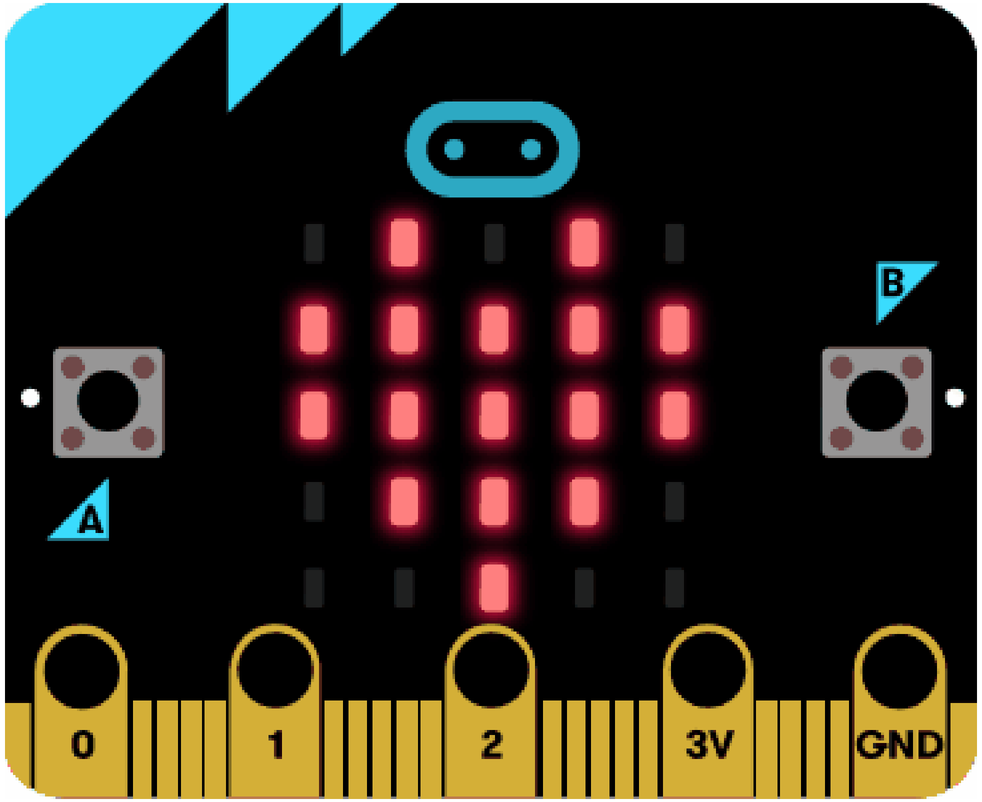
Topic 11 – LED Operation

Designing Real Systems

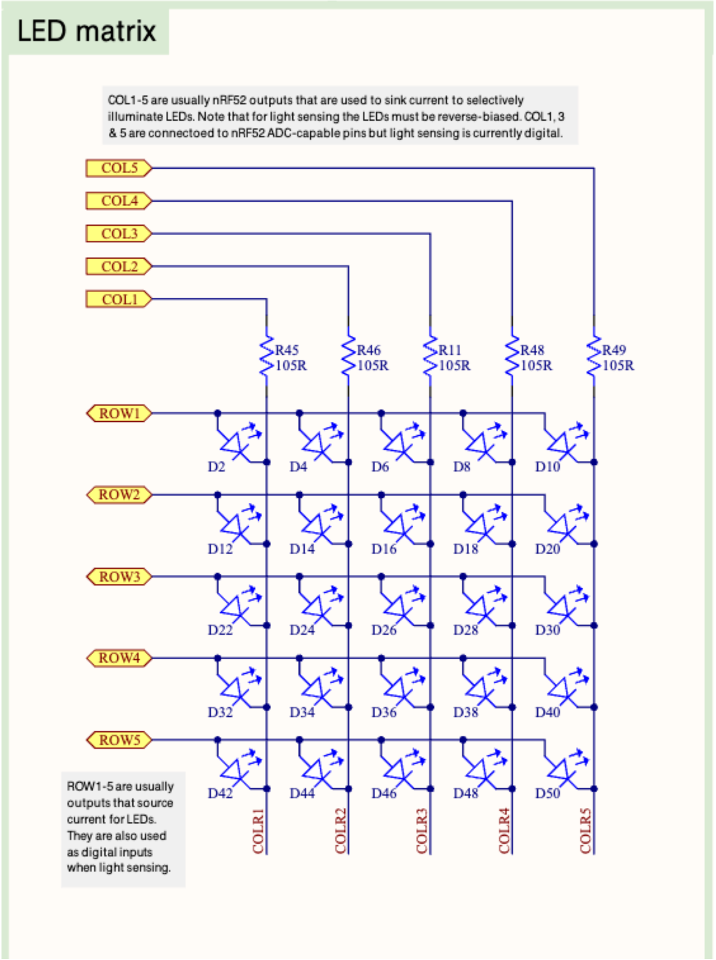
- When designing systems, several factors may complicate
  the programming model:
  - Cost, hardware limitation, energy, scalability.
- Abstractions can simplify coding, by trading CPU cycles.
- Example: operating micro:bit LEDs



LED schematic

- The **5×5 LED matrix** is wired in a way that:
  - **Columns (x-axis) are controlled separately**.
  - **Rows (y-axis) are controlled separately**.
- *Each LED is at the **intersection of a row and a column**.*
- Complex displays must draw row by row.
  - **Rows (anodes, positive side), Columns (cathodes, negative side)**

- To light up a particular LED:
  1. The corresponding **row is set HIGH** (enabled).
  2. The corresponding **column is set LOW** (to complete the circuit and turn on the LED).

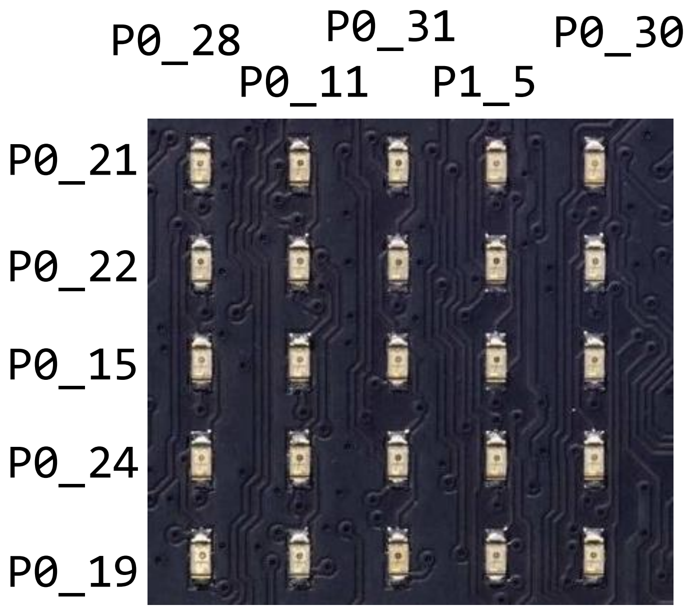


https://github.com/microbit-foundation/microbit-v2-hardware/blob/main/V2.00/MicroBit_V2.0.0_S_schematic.PDF

Micro:bit LED MMIO

- The CPU on the micro:bit uses the GPIO mechanism to control LEDs.
- There are two GPIO ports (0 and 1), with 32 I/O pins each.
- COLs and ROWs spread on both GPIO pins.

- *You need some clever programming to light complex LED patterns.*



GPIO MMIO Register

Name	Address	Description
OUT	0x50000504 - 0x50000804	Write GPIO port
IN	0x50000510 - 0x50000810	Read GPIO port
DIRSET	0x50000518 - 0x50000810	Direction of GPIO pins

DIRSET

Bit number	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Id	f	e	d	c	b	a	Z	Y	X	W	V	U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
Reset 0x00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Id	RW	Field	Value Id	Value	Description
A	RW	PIN0			Set as output pin 0
			Input	0	Read: pin set as input
			Output	1	Read: pin set as output
			Set	1	Write: writing a '1' sets pin to output; writing a '0' has no effect
B	RW	PIN1			Set as output pin 1
			Input	0	Read: pin set as input
			Output	1	Read: pin set as output
			Set	1	Write: writing a '1' sets pin to output; writing a '0' has no effect
C	RW	PIN2			Set as output pin 2
			Input	0	Read: pin set as input
			Output	1	Read: pin set as output
			Set	1	Write: writing a '1' sets pin to output; writing a '0' has no effect

https://infocenter.nordicsemi.com/index.jsp?topic=%2Fcom.nordic.infocenter.nrf52832.ps.v1.1%2Fgpio.html

CODAL Display API

- The CODAL LED API is built on top of **multiplexing**, where the **5×5 LED matrix is refreshed row by row**.

- The API allows users to:
  - **Set individual LEDs** (`display.image.setPixelValue(x, y, value)`)
  - **Show pre-defined or custom images** (`display.print()`)
  - **Control brightness** (display.image.setPixelValue() with brightness level)
  - **Scroll text** (`display.scroll()`)

- Things are much more complex under the hood…

LED programming

```
@ Init LEDs
ldr r0, =0x50000514 @ GPIO0_DIR register
ldr r1, =0xd1688800 @ LED pins as outputs
str r1, [r0]
ldr r0, =0x50000814 @ Same for GPIO1_DIR
ldr r1, =0x00000020
str r1, [r0]

ldr r4, =0x50000504 @ Address of GPIO0_OUT
register
ldr r5, =0x50000804 @ Address of GPIO1_OUT
register
ldr r6, =0x50008800 @ Bit pattern 0 for dot
ldr r7, =0x00000020 @ Bit pattern 1 for dot
str r6, [r4]        @ Light an LED
str r7, [r5]
```

Set ports as outputs for every PIN used to control LEDs.

Set Row 3 and Columns 1,2,4,5 to 1.

Note: In order to light a led, you need to turn on ts input, and turn off the output, to allow current to flow.

ARM Constants

- ARM Assembly offers a set of directives to define constant values.
  - .equ: Assign a name to a constant value - immutable.

```
.set GPIO1_OUT, 0x50000804
```

  - .set: Assign a name to a constant value – mutable.

```
.equ ROW_1, 21
```

  - Look like `#define` in C.
  - Assembler will pattern match replace during binary conversion.

```
ldr r5, =GPIO1_OUT
```

LED initialization function

- Need to set the GPIO LED pins as output pins.

```
led_init:
 ldr r0, =GPIO0_DIR @ GPIO0_DIR register
 ldr r1, =0xd1688800 @ LED pins as outputs
 str r1, [r0]
 ldr r0, =GPIO1_DIR @ Same for GPIO1_DIR
 ldr r1, =0x00000020
 str r1, [r0]
 bx lr
```

Turn on a single LED

- In order to turn on LED (1, 1) need to turn on row 1 and columns 2,3,4,5.

```
mov r1, #0x1
mov r6, #0x0
orr r6, r6, r1, lsl ROW_1
orr r6, r6, r1, lsl COL_2
orr r6, r6, r1, lsl COL_3
orr r6, r6, r1, lsl COL_5
str r6, [r4] @ Light an LED
mov r6, #0x0 @ P1.5
orr r6, r6, r1, lsl COL_4
str r6, [r5] @ Light an LED
```

LED multiplexing

- We cannot light up multiple rows at the same time.
  - How can we display a heart?

- Ideas: turn-on LED, line by line.
- Human eye cannot perceive the difference, if frequency is above 60Hz (i.e. 40 msec).

(0,0) **(1,0)** (2,0) **(3,0)** (4,0)
(0,1) (1,1) (2,1) (3,1) (4,1)
(0,2) (1,2) (2,2) (3,2) (4,2)
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LED multiplexing

Lancaster University

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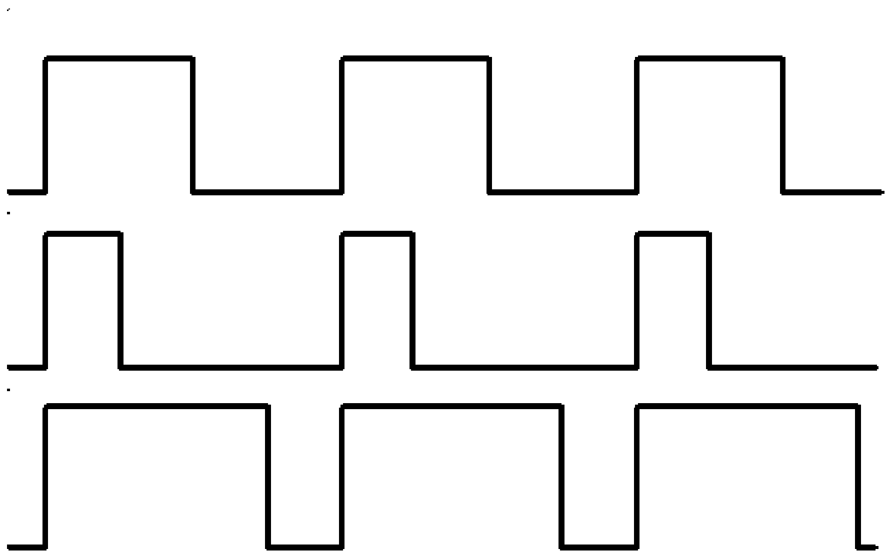
Code details

- Check sample code at: **https://scc-source.lancs.ac.uk/scc.Y1/scc.131/arm-assembly-examples/-/tree/main/lec10**

Pulse Width modulation

- The pins of your board cannot output an analog signal the way an audio amplifier can – by modulating the voltage on the pin.
- Those pins can only either enable the full 3.3V output, or pull it down to 0V.
- How does LED brightness work?
  - Switch that voltage on and off very fast.
  - Control how long it is on and how long it is off.
- This technique is called **Pulse-Width Modulation (PWM)**.



Recap

- Example LED use-case
  - LED Multiplexing concept.
  - Design code to display a heart
  - PWM concept.

- Next: lab solutions