BLM4021 Gömülü Sistemler

Doç. Dr. Ali Can KARACA

ackaraca@yildiz.edu.tr

Yıldız Teknik Üniversitesi – Bilgisayar Mühendisliği

Sunum 6 – ARM Komut Setleri ve Raspberry Pi Kitleri

- ARM komut setleri (devam)
- Visual ARM üzerinde örnekler
- Raspberry Pi Versiyon ve Özellikleri
- Genel amaçlı giriş çıkış (GPIO) birimleri

Ders Materyalleri

Gerekli Kaynaklar:

- Derek Molloy, Exploring Raspberry Pi: Interfacing to the Real World with Embedded Linux, Wiley, 2016.
- M. Wolf, Computers as Components: Principles of Embedded Computing System Design, Elsevier, 2008.

Yardımcı Kaynaklar:

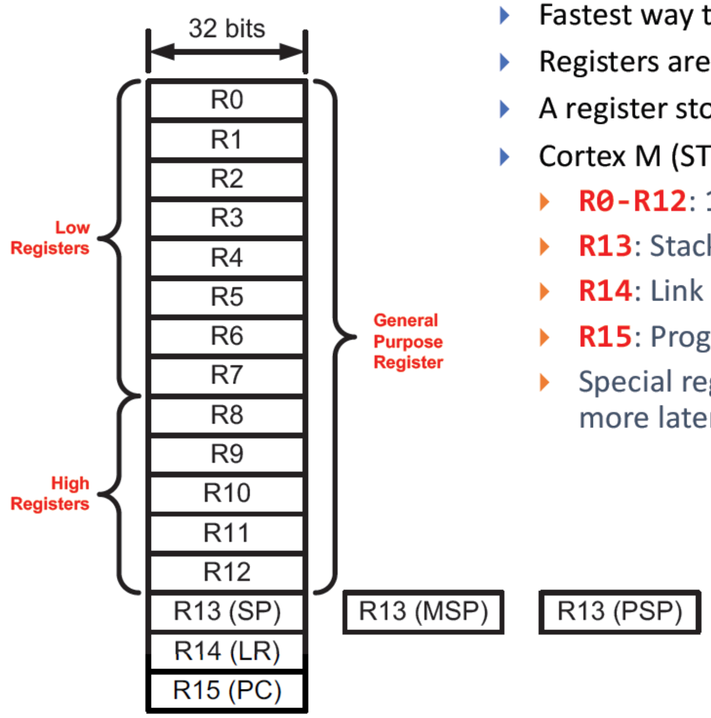
- P. Membrey, D. Hows, Learn Raspberry Pi 2 with Linux and Windows 10, Apress, 2015.
- Ali Saidi, The ARM architecture slide.
- Farid Farahmand, Chapter- 3, Embedded Systems with ARM Cortex-M, 2018.
- O. Urhan, Gömülü Sistem Lisansüstü Ders Notları, 2018.
- V. Weawer, ECE 471 – Embedded Systems Lecture 3, 2020.

Haftalık Konular

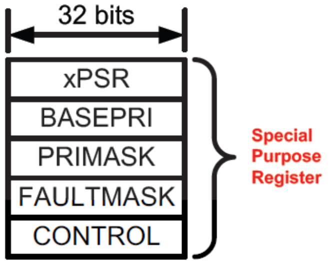
Hafta	Teorik	Laboratuvar
1	Giriş ve Uygulamalar, Mikroişlemci, Mikrodenetleyici ve Gömülü sistem kavramlarının açıklanması	Grupların oluşturulması & Kitlerin Testi
2	Bir Tasarım Örneği, Mikroişlemci, Mikrodenetleyici, DSP, FPGA, ASIC kavramları	Kitlerin gruplara dağıtımı + Raspberry Pi Kurulumu
3	16, 32 ve 64 bitlik mikrodenetleyiciler, pipeline, PIC ve MSP430 özellikleri	Raspberry Pi ile Temel Konfigürasyon
4	ARM tabanlı mikrodenetleyiciler ve özellikleri	---- Resmi Tatil ---
5	ARM Komut setleri ve Assembly Kodları-1	Uygulama 1 – Raspberry Pi ile Buzzer Uygulaması
6	ARM Komut setleri ve Assembly Kodları-2, Raspberry Pi vers. ve GPIO'ları	Uygulama 2 – Raspberry Pi ile Ivme ve Gyro Uygulaması
7	Veri toplama; algılayıcı, örnekleme teoremi, ADC, DAC	Uygulama 3 – Raspberry Pi ile Motor Kontrol Uygulaması
8	*Vize Sınavı*	
9	Çoklu ortam algılayıcıları ve arayüzleri (SPIE, I2C…)	Proje Soru-Cevap Saati - 1
10	Zamanlayıcı ve kesmeler	Proje Soru-Cevap Saati -2
11	Görüntü, Ses ve Video	Proje kontrolü-1
12	Gerçek Zaman Sistemlerinde temel kavramlar	Proje Kontrolü-2
13	Gerçek zaman İşletim Sistemleri	Mazeret sebepli son proje kontrollerinin yapılması
14	Nesnelerin İnterneti	
15	*Final Sınavı*	

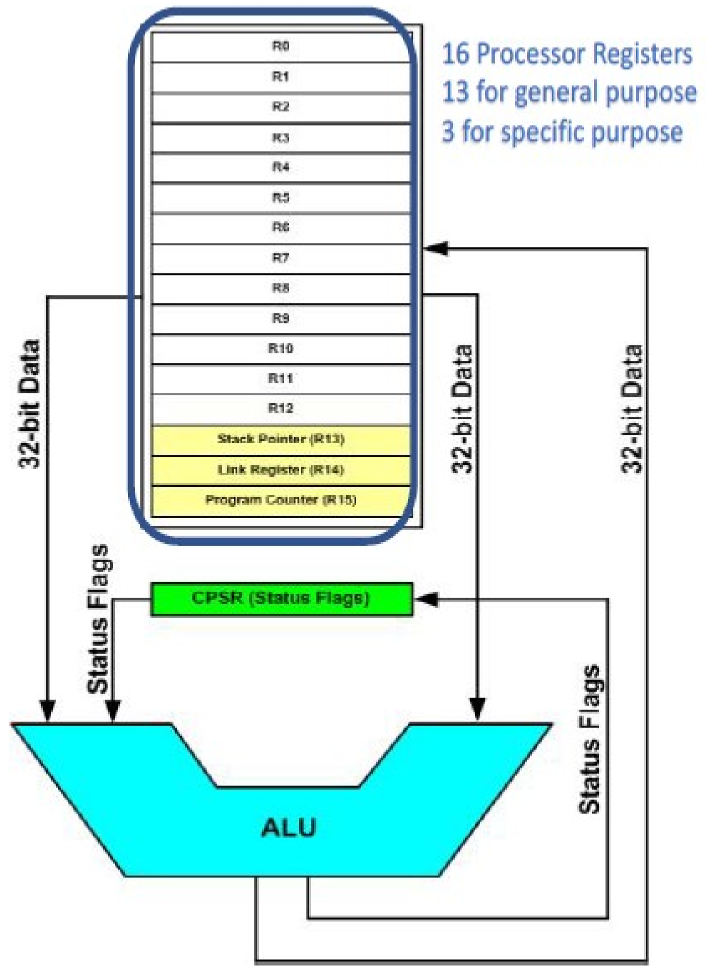
For more details -> Bologna page: http://www.bologna.yildiz.edu.tr/index.php?r=course/view&id=9463&aid=3

ARM Registers



- Fastest way to read and write
- Registers are within the processor chip
- A register stores 32-bit value
- Cortex M (STM32L) has
  - **R0-R12**: 13 general-purpose registers
  - **R13**: Stack pointer (Shadow of MSP or PSP)
  - **R14**: Link register (LR)
  - **R15**: Program counter (PC)
  - Special registers (xPSR, BASEPRI, PRIMASK, etc.)- more later





Credit by Farih Farahmand

Instruction Syntax in ARM

```
label          mnemonic operand1, operand2, operand3    ; comments
```

- Label is a reference to the **memory address** of this instruction.
- **Mnemonic** represents the operation to be performed (ADD, SUB, etc.).
- The number of **operands** varies, depending on each specific instruction. Some instructions have no operands at all.
  - Typically, operand1 is the **destination** register, and operand2 and operand3 are source operands.
  - operand2 is usually a register.
  - operand3 may be a register, an immediate number, a register shifted to a constant amount of bits, or a register plus an offset (used for memory access).
- Everything after the semicolon ";" is a comment, which is an annotation explicitly declaring programmers' intentions or assumptions.

```
target   ADD r0, r2, r3  ; r0 = r2 + r3
```

label | mnemonic | destination operand | 1st source operand | 2nd source operand | comment

Credit by Farid Farahmand

Instructions: Branch Operations

- Branch instruction

```
        B   label
        …
label:  …
```

- Conditional branches

```
        MOV   R0, #0
loop:         …
        ADD   R0, R0, #1
        CMP   R0, #10
        BNE   loop
```

Credit by Yung-Yu Chuang

Compare	Signed	Unsigned
==	EQ	EQ
≠	NE	NE
>	GT	HI
≥	GE	HS
<	LT	LO
≤	LE	LS

Compare	Signed	Unsigned
==	BEQ	BEQ
!=	BNE	BNE
>	BGT	BHI
>=	BGE	BHS
<	BLT	BLO
<=	BLE	BLS

Instructions: Branch with Link Operations

1. Example of using 'B' instruction:

```
      CMP   r0,#0        ; check if r0 == 0
      BNE   r2inc        ; if r0 !=0 branch to 'r2inc'
      ADD   r1,r1,#1     ; r1 += 1
      B     next         ; unconditional branch to 'next'
r2inc ADD   r2,r2,#1     ; r2 += 1
next  ----               ; continue
```

2. Example of using 'BL' instruction

```
      BL    funct1       ; save return addr. & subroutine
      CMP   r0,#5        ; next instruction
      ---
func1 ADD   r0,r0,#1     ; subroutine
      ---                ; codes
      MOV   pc,lr        ; return to program
```

N. Mathivanan

```
MOV r1, #10
MOV r2, #15
BL subLoop
CMP r1, #10
MOVEQ r1, #100

subLoop MOV pc, lr
```

Example for a subroutine

```c
int main(int argc, char **argv)
{

    int y;
    y = diffofsums(2, 3, 4, 5);
}

int diffofsums(int f, int g, int h, int i)
{

    int result;
    result = (f + g) - (h + i);
    return result;
}
```

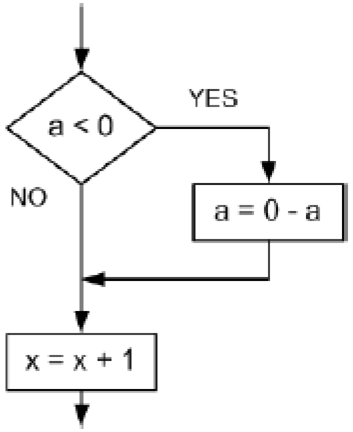
```
MAIN
        MOV     R0, #0X2
        MOV     R1, #0X3
        MOV     R2, #0X4
        MOV     R3, #0X5
        BL      DIFFOFSUMS
        MOV     R4, R0
        END
DIFFOFSUMS
        ADD     R8, R0, R1
        ADD     R9, R2, R3
        SUB     R4, R8, R9
        MOV     R0, R4
        MOV     PC, LR
```

IF – THEN statement

If-then Statement

C Program

```
if (a < 0 ) {
  a = 0 - a;
}
x = x + 1;
```




```
      ;CONDITIONAL   BRANCH
      MOV     R1,#-5
      CMP     R1,#0
      BGE     MENDIF  ;BRANCH IF R1>0 (SIGNED)
      RSB     R1,R1,#0
MENDIF ADD    R2,R2,#1
```

Implementation 1:

```
        ; r1 = a, r2 = x
        CMP r1, #0          ; Compare a with 0
        BGE endif           ; Go to endif if a ≥ 0
then    RSB r1, r1, #0      ; a = - a
endif   ADD r2, r2, #1      ; x = x + 1
```

Credit by Farid Farahmand

Compound Boolean Expression

```
x > 20 && x < 25
x == 20 || x == 25
!(x == 20 || x == 25)
```

```
        ;IF-THEN    WITH COMPOUNN LOGICAL OR
        ;       IF (R0 <= 20 || R0>=25)--> R1=1
        MOV     R0, #-2
        CMP     R0,#20
        BLE     S_THEN
        CMP     R0,#25
        BLT     S_ENDIF
S_THEN  MOV     R1,#1
S_ENDIF
```

C Program	Assembly Program

`// x is a signed integer`
`if(x <= 20 || x >= 25){`
`    a = 1`
`}`
	`        ; r0 = x`
	`        CMP  r0, #20   ; compare x and 20`
	`        BLE  then      ; go to then if x ≤ 20`
	`        CMP  r0, #25   ; compare x and 25`
	`        BLT  endif     ; go to endif if x < 25`
	`then    MOV  r1, #1    ; a = 1`
	`endif`

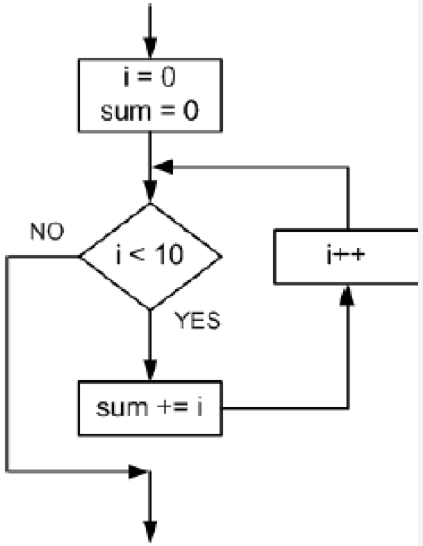
Veya:

```
        ;SAME    AS ABOVE BUT S        R
        ;IF-THEN    WITH COMPO      LOGICAL OR
        ;       IF (R0 <= 20 || R     25)--> R1=1
        MOV     R1, #0
        MOV     R0, #19
        CMP     R0,#20
        MOVLE R1,#1
        CMP     R0,#25
        MOVGE R1,#1
```

For Loop

For Loop

C Program
```c
int i;
int sum = 0;
for(i = 0; i < 10; i++){
  sum += i;
}
```



One Implementation is

```
        MOV r0, #0   ; i
        MOV r1, #0   ; sum

loop    CMP r0, #10
        BGE endloop
        ADD r1, r1, r0
        ADD r0, r0, #1
        B   loop
endloop
```

For Loop-2

```c
int main(int argc, char **argv)
{

    int v[] = {1, 5, 4, 7, 9, 1, 6, 5};

    for (int i = 0; i < 8; ++i)
        v[i] += 10;

    return 0;
}
```

```
ARRAY DCD 1, 5, 4, 7, 9, 1, 6, 5
LDR r0, =ARRAY
MOV r1, #0x0

FOR
      CMP r1, #8 ; r1 indisi tutuyor
      BGE BITIR ; 8'e eşit veya büyükse bitir
      LSL r2, r1, #2 ; r1'i 2 kaydır
      LDR r3, [r0,r2] ; r0'ın adresinin r2 sonrasını yükle
      ADD r3, r3, #10 ; r3 toplam değeri
      STR r3, [r0,r2]
      ADD r1,r1,#1 ; r1 program sayacını bir arttır
      B FOR

BITIR
```

Using Stack Pointer & LDR/STR

Stack Pointer -> Register 13

```c
int main(int argc, char **argv)
{

    int y;
    y = diffofsums(2, 3, 4, 5);
}

int diffofsums(int f, int g, int h, int i)
{

    int result;
    result = (f + g) - (h + i);
    return result;
}
```

- First, store all used registers to stack,
- Second, use it for the equations
- Last, restore all used registers to original

```
MAIN
        MOV r0, #2
        MOV r1,#3
        MOV r2, #5
        MOV r3, #2
        BL DIFFOFSUMS
END

DIFFOFSUMS
        SUB SP, SP, #0xc
        STR r9, [sp,#0x8]
        STR r8, [sp,#0x4]
        STR r4, [sp]

        ADD r8, r0,r1
        ADD r9, r2,r3
        SUB r4,r8,r9
        MOV r0,r4

        LDR r4, [sp]
        LDR r8,[sp,#0x4]
        LDR r9, [sp,#0x8]
        ADD sp,sp,#0xc

        MOV pc, lr
```

```
MAIN
      MOV r0, #2
      MOV r1,#3
      MOV r2, #5
      MOV r3, #2
      BL DIFFOFSUMS
END

DIFFOFSUMS
      SUB SP, SP, #0xc
      STR r9, [sp,#0x8]
      STR r8, [sp,#0x4]
      STR r4, [sp]

      ADD r8, r0,r1
      ADD r9, r2,r3
      SUB r4,r8,r9
      MOV r0,r4

      LDR r4, [sp]
      LDR r8,[sp,#0x4]
      LDR r9, [sp,#0x8]
      ADD sp,sp,#0xc

      MOV pc, lr
```

Registers	Before entering subroutine:	Register values in subroutine: line 23	After subroutine:
R0	2	-2	-2
R1	3	3	3
R2	5	5	5
R3	2	2	2
R4	0	-2	0
R5	0	0	0
R6	0	0	0
R7	0	0	0
R8	0	5	0
R9	0	7	0
R10	0	0	0
R11	0	0	0
R12	0	0	0
R13	-16777216	-16777228	-16777216
R14	0	20	20
R15	16	56	20

```
SUB SP, SP, #0xc
 STR r9, [sp,#0x8]
 STR r8, [sp,#0x4]
 STR r4, [sp]
```

Registers | Memory | Symbols

Enable Byte View

Enable Reverse Direction

Symbol	Address	Value
SP →	0×FEFFFFF4	0
	0×FEFFFFF8	0
(DIFFOFSUMS)	0×FEFFFFFC	0

Uninitialized memory is zeroed

```
LDR r4, [sp]
LDR r8,[sp,#0x4]
LDR r9, [sp,#0x8]
```

That's an important example about how to use STR and LDR instructions?

What about LDM ? STM?

Instructions: Multiple Load/Store Registers

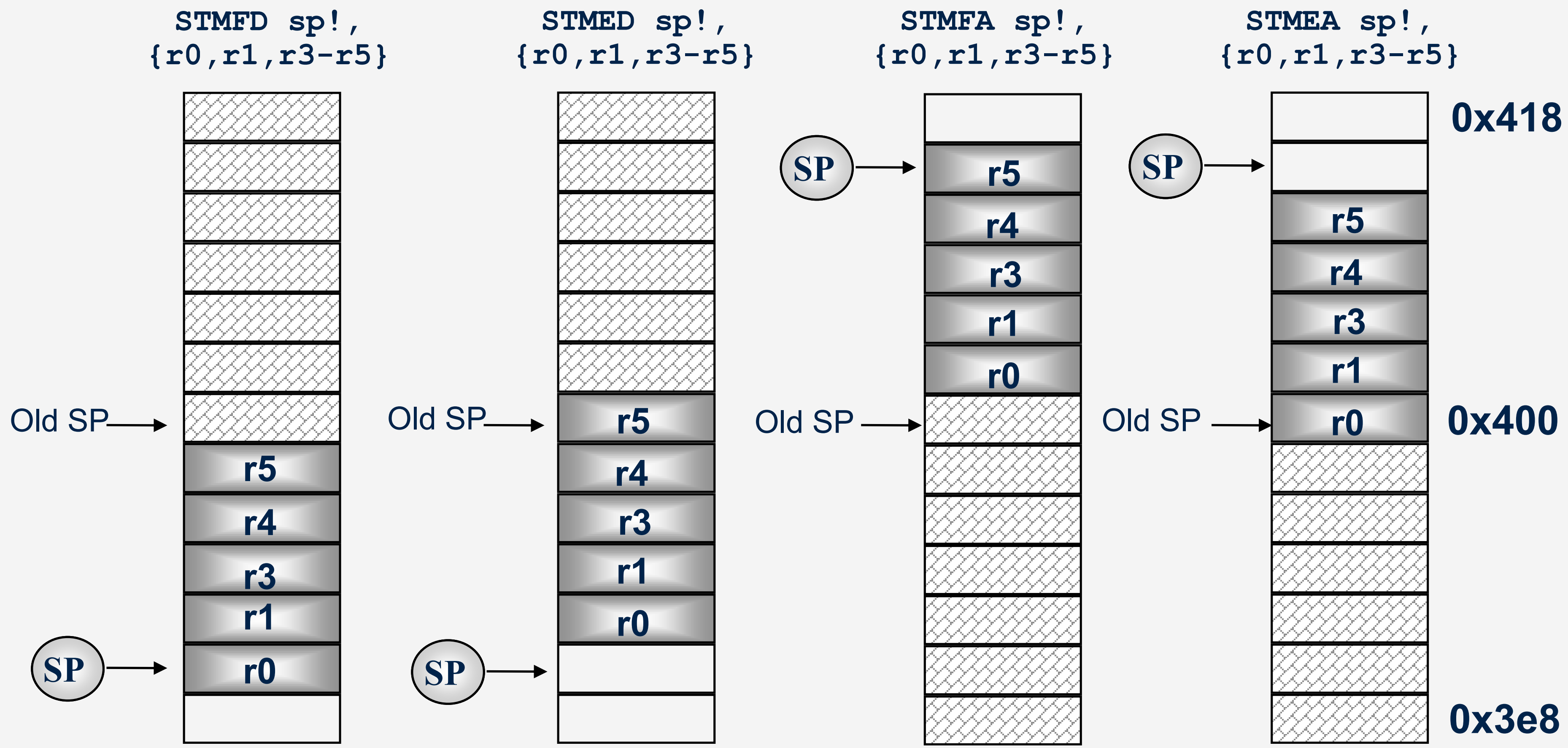
```
LDM    load multiple registers
STM    store multiple registers

suffix      meaning
  IA    increase after
  IB    increase before
  DA    decrease after
  DB    decrease before
```

```
Syntax: <LDM|STM>{<cond>}<addressing mode> Rn{!},<registers>{^}
```

Addressing mode	Description	Start address	End address	$Rn!$
IA	increment after	Rn	$Rn + 4^*N - 4$	$Rn + 4^*N$
IB	increment before	$Rn + 4$	$Rn + 4^*N$	$Rn + 4^*N$
DA	decrement after	$Rn - 4^*N + 4$	Rn	$Rn - 4^*N$
DB	decrement before	$Rn - 4^*N$	$Rn - 4$	$Rn - 4^*N$

Stack Examples



- STMIA, STMIB, STMDA, STMDB are the same instructions as STMEA, STMFA, STMED, STMFD, respectively

Using Stack Pointer & LDM/STM

Stack Pointer -> Register 13

```c
int main(int argc, char **argv)
{

    int y;
    y = diffofsums(2, 3, 4, 5);
}

int diffofsums(int f, int g, int h, int i)
{

    int result;
    result = (f + g) - (h + i);
    return result;
}
```

```
MAIN
        MOV r0, #2
        MOV r1,#3
        MOV r2, #5
        MOV r3, #2
        BL DIFFOFSUMS
        END

DIFFOFSUMS
        STMFD sp!,{r4,r8,r9}

        ADD r8, r0,r1
        ADD r9, r2,r3
        SUB r4,r8,r9
        MOV r0,r4
        LDMFD sp!,{r4,r8,r9}

        MOV pc, lr
```

What is Raspberry Pi?

- The Raspberry Pi is a series of small single-board computers developed in the United Kingdom by the Raspberry Pi Foundation to promote the teaching of basic computer science in schools and in developing countries.

- Over 5 million Raspberry Pis have been sold before February 2015, making it the best-selling British computer. By November 2016 they had sold 11 million units.

- Till now, Raspberry has lots of model versions. (Zero, 1-4)

Credit by Tushar B. Kute

The Timeline

- The first generation (Raspberry Pi 1 Model B) was released in February 2012. It was followed by a simpler and inexpensive model Model A.
- In 2014, the foundation released a board with an improved design in Raspberry Pi 1 Model B+. These boards are approximately credit-card sized and represent the standard mainline form-factor.
- Improved A+ and B+ models were released a year later. A "compute module" was released in April 2014 for embedded applications, and a Raspberry Pi Zero with smaller size and reduced input/output (I/O) and general-purpose input/output (GPIO) capabilities was released in November 2015 for US$5.

The Timeline

- The Raspberry Pi 2 which added more RAM was released in February 2015.
- Raspberry Pi 3 Model B released in February 2016, is bundled with on-board WiFi, Bluetooth and USB boot capabilities.
- As of January 2017, Raspberry Pi 3 Model B is the newest mainline Raspberry Pi.
- Raspberry Pi boards are priced between US$5–35.
- As of 28 February 2017, the Raspberry Pi Zero W was launched, which is identical to the Raspberry Pi Zero, but has the Wi-Fi and Bluetooth functionality of the Raspberry Pi 3 for US$10.

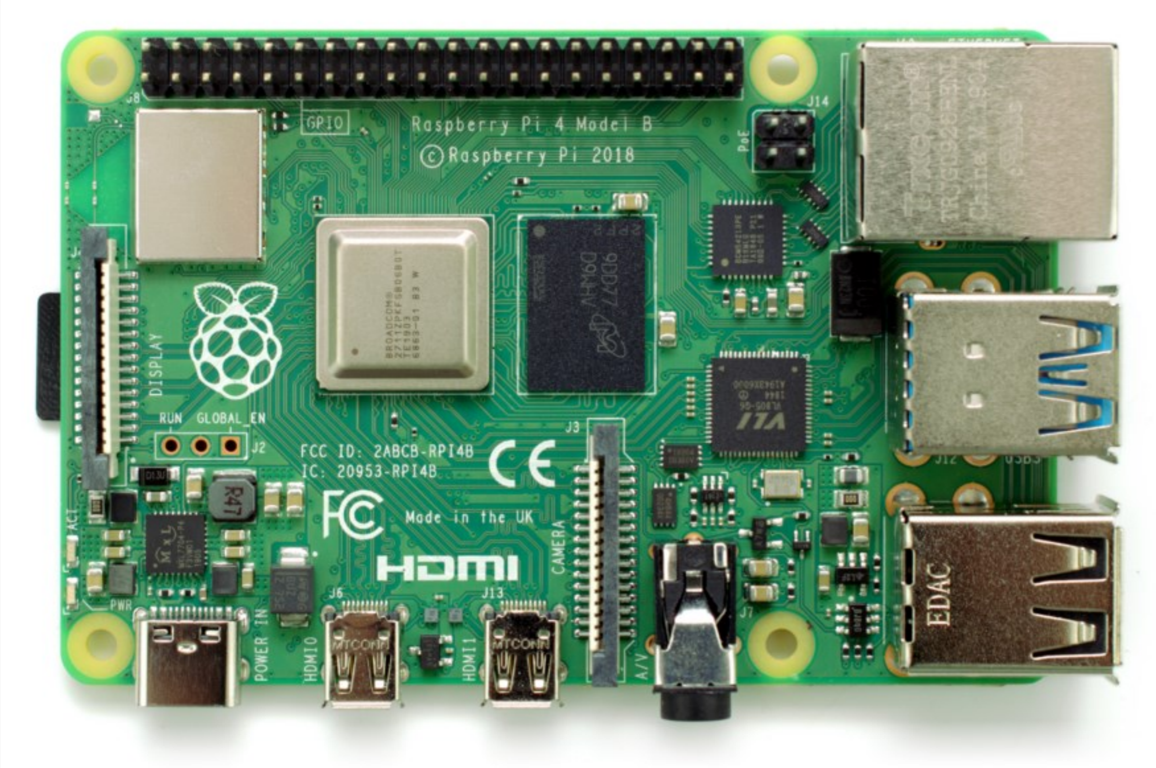
The Timeline

- Now, there are also Raspberry Pi 4 model.

- Raspberry Pi 4 was released in June 2019. 1.5 MHz, 64-bit quad core ARM Cortex-A72

- 4K resolution and USB Type-C.

- Price: ~1000 TL



Operating System

- The Foundation provides Raspbian, a Debian-based Linux distribution for download, as well as third party Ubuntu, Windows 10 IOT Core, RISC OS, and specialised media center distributions.
- It promotes Python and Scratch as the main programming language, with support for many other languages.
- The default firmware is closed source, while an unofficial open source is available.

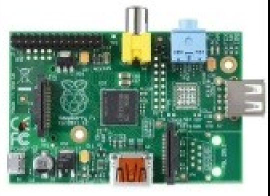
Processor

- The Broadcom BCM2835 SoC used in the first generation Raspberry Pi is somewhat equivalent to the chip used in first modern generation smartphones (its CPU is an older ARMv6 architecture), which includes a 700 MHz ARM1176JZF-S processor, VideoCore IV graphics processing unit (GPU), and RAM.
- It has a level 1 (L1) cache of 16 KB and a level 2 (L2) cache of 128 KB. The level 2 cache is used primarily by the GPU. The SoC is stacked underneath the RAM chip, so only its edge is visible.
- The Raspberry Pi 2 uses a Broadcom BCM2836 SoC with a 900 MHz 32-bit quad-core ARM Cortex-A7 processor, with 256 KB shared L2 cache.
- The Raspberry Pi 3 uses a Broadcom BCM2837 SoC with a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor, with 512 KB shared L2 cache

Performance

- The Raspberry Pi 3, with a quad-core Cortex-A53 processor, is described as 10 times the performance of a Raspberry Pi 1. This was suggested to be highly dependent upon task threading and instruction set use. Benchmarks showed the Raspberry Pi 3 to be approximately 80% faster than the Raspberry Pi 2 in parallelized tasks.
- Raspberry Pi 2 includes a quad-core Cortex-A7 CPU running at 900 MHz and 1 GB RAM. It is described as 4–6 times more powerful than its predecessor. The GPU is identical to the original. In parallelized benchmarks, the Raspberry Pi 2 could be up to 14 times faster than a Raspberry Pi 1 Model B+.

All Versions

						
Raspberry Pi	Modelo A	Modelo A+	Modelo B	Modelo B+	RPi V2 modelo B	RPi 3 modelo B
SoC	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2836	Broadcom BCM2837
CPU	700MHz ARM1176JFZ-S	700MHz ARM1176JFZ-S	700MHz ARM1176JFZ-S	700MHz ARM1176JFZ-S	900MHz Quad-core ARM Cortex-A7	1.2Ghz Quad Cortex A53
GPU	VideoCore IV	VideoCore IV	VideoCore IV	VideoCore IV	250Mhz VideoCore IV	400Mhz VideoCore IV
RAM	256Mb	512Mb	512Mb	512Mb	1Gb	1Gb
USB	1	1	2	4	4	4
Video	RCA, HDMI	Jack, HDMI	RCA, HDMI	Jack, HDMI	Jack, HDMI	Jack, HDMI
Audio	Jack, HDMI	Jack, HDMI	Jack, HDMI	Jack, HDMI	Jack, HDMI	Jack, HDMI
Boot	Memoria SD	Memoria microSD	Memoria SD	Memoria microSD	Memoria microSD	Memoria microSD
Wireless	No tiene	No tiene	No tiene	No tiene	No tiene	802.11n / Bluetooth 4.1
Red Ethernet	No tiene	No tiene	Ethernet 10/100	Ethernet 10/100	Ethernet 10/100	Ethernet 10/100
Alimentación	5V / 2Amp	5V / 2Amp	5V / 2Amp	5V / 2Amp	5V / 2Amp	5V / 2,5Amp
GPIO	26 pines GPIO	40 pines GPIO	26 pines GPIO	40 pines GPIO	40 pines GPIO	40 pines GPIO
Tamaño	85,6 x 53,98 mm	65 x 56 mm	85,6 x 53,98 mm	85 x 56 x 17 mm	85 x 56 x 17 mm	85 x 56 x 17 mm

Rpi 4
BroadCom BCM2711
1.5 GHz Quad Cortex
2-8 GB
2 HDMI Port
MicroSD
Bluetooth&wireless
40 pin
H265 support

Operating Systems

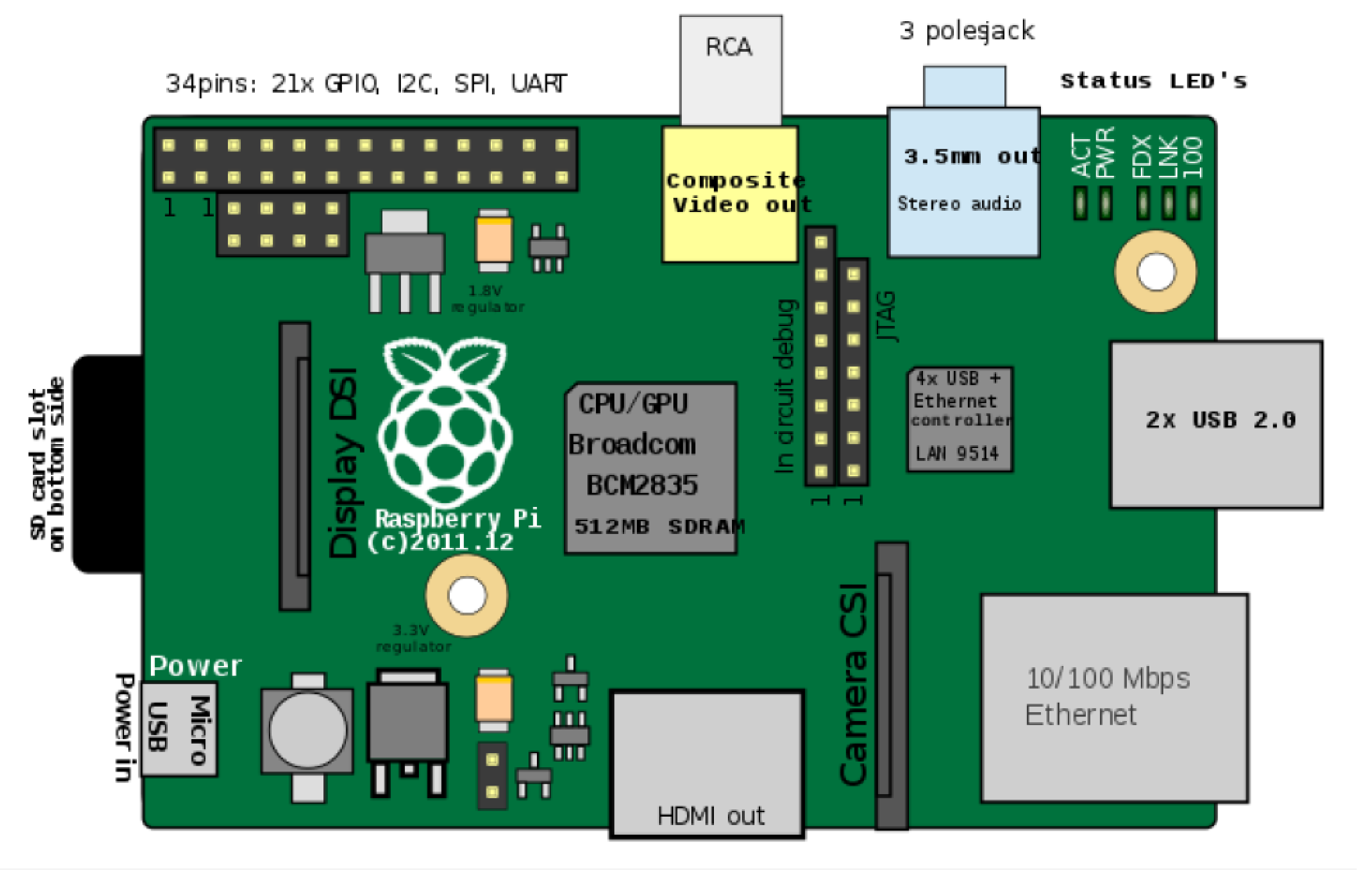
- The Raspberry Pi Foundation recommends the use of Raspbian, a Debian-based Linux operating system.
- Other third party operating systems available via the official website include Ubuntu MATE, Snappy Ubuntu Core, Windows 10 IoT Core, RISC OS and specialised distributions for the Kodi media center and classroom management.

The MagPi

- The MagPi is a free fanzine for users of the Raspberry Pi computer.
- It was created by the community as an unofficial volunteer produced Raspberry Pi publication and in 2015 was handed over to the Raspberry Pi Foundation to be run in-house as the official Raspberry Pi magazine.
- It was launched in May 2012 and contains news, projects and tutorials.

The MagPi
raspberrypi.org/magpi Magazine
The official Raspberry Pi magazine

Raspberry Pi Model B



Raspberry Pi Model A & B (P1 Header)

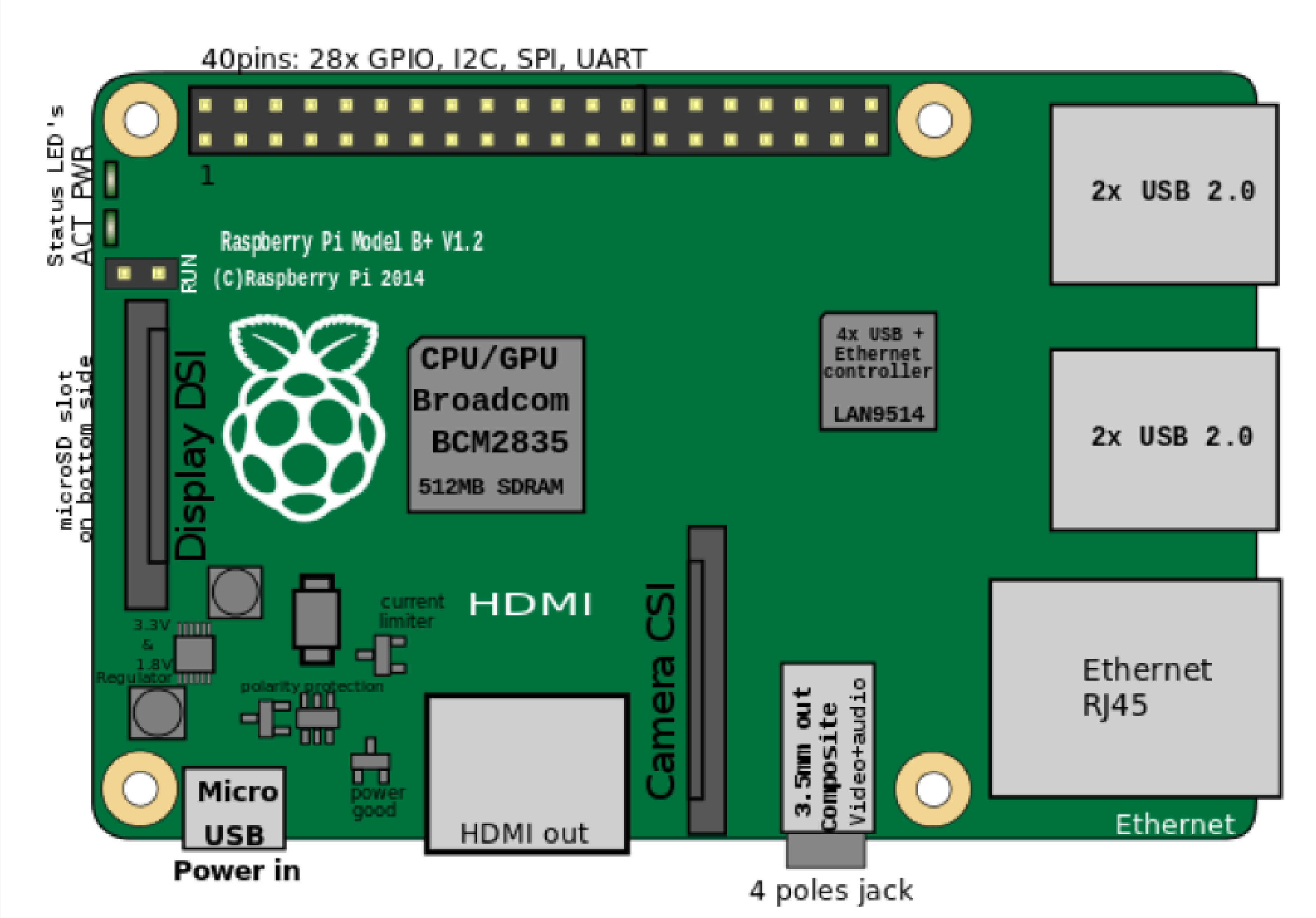
PIN #	NAME			NAME	PIN #
	3.3 VDC Power	1	2	5.0 VDC Power	
8	SDA0 (I2C)	3	4	DNC	
9	SCL0 (I2C)	5	6	0V (Ground)	
7	GPIO 7	7	8	TxD (UART)	15
	DNC	9	10	RxD (UART)	16
0	GPIO 0	11	12	GPIO1	1
2	GPIO2	13	14	DNC	
3	GPIO3	15	16	GPIO4	4
	DNC	17	18	GPIO5	5
12	MOSI	19	20	DNC	
13	MISO	21	22	GPIO6	6
14	SCLK	23	24	CE0	10
	DNC	25	26	CE1	11

Attention! The GIPO pin numbering used in this diagram is intended for use with WiringPi / Pi4J. This pin numbering is not the raw Broadcom GPIO pin numbers.

http://www.pi4j.com

https://pi4j.com/1.2/pins/model-b-rev2.html

Raspberry Pi 2 Model B



Raspberry Pi 2 Model B (J8 Header)

GPIO#	NAME	Pin	Pin	NAME	GPIO#
	3.3 VDC Power	1	2	5.0 VDC Power	
8	GPIO 8 SDA1 (I2C)	3	4	5.0 VDC Power	
9	GPIO 9 SCL1 (I2C)	5	6	Ground	
7	GPIO 7 GPCLK0	7	8	GPIO 15 TxD (UART)	15
	Ground	9	10	GPIO 16 RxD (UART)	16
0	GPIO 0	11	12	GPIO 1 PCM_CLK/PWM0	1
2	GPIO 2	13	14	Ground	
3	GPIO 3	15	16	GPIO 4	4
	3.3 VDC Power	17	18	GPIO 5	5
12	GPIO 12 MOSI (SPI)	19	20	Ground	
13	GPIO 13 MISO (SPI)	21	22	GPIO 6	6
14	GPIO 14 SCLK (SPI)	23	24	GPIO 10 CE0 (SPI)	10
	Ground	25	26	GPIO 11 CE1 (SPI)	11
30	SDA0 (I2C ID EEPROM)	27	28	SCL0 (I2C ID EEPROM)	31
21	GPIO 21 GPCLK1	29	30	Ground	
22	GPIO 22 GPCLK2	31	32	GPIO 26 PWM0	26
23	GPIO 23 PWM1	33	34	Ground	
24	GPIO 24 PCM_FS/PWM1	35	36	GPIO 27	27
25	GPIO 25	37	38	GPIO 28 PCM_DIN	28
	Ground	39	40	GPIO 29 PCM_DOUT	29

Attention! The GIPO pin numbering used in this diagram is intended for use with WiringPi / Pi4J. This pin numbering is not the raw Broadcom GPIO pin numbers.

http://www.pi4j.com