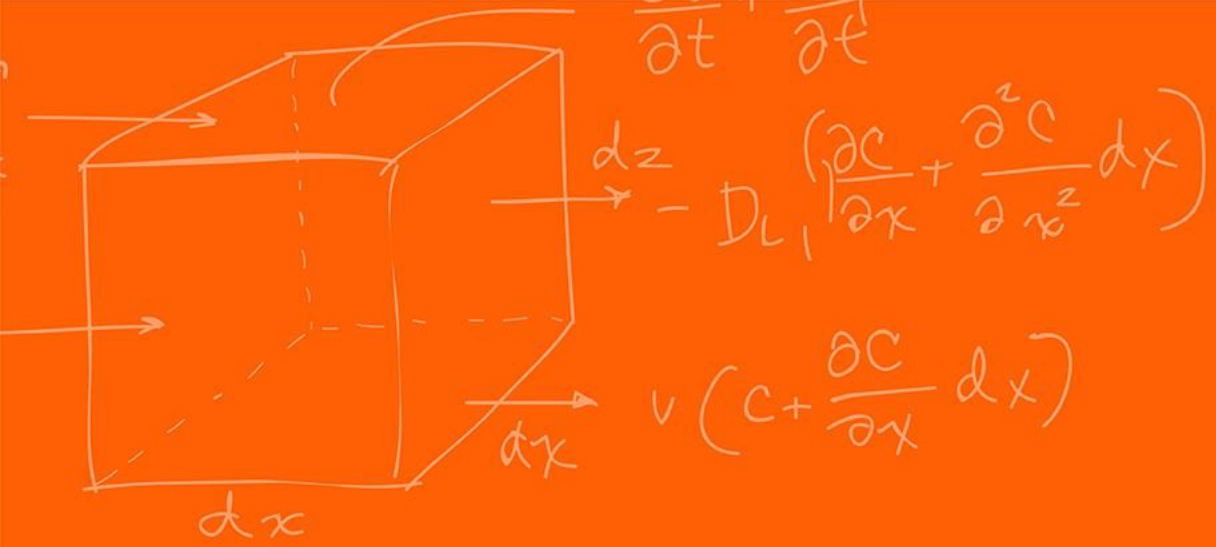
- Control loop sampling rate (user defined controller)
- Task scheduling
- PWM updates

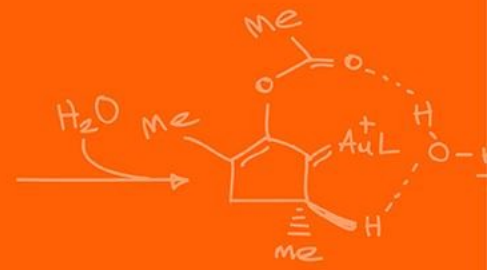
Can control interrupt how often the software interrupts get called:

```
// Configure CPU-Timer 0, 1, and 2 to interrupt every given period:
// 200MHz CPU Freq,                       Period (in uSeconds)
ConfigCpuTimer(&CpuTimer0, LAUNCHPAD_CPU_FREQUENCY, 10000);
ConfigCpuTimer(&CpuTimer1, LAUNCHPAD_CPU_FREQUENCY, 20000);
ConfigCpuTimer(&CpuTimer2, LAUNCHPAD_CPU_FREQUENCY, 40000);
```

Questions?

(Lecture Wednesday online or not?)





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