LECTURE 2 - MSP432 ARCHITECTURE AND GPIO CONFIGURATION

* CHAPTER REVIEW:
Section 2.1: MSP432 Microcontroller and LaunchPad
Section 2.2: GPIO (General Purpose I/O) Programming and Interfacing
Section 2.3: Seven-segment LED interfacing and programming
Section 2.4: I/O Port Programming in Assembly
Section 2.5: 16-BIT I/O ports in MSP432
Section 2.6: Port mapping controller

* MSP432P401R MAIN FEATURES:
1. ARM® Cortex™ - M4 Processor (ARM version 7)
2. 100-pin microcontroller chip
3. 256 K bytes (256 KB) of on-chip Flash memory for code - To store program
4. 64 KB of on-chip SRAM for data - To store data
5. Large number of on-chip peripherals

* TI MSP432P401R MICROCONTROLLER HIGH-LEVEL BLOCK DIAGRAM:
There are many peripherals present in this processor. Inside the CPU, we have ARM Cortex-M4F, Memory Protection Unit (MPU), NVIC, System Tick (SysTick) Timer, Flash Patch and Breakpoint (FPB), Data Watchpoint and Trace (DWT), Instrumentation Trace Macrocell (ITM), Trace Port Interface Unit (TPIU), JTAG and SWD. JTAG and SWD is used for on-chip debugging.
JTAG → single wired
JTAG
Debug Access Port

* MEMORY MAP IN MSP432P401R:

	Allocated size	Allocated Address
Flash	256 KB	0x0000 0000 to 0x0003 FFFF
SRAM	64 KB	0x2000 0000 to 0x2000 FFFF
I/O	All the peripherals	0x4000 0000 to 0x4001 FFFF

LPC2148 - Quad Flag Package (QFP) - Pins on all four sides of IC
MSP432 - Dual Inline Package (DIP) - Pins on both the sides of IC

2 bits

* TI'S NAMING CONVENTION FOR MSP432:

- MSP - Processor Family
- 432 - 432 MCU Platform [Cortex-4 ARM (32-bit)]
- P - Series (performance)
- 401R - Feature Set
- I - optional: Temperature Range
- PZ - Packaging Type
- T - optional: Distribution Format
- XX - optional: Additional Features

Mixed Signal Processor
Handle both analog and digital data along with many DSP operations

All the peripherals including GPIO, Timer, etc are mapped

4G		0xFFFF FFFF
3G		0xC000 0000
2G		0x8000 0000
1G	I/O	0x4001 FFFF
		0x4000 0000
Physical Parameters	SRAM	0x2001 FFFF 0x2000 0000
		0x1FFF FFFF
0	Flash	0x0003 FFFF 0x0000 0000

Processor Family	MSP = Mixed signal processor XMS = Experimental silicon - Not used nowadays
432 MCU Platform	TI's 32-bit Low-Power Microcontroller Platform With Cortex-M4 Core
Series	P = Performance and Low-Power Series

Feature Set	First Digit	Second Digit	Third Digit	Fourth Digit
	4 = Flash based devices up to 48 MHz	0 = General Purpose Processor/ Microcontroller	1 = ADC 14 (14-bit ADC)	R = 256 KB of Flash, 64 KB of SRAM M = 128 KB of Flash, 32 KB of SRAM

Optional: Temperature Range	S = 0°C to 50°C I = -40°C to 85°C ✓ T = -40°C to 105°C (Military for extreme conditions)
Packaging	PZ = LQFP [Low-profile Quad Flag Package]

MSP 430 16-bit only operations

* MEMORY ZONES IN MSP432 : (General)

0xFFFF FFFF	0xE010 0000	0xE000 0000	0x4400 0000	0x4000 0000	0x2400 0000	0x2000 0000	0x0200 0000	0x0000 0000
Debug / Trace Peripherals	Unused	Unused	Unused	Peripherals	Unused	SRAM		Code

There is an increase in space observed here as compared to the memory map in MSP432P401R due to bit-banding region being present. Each bit can be accessed seperately. The debug/trace peripherals will be present in the higher region.

* HISTORY AND FEATURES OF MSP432 :

1. TI used the venerable 8051 microcontroller for their mixed signal processors, which can handle both digital and analog signals.
2. TI came up with MSP430 chip due to the need for low power chip and 8051 limitations.
3. MSP stands for Mixed Signal Processor.
4. The MSP430 is a 16-bit RISC CPU designed and marketed exclusively by TI.
5. In 2015, TI introduced an ARM-based device to the MSP430 Family and called it MSP432, having 32-bit ARM Cortex-M4.

PTO

* HISTORY AND FEATURES OF MSP432 :

MSP432

ARM® Cortex™ M4F 48 MHz

FPU | MPU | NVIC | NVIC | JTAG | SWD

(Debugging peripherals)

(Low Power)

1.62V - 3.7V Operation

Memory

Upto 256 KB Flash

Up to 64 KB SRAM

Driver Libraries *

DMA (8 ch)

Bootstrap Loader

32 KB ROM

Debug

Real-time JTAG *

(Average)

Temperature - 85°C

Power & Clocking

Programmable DC

Low-Power oscillator

Real-Time clock

Power & Clocking

4x 16-bit Timer/PWM/CCP

2x32-bit GP Timers

Systick Timer

CRC 32

Watchdog Timer *

Security

AES-256 *

(Not present in MSP 2nd)

Comms Peripherals

4x UART or SPI *

4x I2C or SPI *

Analog

24 ch, 14-bit, 1MSPS SAR ADC *

2x Analog Comparators * (Compare Analog signals)

Voltage Reference *

Temperature sensor *

Capacitive Touch I/O *

* - same as 16-bit MSP430 MCUs

* GPIO (GENERAL PURPOSE I/O) PROGRAMMING AND INTERFACING :

In the microcontroller, we have two types of I/O:

(a) General Purpose I/O (GPIO) - The GPIO ports are used for interacting devices such as LEDs, switches, LCD, keypad and so on.

(b) Special Purpose I/O - These I/O ports have designated function such as ADC (Analog-to-Digital), Timer, UART (universal asynchronous receiver transmitter), and so on.

* GPIO:

① The GPIO ports in MSP432 are designated as port P_1 to P_{10} + PJ.
② P1 to P10 are also referred as the Simple I/O or Digital I/O ports.
③ port J has special function such as external crystal oscillator and JTAG connections.
④ The base address of I/O port is 0x4000 4C00.

* GPIO OFFSET ADDRESS:

GPIO P_1 - 0x4000 4C00 + 0 (even addresses)
GPIO P_2 - 0x4000 4C00 + 1 (odd addresses)
GPIO P_3 - 0x4000 4C00 + 20 (even addresses)
GPIO P_4 - 0x4000 4C00 + 21 (odd addresses)
GPIO P_5 - 0x4000 4C00 + 40 (even addresses)
GPIO P_6 - 0x4000 4C00 + 41 (odd addresses)
GPIO P_7 - 0x4000 4C00 + 60 (even addresses)
GPIO P_8 - 0x4000 4C00 + 61 (odd addresses)
GPIO P_9 - 0x4000 4C00 + 80 (even addresses)
GPIO P_{10} - 0x4000 4C00 + 81 (odd addresses)

* I/O PINS IN MSP432 LAUNCHPAD BOARD:

① I/O ports are named with numbers P_1, P_2, P_3, and so on.
② The pins are designated as P1.0 - P1.7, P2.0 - P2.7, P3.0 - P3.7, and so on.
③ The MSP432P401R has ports P_0, P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10} and P_J.
④ P_{10} and P_J have only 6 pins while all other ports have 8 pins.
⑤ We can combine two 8-bit ports to come up with 16-bit port.

* MSP432P401R 100-PIN PACKAGE PIN-OUT:

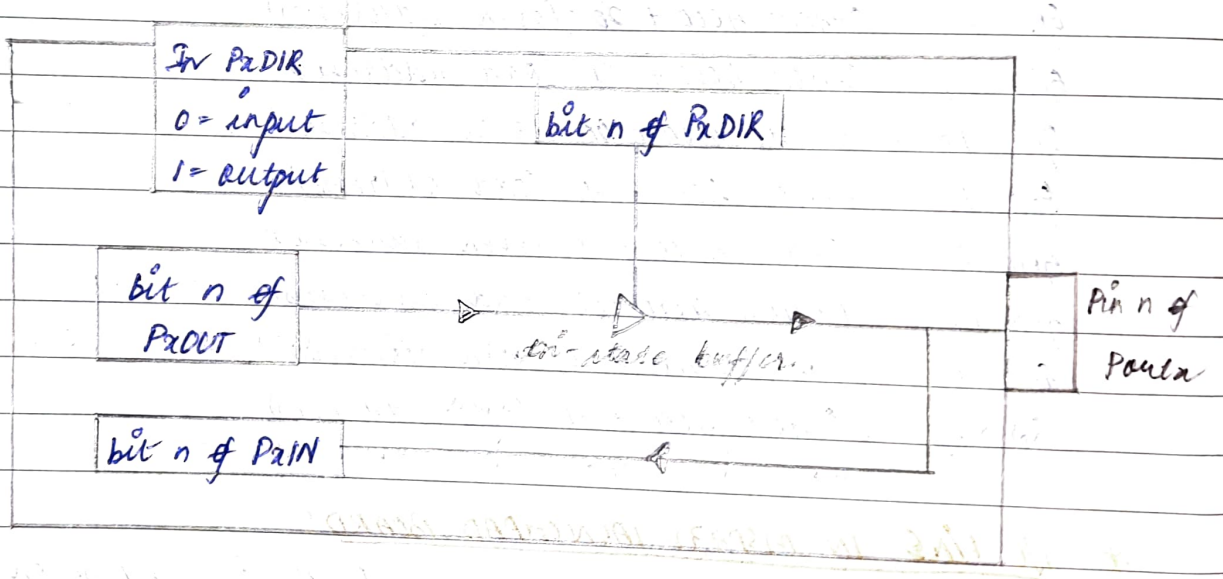
There will a small dip/round present in one of the corners of the microcontroller. From that, numbering starts in the anticlockwise manner: 1, 2, 3, ..., 100.

[Refer to slide 15/31 for diagrammatic representation.]

* DIRECTION AND DATA REGISTERS:

① Generally every microcontroller has minimum of three registers associated with each of GPIO port.
② Data IN, Data Out, and Direction.
③ The Direction register is used to make the pin either input or output.
④ We use the Data register to actually write to the pin (PxOUT) or read data from the pin (PxIN). x stands for port number.

* THE DATA AND DIRECTION REGISTERS AND A SIMPLIFIED VIEW OF AN I/O PIN:



1- output.
0- input.

① If configured as output, the tri-state buffer will be ON and data written in PxOUT register will be taken to the external pin of the IC.
② If configured as input, the tri-state buffer will be OFF. The data available in external pin can be read by PxIN register.

* DIRECTION REGISTER IN MSP432 ARM:

① Each of the direction register bit needs to be a 0 to configure the port pin as input and a 1 as output.

PxDIR:	D7	D6	D5	D4	D3	D2	D1	D0	
	PDIR								0x0004
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

② For example, by writing 0x03 (0b00000011 in binary) into the P1DIR register, pins 0 and 1 of P1 become outputs while the other pins become inputs.

* PORT DATA OUTPUT REGISTER (PxOUT) IN MSP432 ARM:

① To send data to pins, we write it to PxOUT register after the pin is configured as an output in the PxDIR register.

	D7	D6	D5	D4	D3	D2	D1	D0	
PxOUT:	POUT								0x0002
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

② For example, by writing 0x03 into the P1DIR register and 0x02 in P1OUT register, pin 0 of P1 become 0 while pin 1 of P1 become 1.

* PORT DATA INPUT REGISTER (PxIN) IN MSP432 ARM:

To bring into CPU data from a pin, we read it from PxIN register after the pin is configured as an input in the PxDIR Register.

	D7	D6	D5	D4	D3	D2	D1	D0	
PxIN:	PIN								0x0000
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

* SOME COMMONLY USED REGISTERS OF PORT1:

Address	Name	Description	Type	Reset value
0x40004C00	P1IN	Port 1 Input Register	R	0b00000000
0x40004C02	P1OUT	Port 1 Output Register	R/W	0b00000000
0x40004C04	P1DIR	Port 1 Direction Register	R/W	0b00000000
0x40004C06	P1REN	Port 1 Resistor Enable Register	R/W	0b00000000
0x40004C08	P1DS	Port 1 Drive strength Register	R/W	0b00000000
0x40004C0A	P1SEL0	Port 1 Select 0 Register	R/W	0b00000000
0x40004C0C	P1SEL1	Port 1 Select 1 Register	R/W	0b00000000

* SOME COMMONLY USED REGISTERS OF PORT2 :

Address	Name	Description	Type	Reset Value
0x40004C01	P2IN	Port2 Input Register	R	0b00000000
0x40004C03	P2OUT	Port2 Output Register	R/W	0b00000000
0x40004C05	P2DIR	Port2 Direction Register	R/W	0b00000000
0x40004C07	P2REN	Port2 Resistor Enable Register	R/W	0b00000000
0x40004C09	P2DS	Port2 Drive Strength Register	R/W	0b00000000
0x40004C0B	P2SEL0	Port2 Select 0 Register	R/W	0b00000000
0x40004C0D	P2SEL1	Port2 Select 1 Register	R/W	0b00000000

* SOME COMMONLY USED REGISTERS FOR PORT3 :

Address	Name	Description	Type	Reset Value
0x40004C20	P3IN	Port3 Input Register	R	0b00000000
0x40004C22	P3OUT	Port3 Output Register	R/W	0b00000000
0x40004C24	P3DIR	Port3 Direction Register	R/W	0b00000000
0x40004C26	P3REN	Port3 Resistor Enable Register	R/W	0b00000000
0x40004C28	P3DS	Port3 Drive strength Register	R/W	0b00000000
0x40004C2A	P3SEL0	Port3 Select 0 Register	R/W	0b00000000
0x40004C2C	P3SEL1	Port3 Select 1 Register	R/W	0b00000000

* SOME COMMONLY USED REGISTERS FOR PORT4 :

Address	Name	Description	Type	Reset value
0x40004C21	P4IN	Port4 Input Register	R	0b00000000
0x40004C23	P4OUT	Port4 Output Register	R/W	0b00000000
0x40004C25	P4DIR	Port4 Direction Register	R/W	0b00000000
0x40004C27	P4REN	Port4 Resistor Enable Register	R/W	0b00000000
0x40004C29	P4DS	Port4 Drive strength Register	R/W	0b00000000
0x40004C2B	P4SEL0	Port4 Select 0 Register	R/W	0b00000000
0x40004C2D	P4SEL1	Port4 Select 1 Register	R/W	0b00000000

* PORT PULL-UP OR PULL-DOWN RESISTOR ENABLE REGISTER (PxREN) IN MSP432 ARM:

① When a pin is configured as an input pin, you may enable the built-in pull-up or pull-down resistor attached to that pin.

② To enable the pull resistor, you need to set the corresponding bit in the PxREN register of that port.

	D7	D6	D5	D4	D3	D2	D1	D0	
PxREN:	PxREN								0x0006
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

③ Pull-up or pull-down resistor is only used when the pin is configured as an input pin.

* EXAMPLE:

Q. Find the value for P2DIR, P2OUT, and P2REN to configure the P2 pins as inputs. Pull down P2.0 and pull up P2.1.

A. P2DIR = 0b00000000 = 0x00

P2REN = 0b00000011 = 0x03

P2OUT = 0b00000010 = 0x02

* ALTERNATE PIN FUNCTIONS AND THE SIMPLE GPIO:

① Each pin of the MSP432 ARM chip can be used for one of several functions.

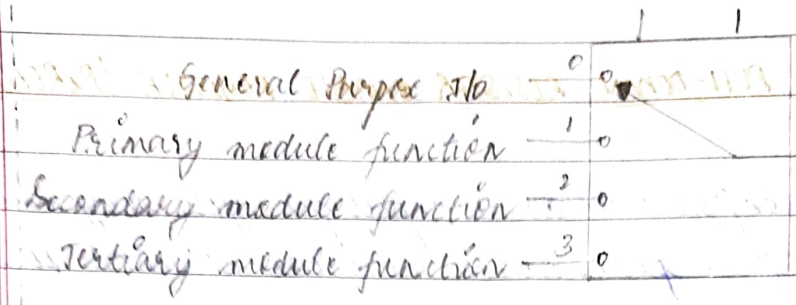
② The function associated with a pin is chosen by programming PxSEL1 and PxSEL0 function selection registers.

③ For example, a given pin can be used as simple digital I/O (GPIO), analog input, or I2C pin.

④ Using a single pin for multiple functions is called pin multiplexing.

⑤ In the absence of pin multiplexing, a microcontroller will need many more pins to support all of its on-chip features.

MUX bits of PxSEL0 & PxSEL1



PxSEL0:

D7	D6	D5	D4	D3	D2	D1	D0	
PxSEL0								0x000A
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

PxSEL1:

D7	D6	D5	D4	D3	D2	D1	D0	
PxSEL1								0x000C
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

PxSEL1	PxSEL0	Meaning
0	0	Alternative 0 (Default) Simple I/O
0	1	Alternative 1 (UART, SPI, I2C, ...)
1	0	Alternative 2 (Timers, ...)
1	1	Alternative 3 (ADC, comparator, ...)

* **MSP432 PORT1 ALTERNATIVE PIN FUNCTIONS:**

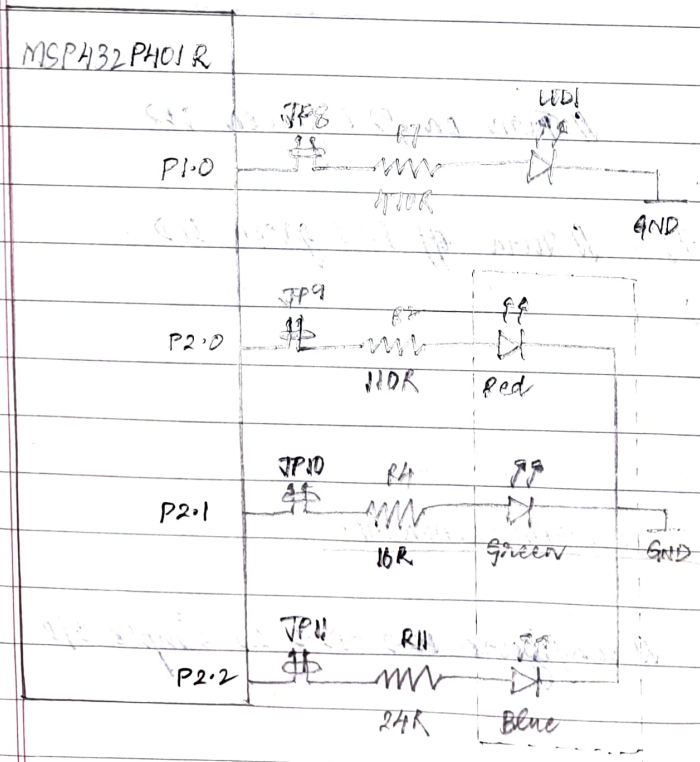
Pin Name	SEL = 00	SEL = 01	SEL = 10	SEL = 11
P1.0	Simple I/O	UCA0STE	-	-
P1.1	Simple I/O	UCA0CLK	-	-
P1.2	Simple I/O	UCA0RXD / UCA0SOMI	-	-
P1.3	Simple I/O	UCA0TXD / UCA0SIMO	-	-
P1.4	Simple I/O	UCB0STE	-	-
P1.5	Simple I/O	UCB0CLK	-	-
P1.6	Simple I/O	UCB0SIMO / UCB0SDA	-	-
P1.7	Simple I/O	UCB0SOMI / UCB0SCL	-	-

* MSP432 PORT2 ALTERNATIVE PIN FUNCTIONS :

Pin Name	SEL=00	SEL=01	SEL=10	SEL=11
P2.0	Simple I/O	PM_UCA1STE	-	-
P2.1	Simple I/O	PM_UCA1CLK	-	-
P2.2	Simple I/O	PM_UCA1RXD / PM_UCA1SOMI	-	-
P2.3	Simple I/O	PM_UCA1TXD / PM_UCA1SIMO	-	-
P2.4	Simple I/O	PM_TA0.1	-	-
P2.5	Simple I/O	PM_TA0.2	-	-
P2.6	Simple I/O	PM_TA0.3	-	-
P2.7	Simple I/O	PM_TA0.4	-	-

* LED CONNECTION IN MSP432 LAUNCHPAD BOARD :

In the MSP432 LaunchPad board, we have a tri-color RGB LED connected to P2.0 (red), P2.1 (green), and P2.2 (blue).



* TOGGLING LEDs IN MSP432 LAUNCHPAD:

1. Configure P2.1 (P2SEL1 : P2SEL0 Register) to select simple GPIO function for P2.1.
2. Set the direction register bit 1 of P2DIR as output.
3. Write HIGH to bit 1 of P2OUT register to turn on the green LED.
4. Call a delay function.
5. Write LOW to bit 1 of P2OUT register to turn off the green LED.
6. Call a delay function.
7. Repeat steps 3 to 7.

* TOGGLING GREEN LED ON MSP432 LAUNCHPAD:

```
int main (void) {
    P2 -> SEL1 &= ~2;   // Configure P2.1 as simple I/O
    P2 -> SEL0 &= ~2;
    P2 -> DIR |= 2;     // P2.1 set as output pin

    while (1) {
        P2 -> OUT |= 2;     // Turn on P2.1 green LED
        delayMs (500);
        P2 -> OUT &= ~2;    // Turn off P2.1 green LED.
        delayMs (500);
    }
}
```

* TOGGLING ALL THREE LEDs ON MSP432 LAUNCHPAD:

```
int main (void) {
    P2 -> SEL1 &= ~7;   // Configure P2.2 - P2.0 as simple I/O
    P2 -> SEL0 &= ~7;

    P2 -> DIR |= 7;     // P2.2 -2.0 set as output
    P2 -> OUT |= 7;     // Turn all three LEDs on
```

```
while (1) {
    P2->OUT ^= 7;  // Toggle P2.2-P2.0 all three LEDs
    delayMs(500);
  }
}
```

* CPU CLOCK FREQUENCY AND TIME DELAY:

① Usually microcontrollers have at least two types of clock source: the on-chip oscillator and the oscillator connected to external crystal.

② The advantage of the external crystal oscillator is the higher precision.

③ The advantage of the on-chip oscillator is that it is always there.

④ The clock from the source may be modified by a divider to reduce the clock rate or use a phase lock loop (PLL) circuit to produce a wider range of clock rates.

* CPU CLOCK FREQUENCY AND TIME DELAY IN MSP432:

① The MSP432 has two oscillators connected to external crystal, LFXT and HFXT for low frequency crystal and high frequency crystal.

② The LFXT is designed to use a 32.768 KHz watch crystal.

③ The HFXT can be used with crystals or resonators ranging from 1MHz to 48MHz.

④ The MSP432 has five internal oscillators, among them the Digitally Controlled Oscillator (DCO) is the most flexible clock source that provides a wide range of clock frequencies.