ENR-325/325L Principles of Digital Electronics and Laboratory

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Fall 2025

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MCU: digital design IRL

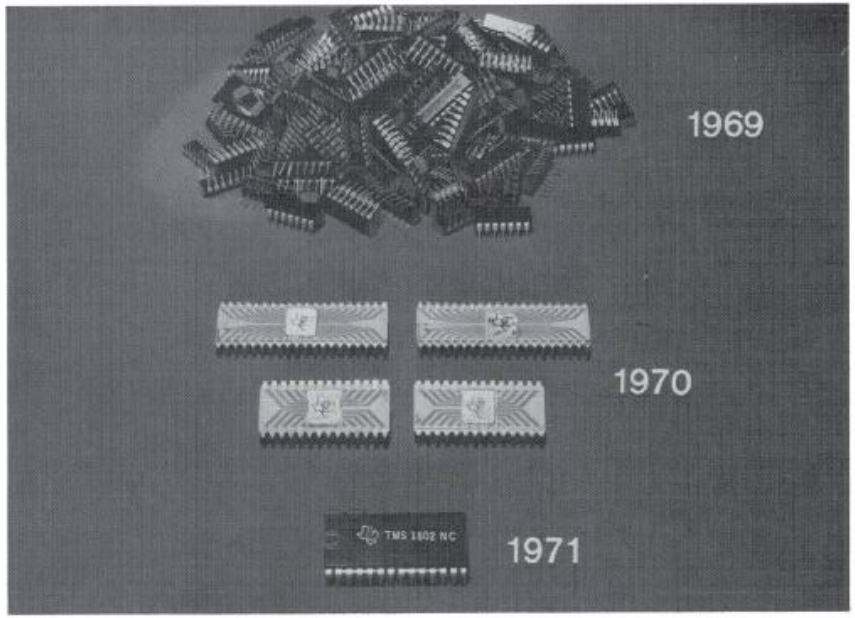
It all started with ALUs and calculators.

Texas Instruments TMS1000

CALCULATOR ON A CHIP

A new standard one-chip MOS/LSI calculator logic circuit has been announced by Texas Instruments. This single chip may make full electronic calculators available to everyone at prices that can put a calculator into every kitchen or businessman's pocket. The chip incorporates all of the logic and memory circuits to perform complete 8-digit 3-register calculator functions, including full precision add, subtract, multiply, and divide operations.

Architecture of the calculator chip is such that the basic chip can host most calculator computing functions requiring up to 8-digit characteristics. The device is totally programmable, the "program" read only memory, timing sections, control section and input/output decoders can be programmed to achieve different computing characteristics. This approach offers maximum design flexibility at very low cost.



Calculator On A Chip

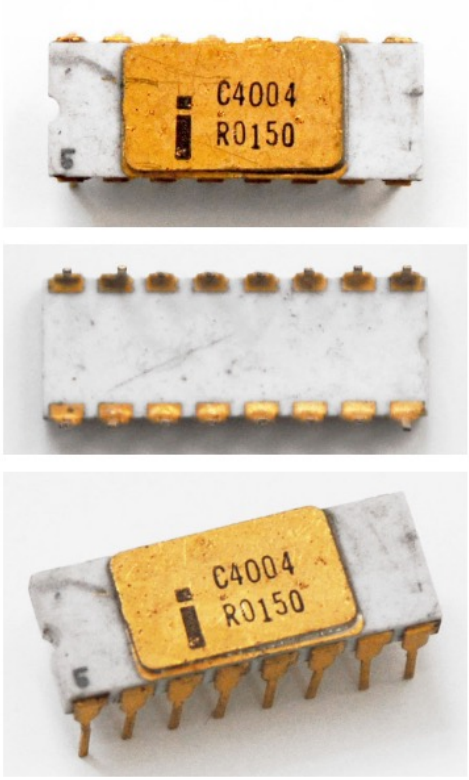
Designated the TMS1802NC, the calculator on a chip is available for immediate delivery and is priced at less than $20 in large quantities. The unit announced today provides an accounting type of keyboard entry. Later this year, a formula keyboard entry model will be introduced.

Circle 71 on Reader Service Card

https://www.oldcalculatormuseum.com/n-ti-tms1802.html

Intel 4004

Intel C4004



Type	Central processing unit / CPU
Family	Intel 4004
CPU part number	C4004
Introduction	11/15/1971
Manufacturing Date	?
Package	16-pin CerDIP
Dimensions	n/a
Manufacturing process	10000 nm
Transistors	2300
Frequency	0.74 MHz
Data width	4 Bit
Floating Point Unit (FPU)	None
Power consumption	0.5 Watt
Vcore	15 Volt

https://cpumuseum.jimdofree.com/museum/intel/4004-4040/

Microcontrollers (MCU) is a Systems on a Chip (SoC)

MICROCHIP

PIC10F200/202/204/206

6-Pin, 8-Bit Flash Microcontrollers

		PIC10F200
Clock	Maximum Frequency of Operation (MHz)	4
Memory	Flash Program Memory	256
	Data Memory (bytes)	16
Peripherals	Timer Module(s)	TMR0
	Wake-up from Sleep on Pin Change	Yes
Features	Comparators	0
	I/O Pins	3
	Input-Only Pins	1
	Internal Pull-ups	Yes
	In-Circuit Serial Programming™	Yes
	Number of Instructions	33
	Packages	6-pin SOT-23 8-pin PDIP, DFN

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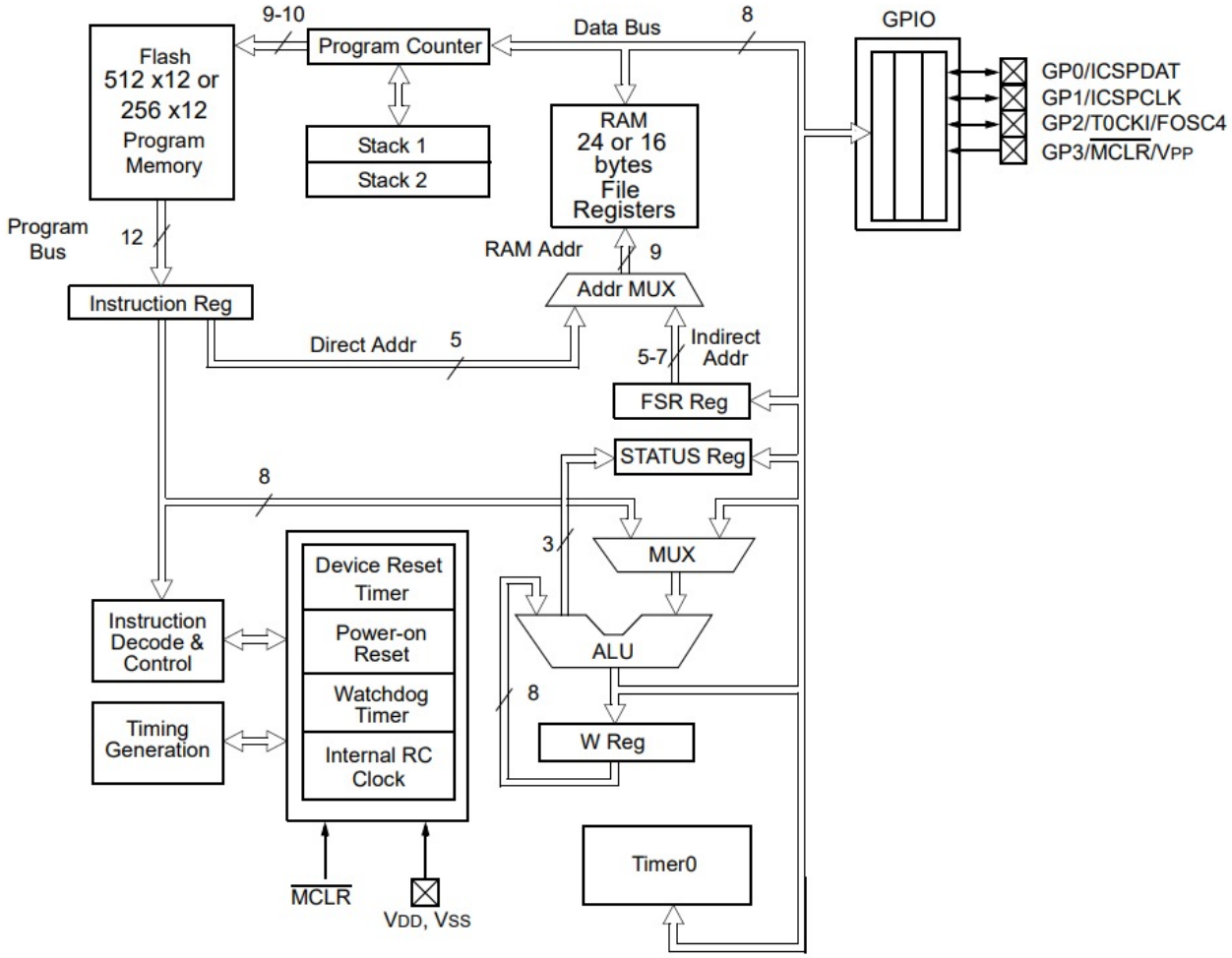
https://www.microchip.com/en-us/product/pic10f200

What is Systems on a Chip?

Block diagram of PIC10F200



https://www.microchip.com/en-us/product/pic10f200

SoC in a nutshell (1/2):

Latches

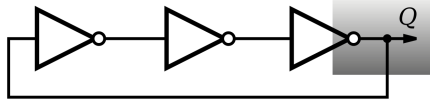
Flip-flop

Memory

Register

Oscillator

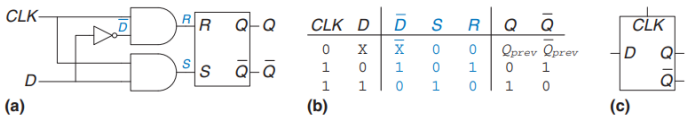
Timer



Logic gates

Adder and co.

ALU



CLK	D	$\bar{D}$	S	R	Q	$\bar{Q}$
0	X	$\bar{X}$	0	0	Q_{prev}	$\bar{Q}_{prev}$
1	0	1	0	1	0	1
1	1	0	1	0	1	0

Figure 3.7 D latch: (a) schematic, (b) truth table, (c) symbol

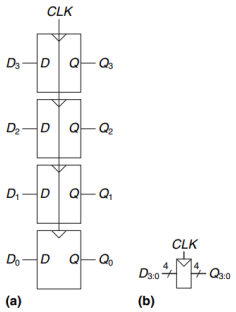
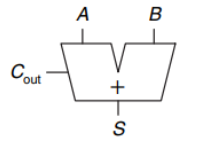


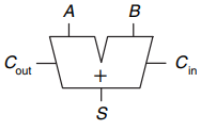
Figure 3.9 A 4-bit register: (a) schematic and (b) symbol

Half Adder



A	B	C_{out}	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

Full Adder



C_{in}	A	B	C_{out}	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

And hook up everything to some wiring called:

Bus

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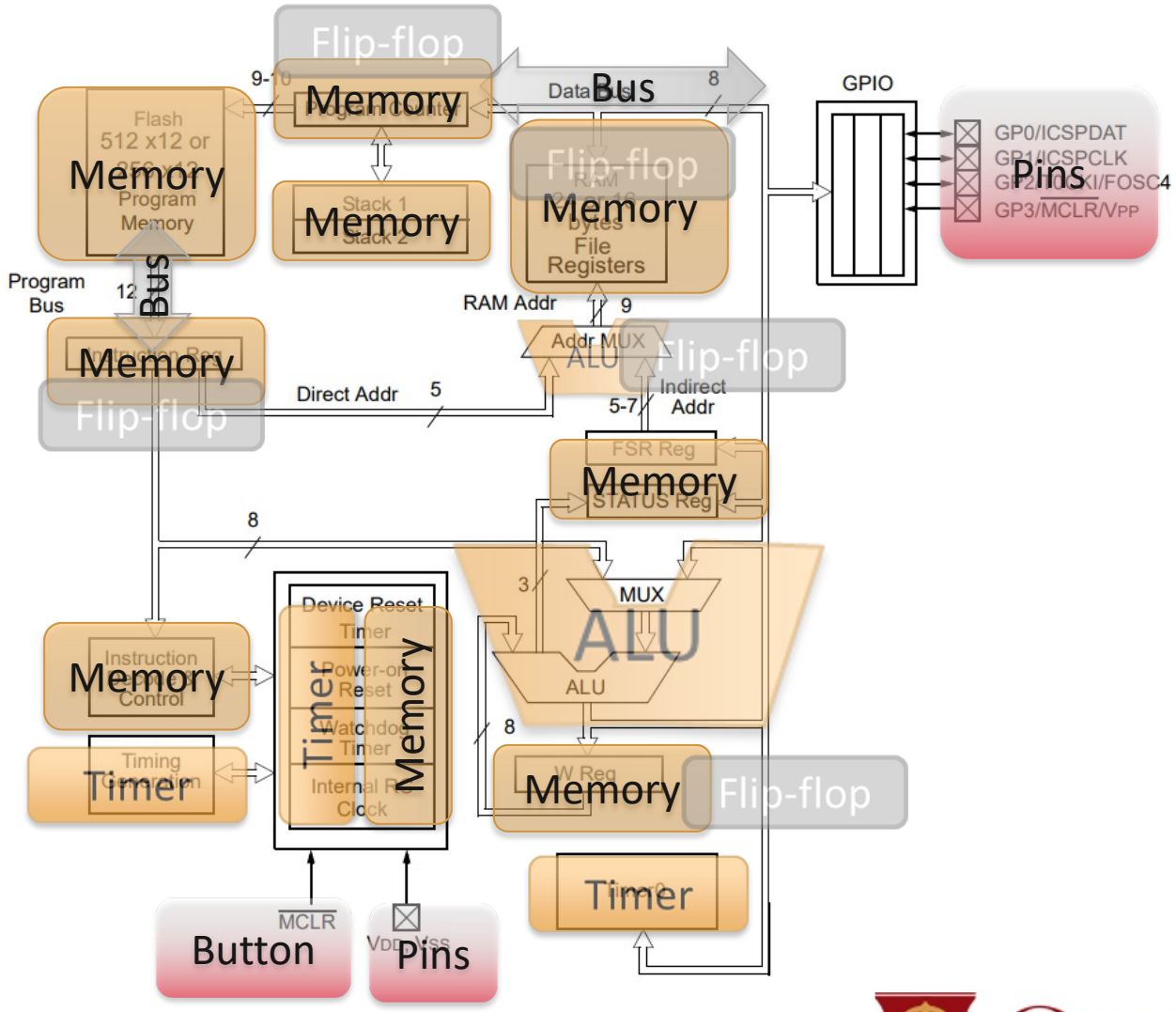
SoC in a nutshell (2/2):



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An MCU can be built with only logic gates:

Build an 8-bit computer from scratch

Table of contents

- Overview
- Complete parts list
- Breadboard computer kits
- Schematics
- Computer modules

Overview

I built a programmable 8-bit computer from scratch on breadboards using only simple logic gates. I documented the whole project in a series of YouTube videos and on this web site. Watch this video for an introduction:

8-bit computer update

https://www.youtube.com/watch?v=HyznrdDSSGM

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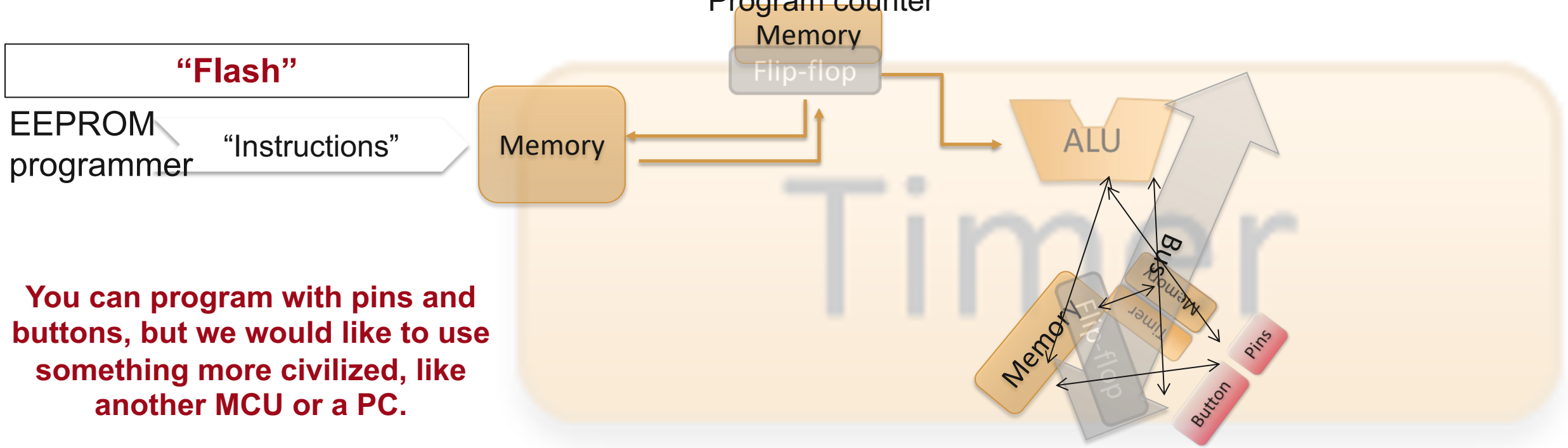
https://eater.net/8bit

One more nice thing to have: EEPROM programmer

https://github.com/beneater/eeprom-programmer?tab=readme-ov-file



You can program with pins and buttons, but we would like to use something more civilized, like another MCU or a PC.

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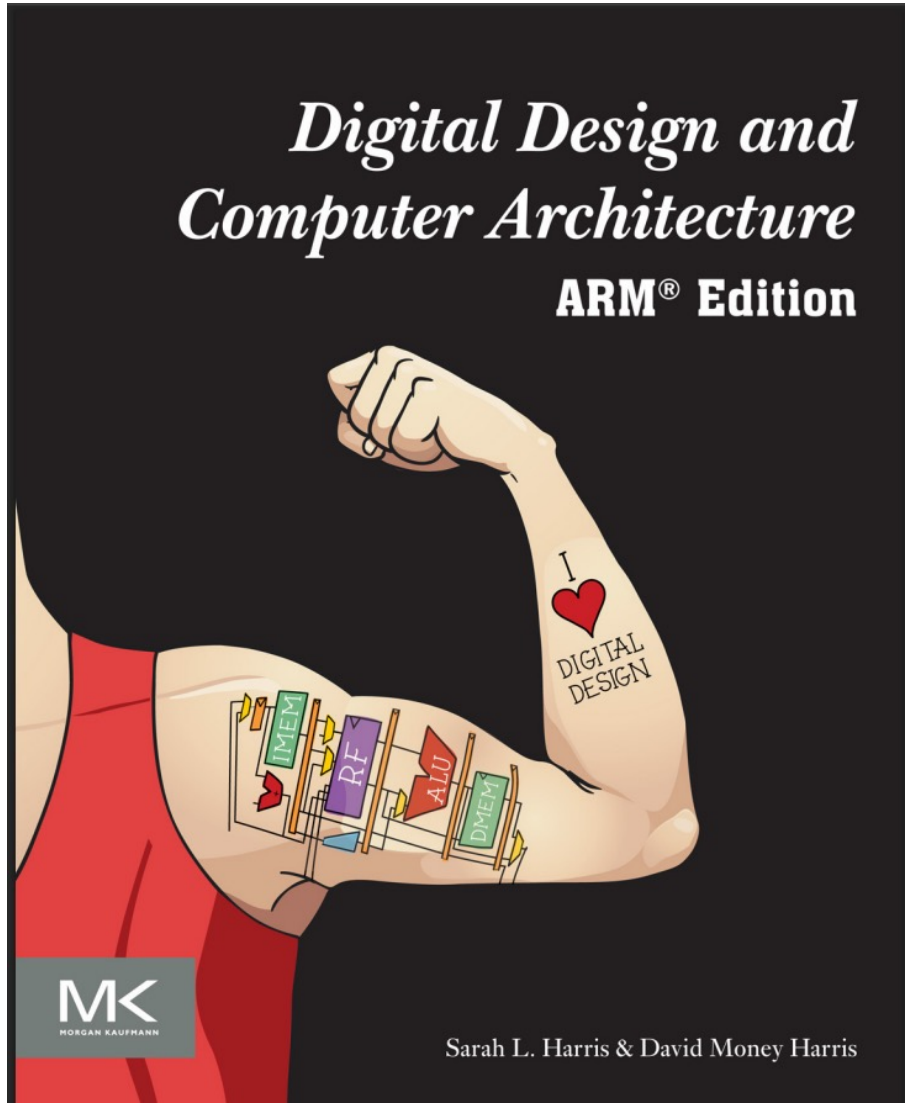
How programming works:



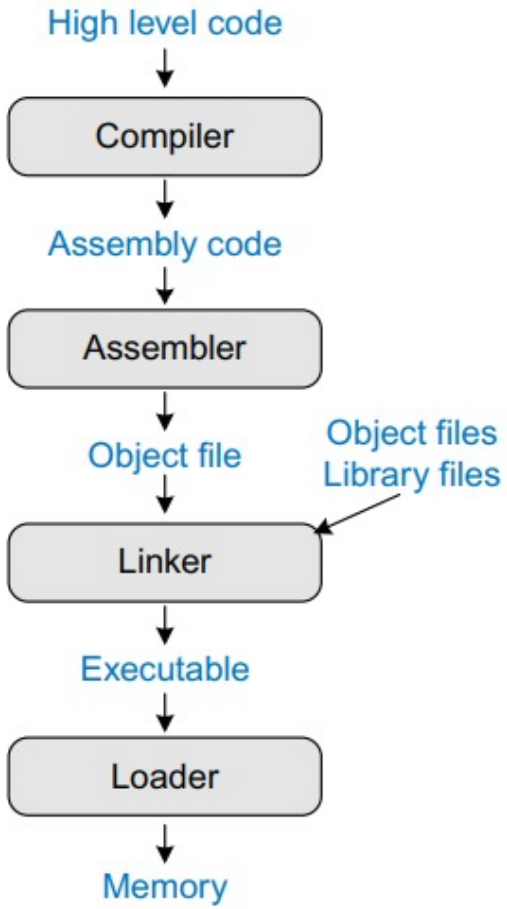


Figure 6.29 Steps for translating and starting a program

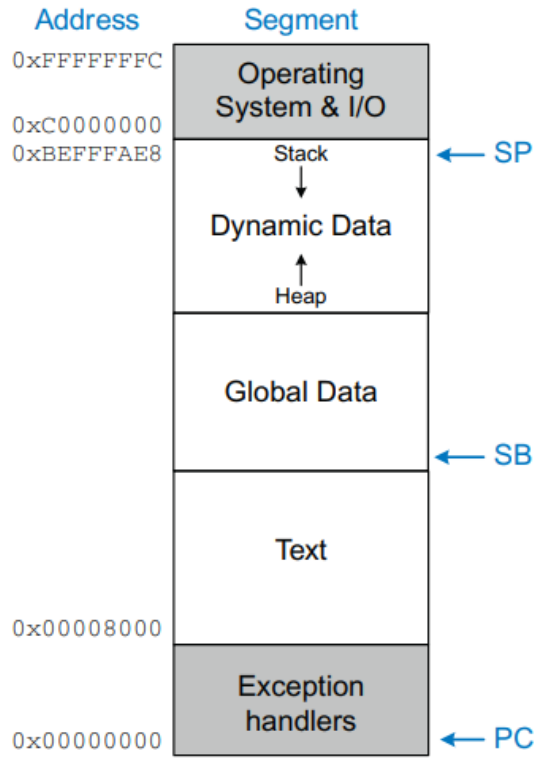


Figure 6.30 Example ARM memory map

Pointers and counters are all the same thing…

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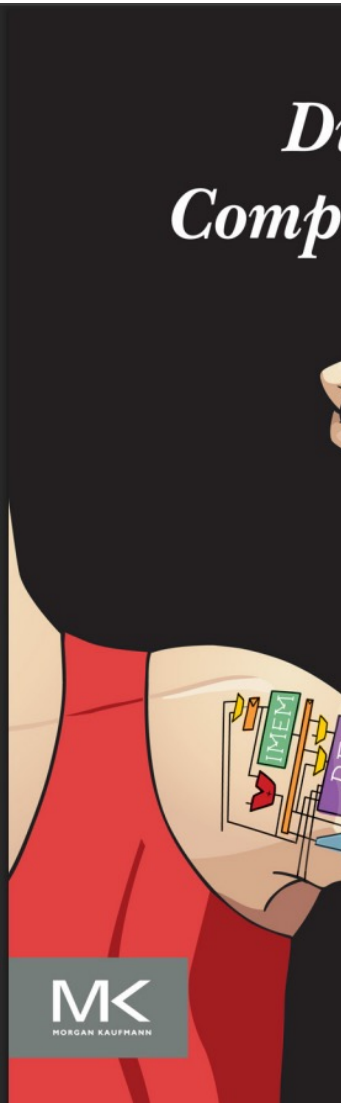
How programming works:



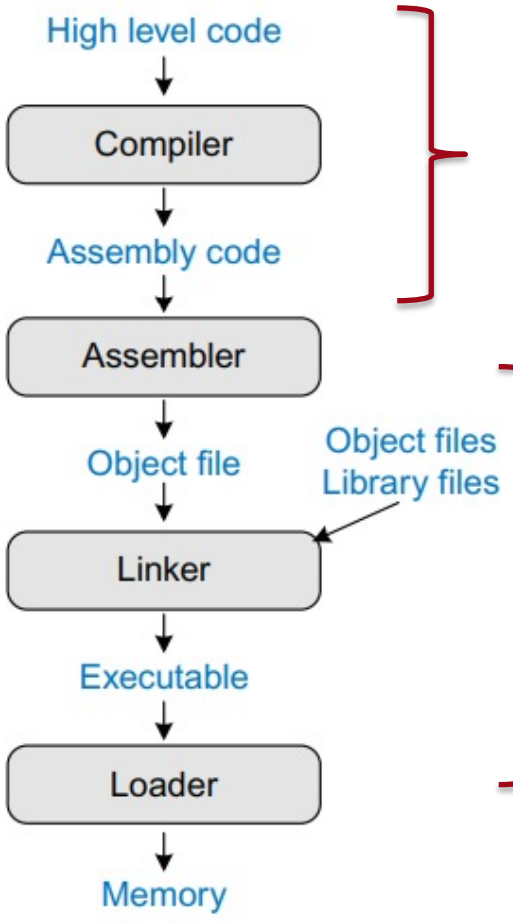


Figure 6.29 Steps for translating and starting a program

Code Example 6.4 REGISTER OPERANDS

High-Level Code	ARM Assembly Code
`a = b + c;`	`; R0 = a, R1 = b, R2 = c` `ADD R0, R1, R2 ; a = b + c`

Assembly Code

```
ADD R5, R6, R7
    (0xE0865007)
SUB R8, R9, R10
    (0xE049800A)
```

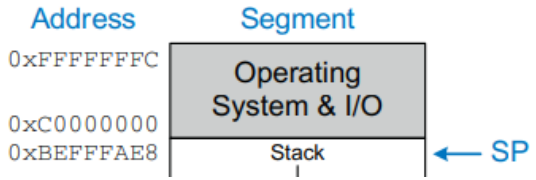
Field Values

31:28	27:26	25	24:21	20	19:16	15:12	11:7	6:5	4	3:0
1110_2	00_2	0	0100_2	0	6	5	0	0	0	7
1110_2	00_2	0	0010_2	0	9	8	0	0	0	10
cond	op	I	cmd	S	Rn	Rd	shamt5	sh		Rm

Machine Code

31:28	27:26	25	24:21	20	19:16	15:12	11:7	6:5	4	3:0
1110	00	0	0100	0	0110	0101	00000	00	0	0111
1110	00	0	0010	0	1001	1000	00000	00	0	1010
cond	op	I	cmd	S	Rn	Rd	shamt5	sh		Rm

Figure 6.18 Data-processing instructions with three register operands



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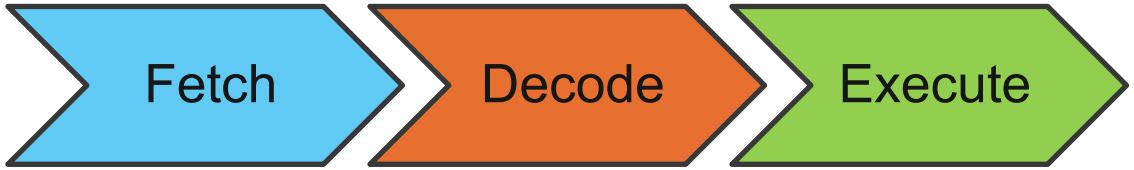
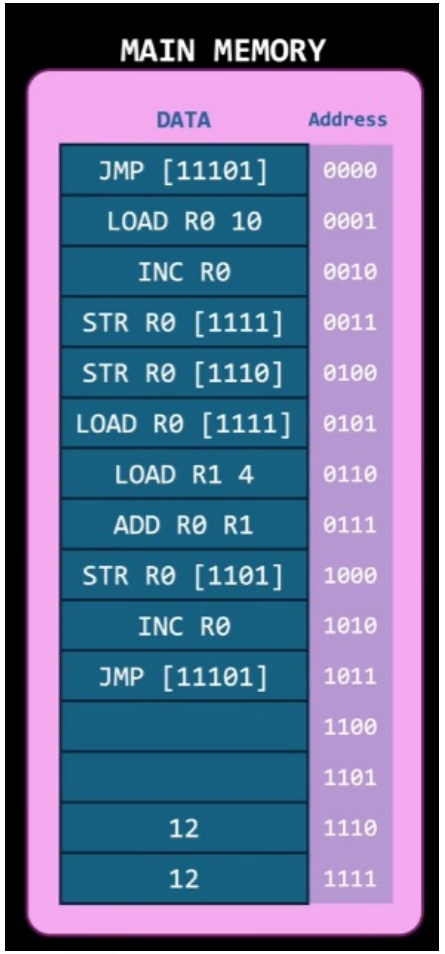
How programming works in order (inside CPU):

It's just a cycle of…





Different architecture have different cycle design (3-5 operations cycling).
So, when a 4 MHz MCU is running a 4-cycle operation, its clock speed is 1 MHz.

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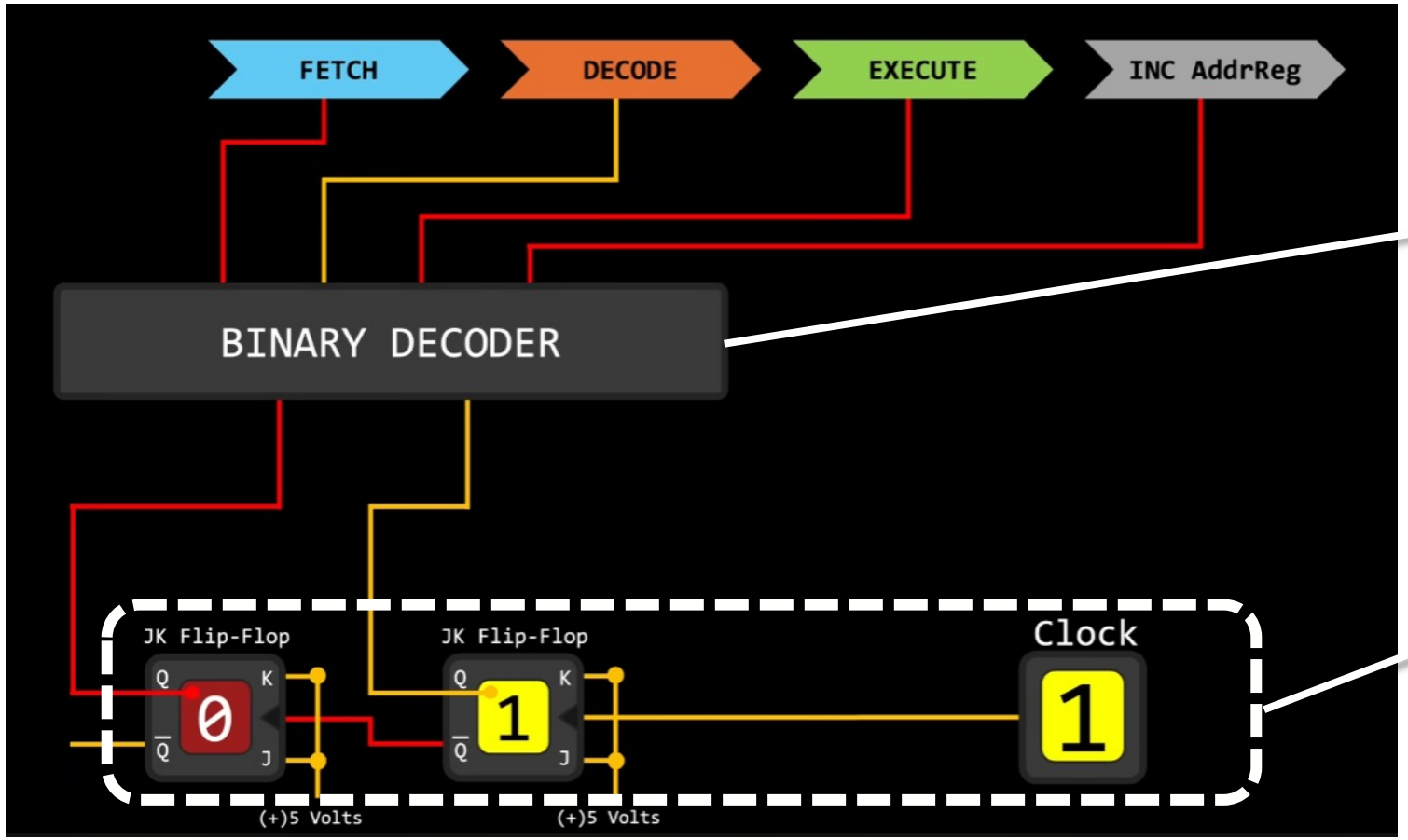
How programming works in order (inside CPU):

With the help of…



When 00, Fetch
When 01, Decode
…

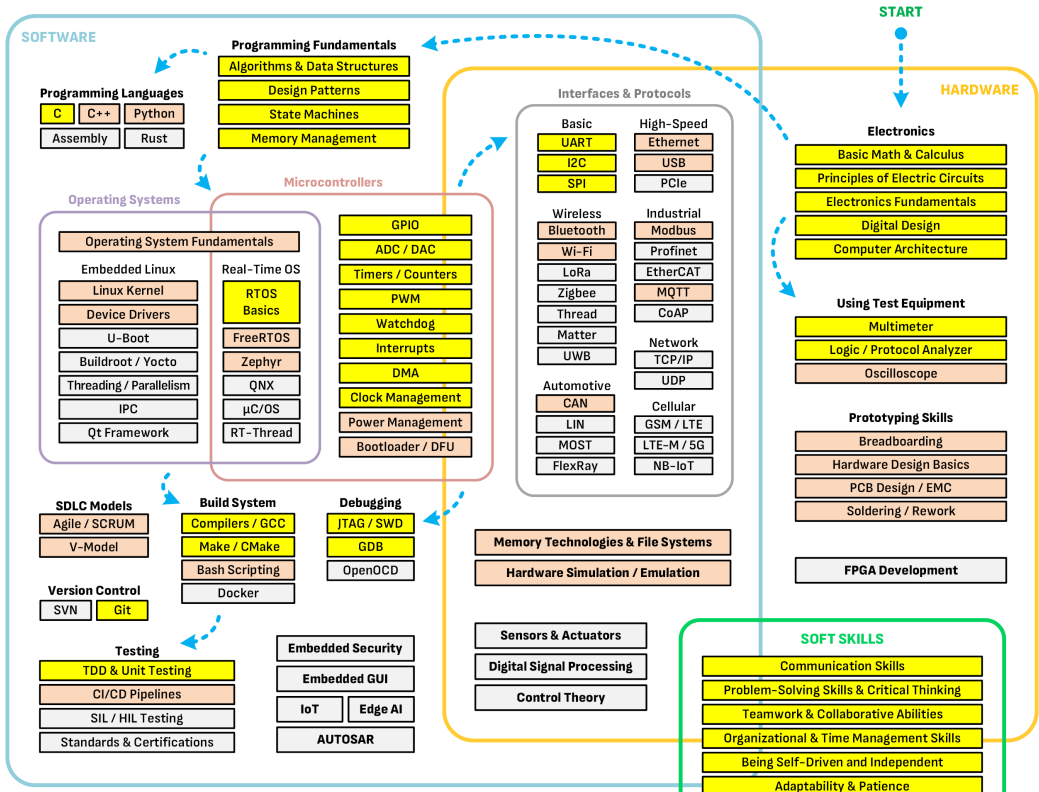
Generating: 00 01 10 11

How the Clock Tells the CPU to "Move Forward“ https://www.youtube.com/watch?v=PVNAPWUxZ0g&list=PL9vTTBa7QaQOoMfpP3ztvgyQkPWDPfJez&index=6

EMBEDDED SYSTEMS ENGINEERING ROADMAP

Required | **Recommended** | **Possibilities**

⚠ These colors indicate the average importance of each topic. It should be noted that the importance of a topic can vary among different industries and job roles.



For a curated list of learning resources tailored to the topics in this roadmap, please visit:
github.com/m3y54m/Embedded-Engineering-Roadmap

Creator & Maintainer: **Meysam Parvizi**
Last Update: **2023-12-23**
Revision: **v1.2.3**

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Supplemental video: how real coders could still use C for great things:

https://www.youtube.com/watch?v=xNX9H_ZkfNE