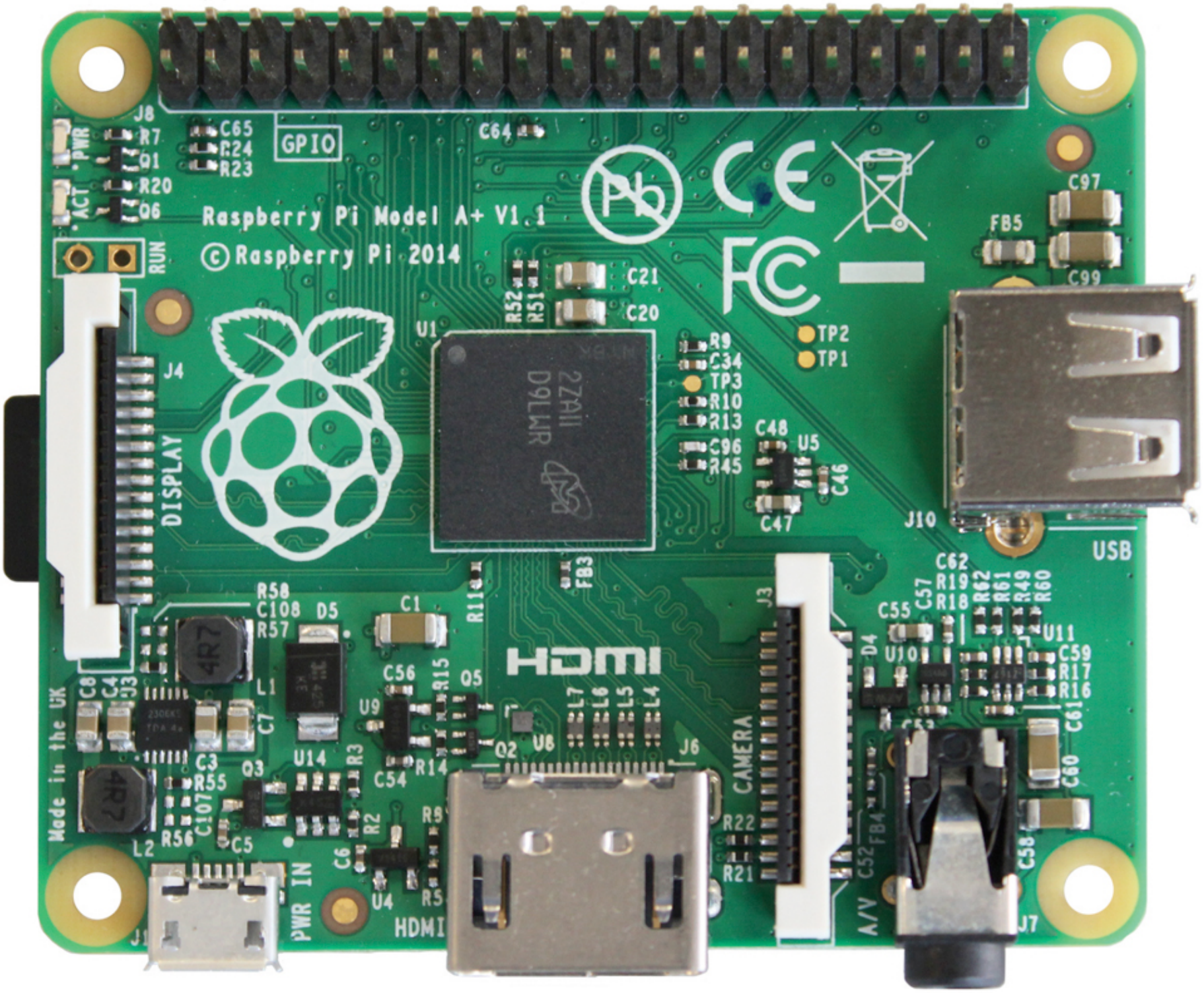
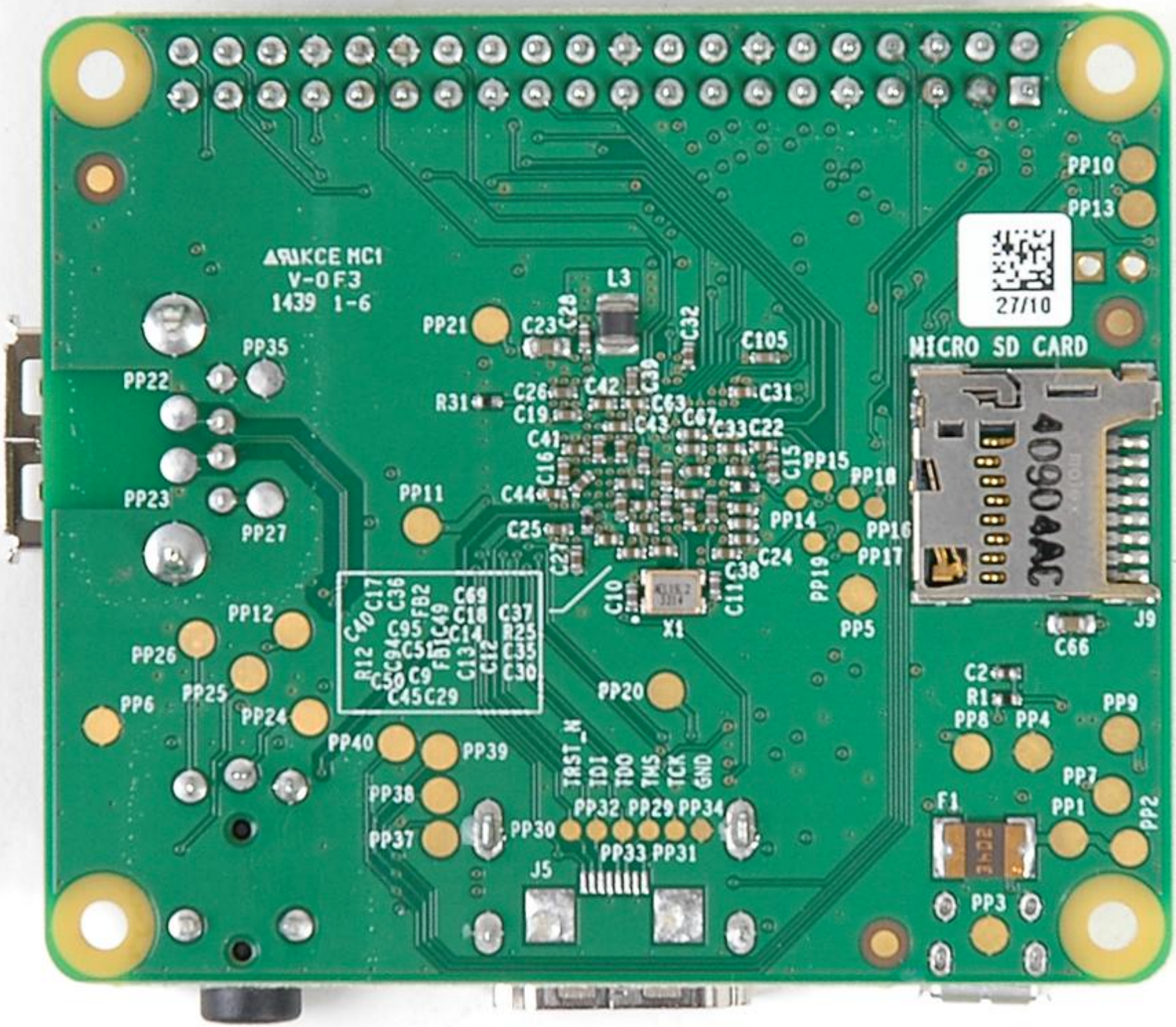
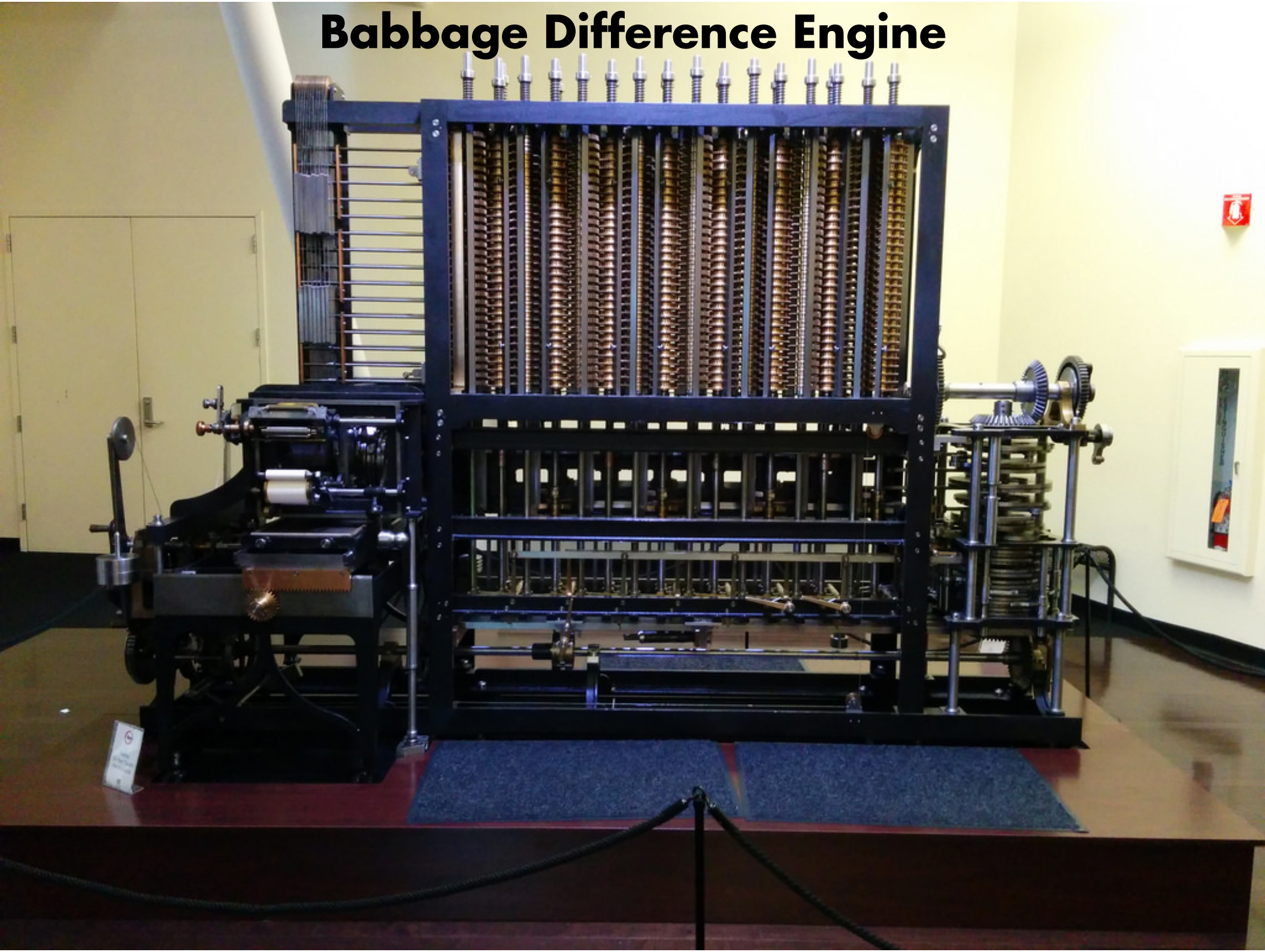
ARM
Processor and Memory Architecture

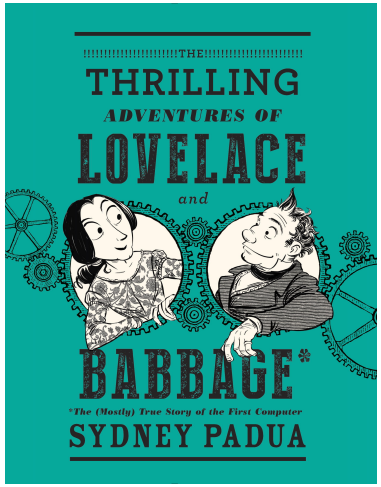
Goal: Turn on an LED


GPIO
Raspberry Pi Model A+ V1.1
© Raspberry Pi 2014
DISPLAY
HDMI
CAMERA
USB
A/V
PWR IN
HDMI
Made in the UK


ARMKCE MC1
V-0 F3
1439 1-6
L3
MICRO SD CARD
27/10
40904AC
J9
C66
X1
J5
F1
PP10
PP13
PP21
PP35
PP22
PP23
PP27
PP11
PP12
PP26
PP25
PP6
PP24
PP40
PP39
PP38
PP37
PP30
PP20
PP32
PP29
PP34
PP33
PP31
PP15
PP18
PP14
PP16
PP17
PP19
PP5
PP8
PP4
PP9
PP7
PP1
PP2
PP3
TRST_N
TDI
TDO
TMS
TCK
GND
C23
C28
C32
C105
C26
C42
C39
C63
C31
R31
C19
C43
C67
C33
C22
C41
C16
C15
C44
C25
C27
C24
C38
C10
C11
C17
C36
FB2
C69
C40
C95
C18
C37
C49
C14
R25
C51
C13
C12
C35
R12
C94
C50
C9
C30
C45
C29
C2
R1

Babbage Difference Engine



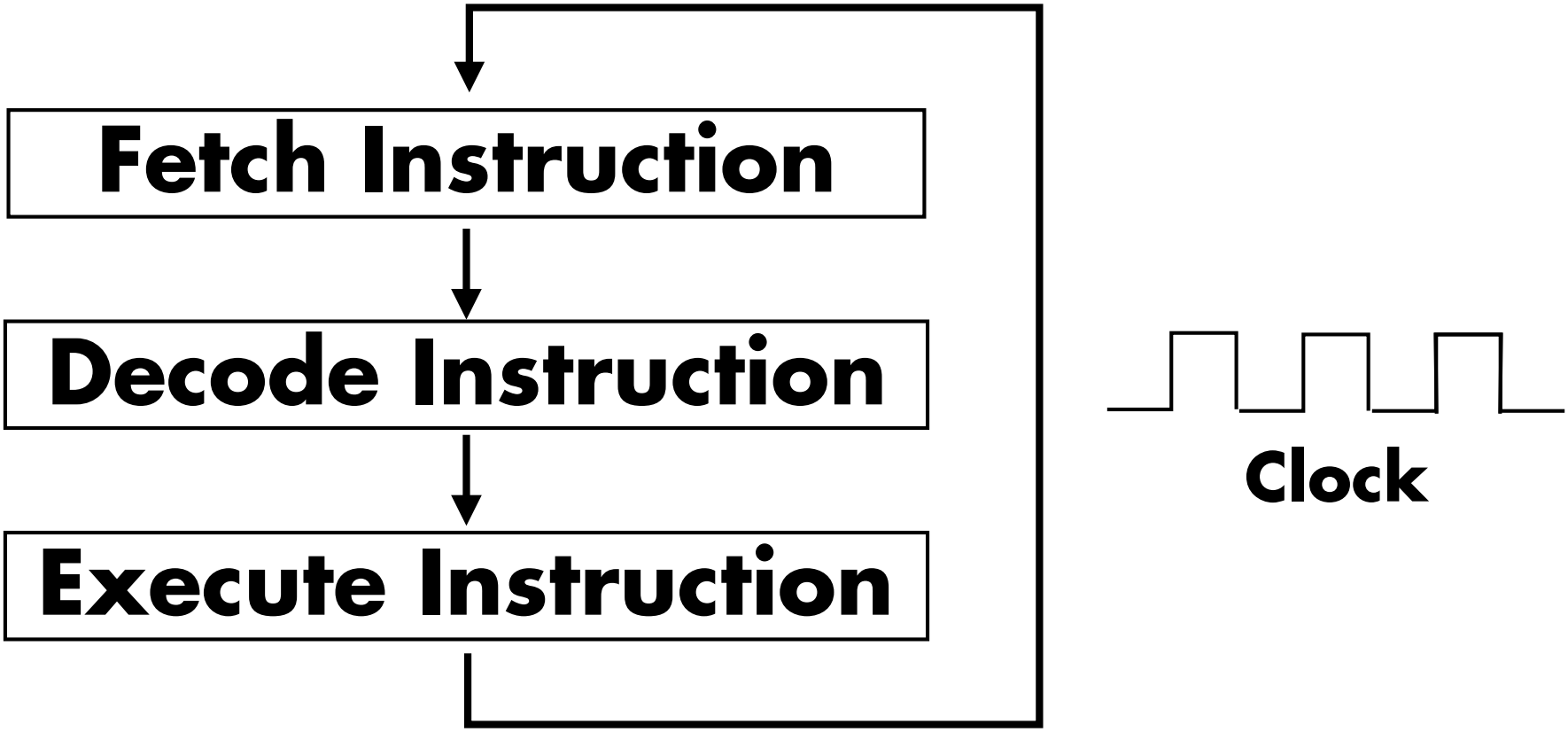


Analytical Engine

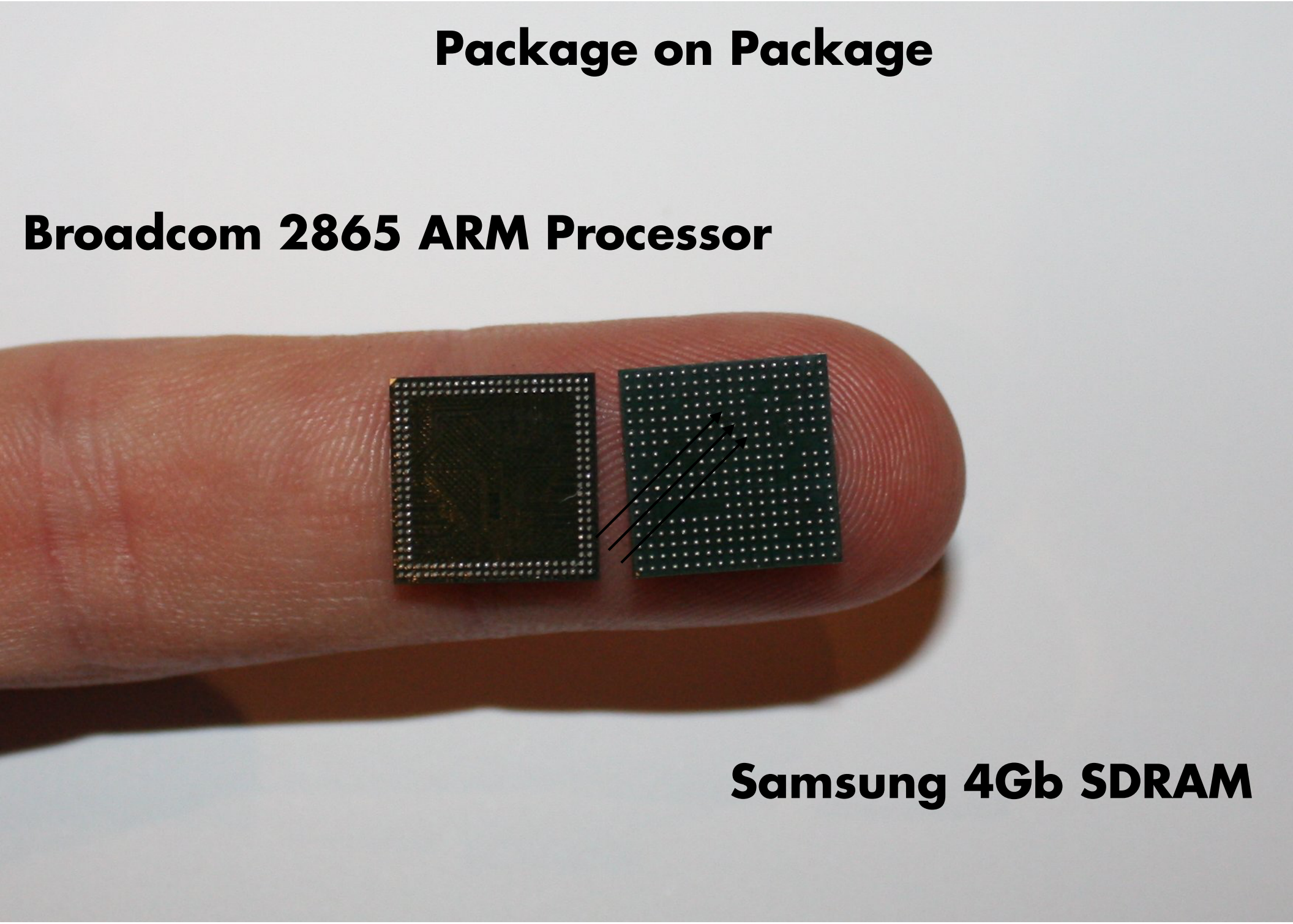
Universal Computer

http://www.theguardian.com/technology/2015/apr/12/thrilling-adventures-ada-lovelace-charles-babbage-sydney-padua

Running a "Program"



Package on Package

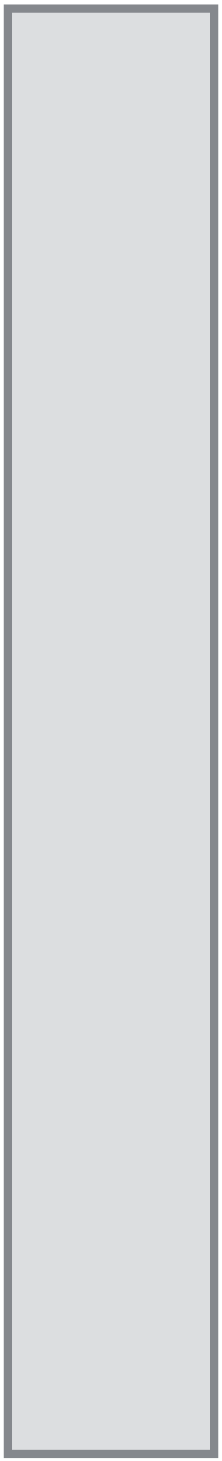


Memory used to store both instructions and data

Storage locations are accessed using 32-bit addresses

Maximum addressable memory is 4 GB

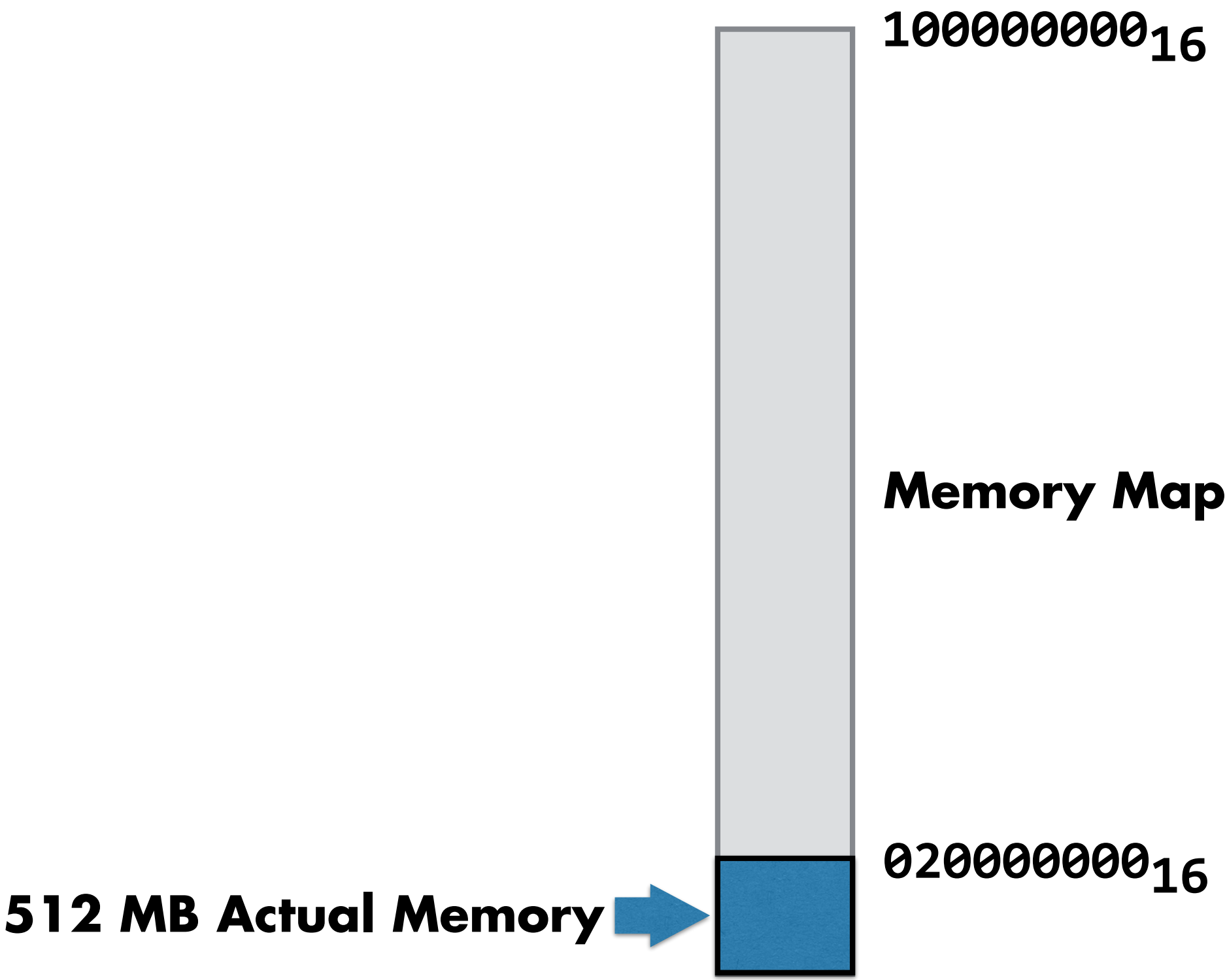
Address refers to a *byte (8-bits)*



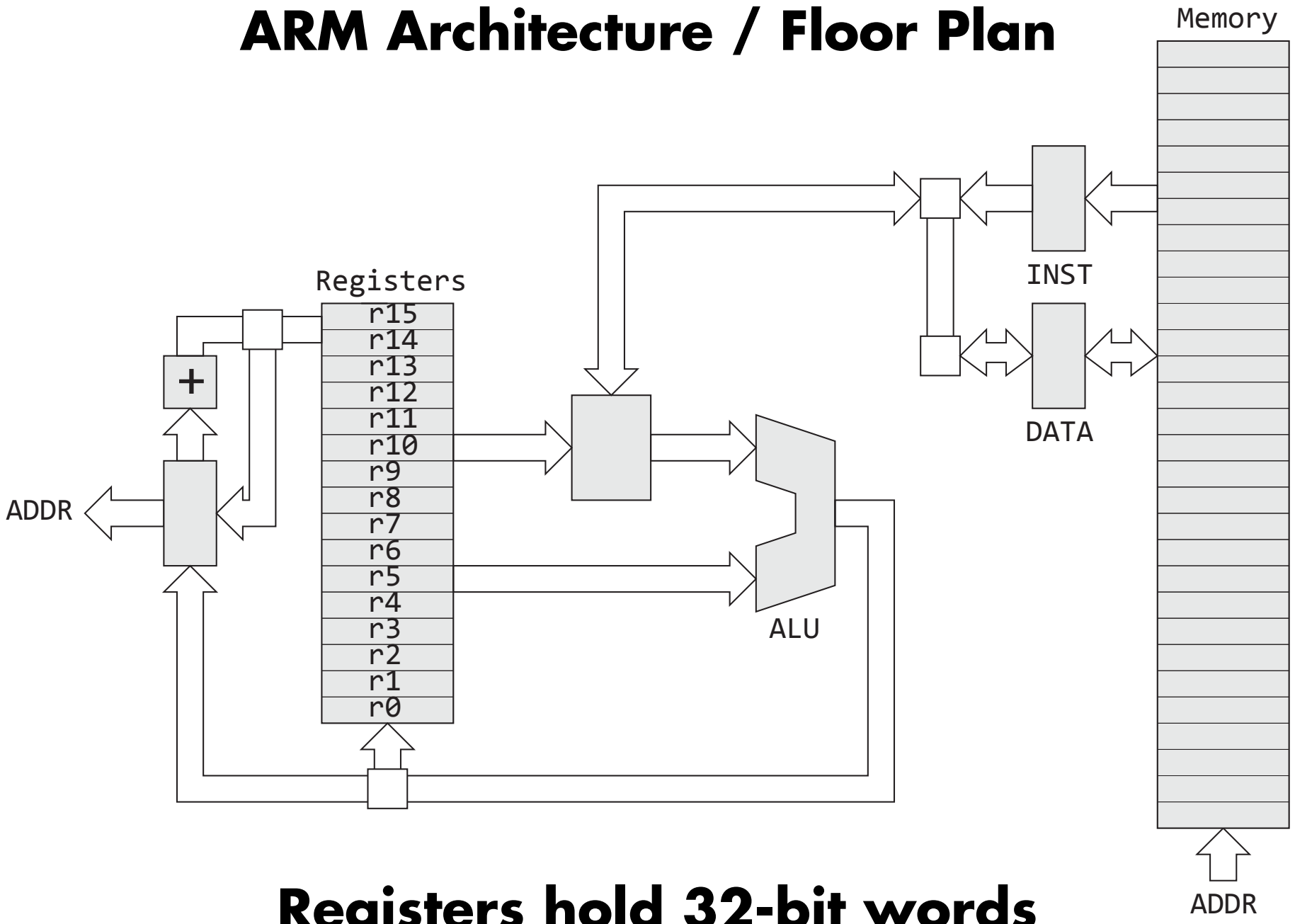
100000000_{16}

Memory Map

00000000_{16}


100000000_{16}
Memory Map
020000000_{16}
512 MB Actual Memory

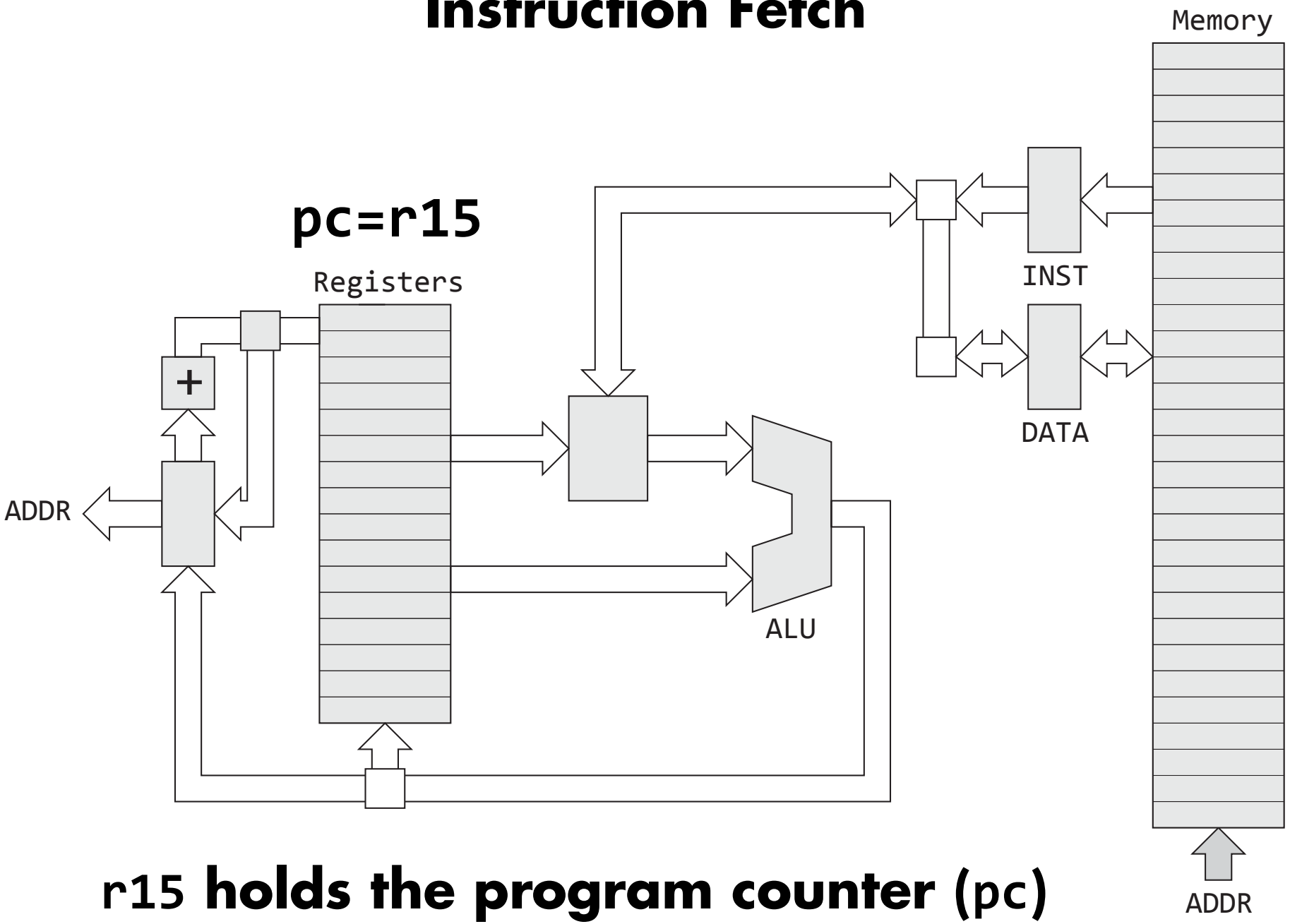
ARM Architecture / Floor Plan



Registers hold 32-bit words

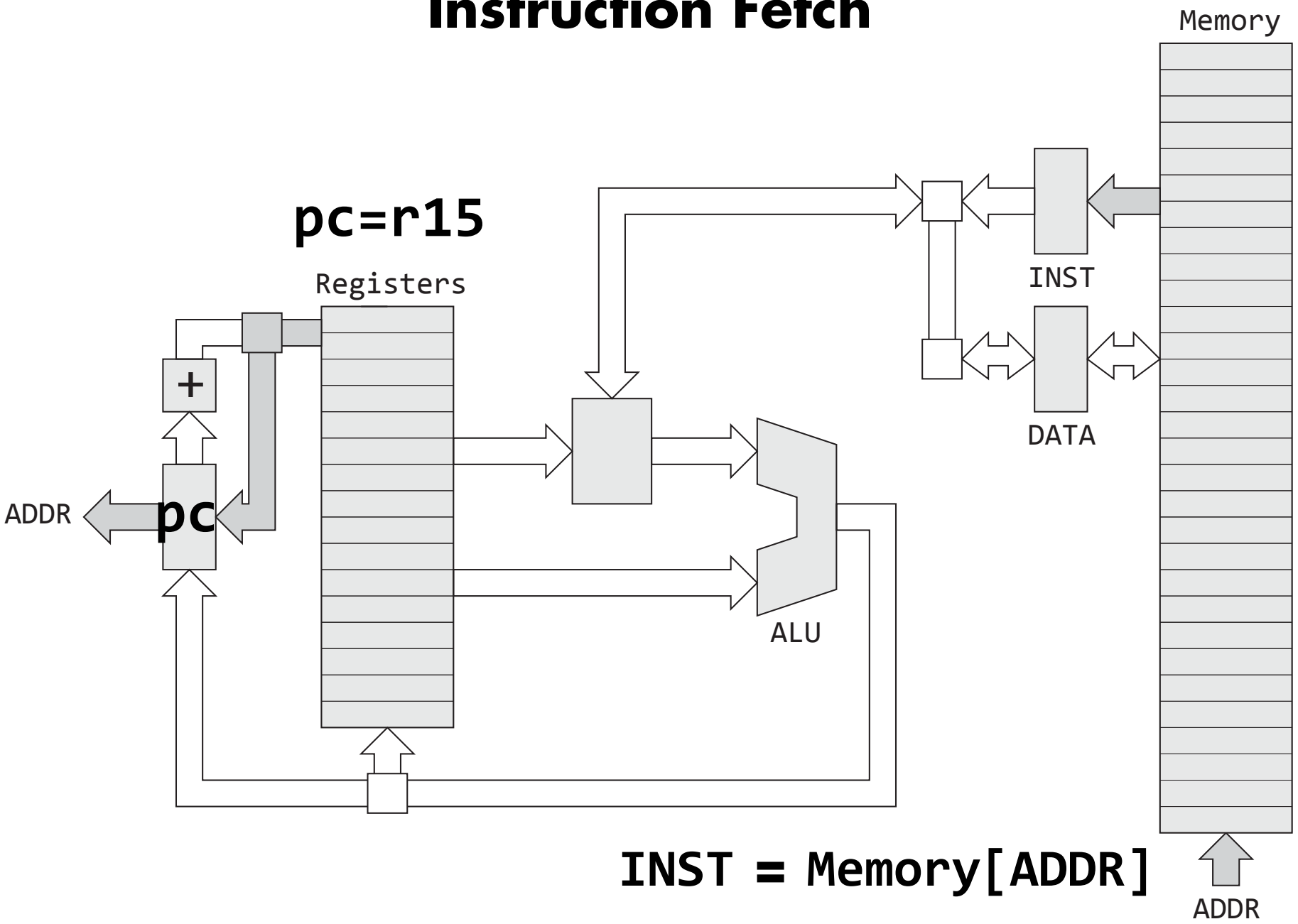
Arithmetic-Logic Unit (ALU) operates on 32-bit words

Instruction Fetch



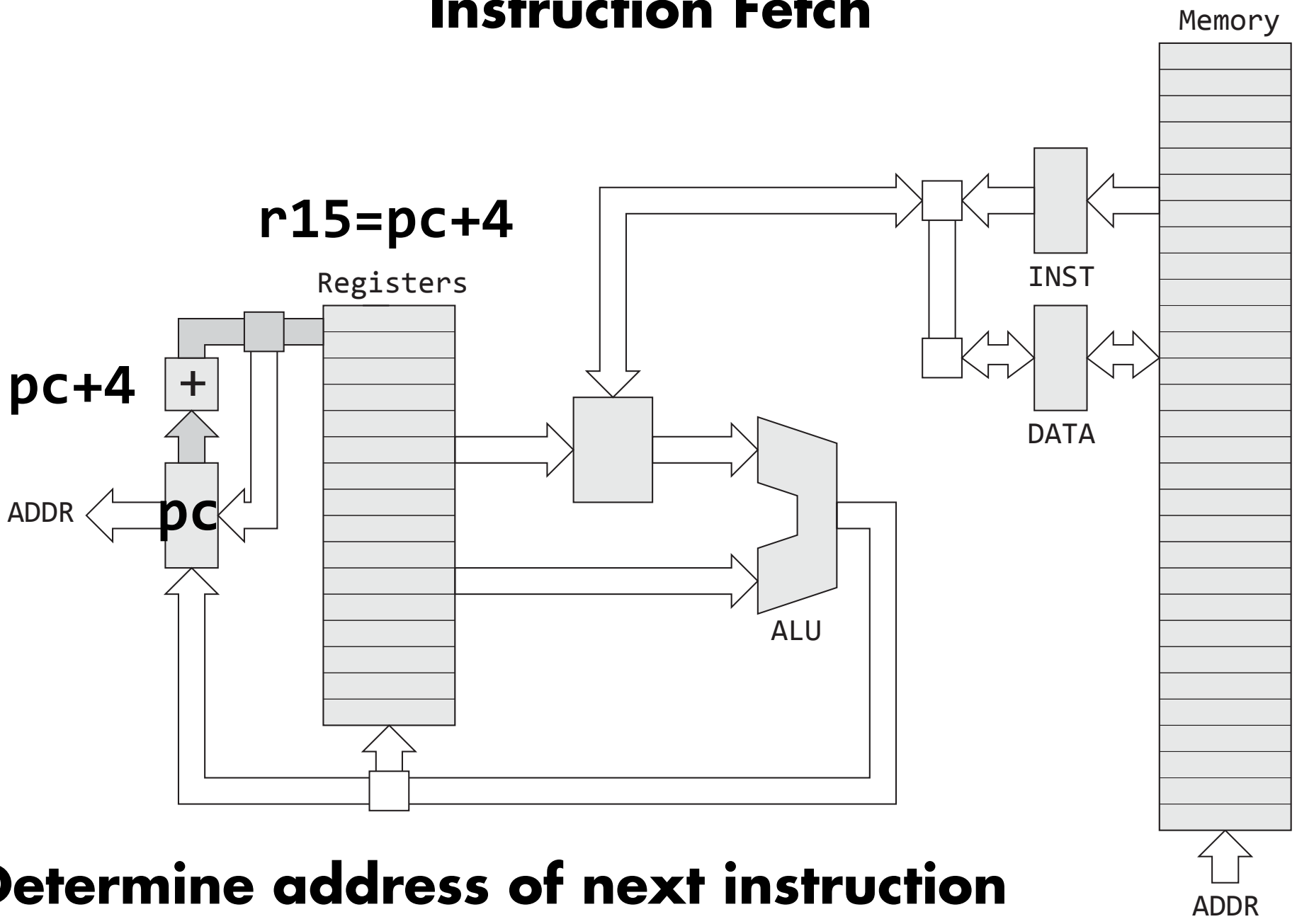
r15 holds the program counter (pc)

Instruction Fetch



Addresses and instructions are 32-bit words

Instruction Fetch

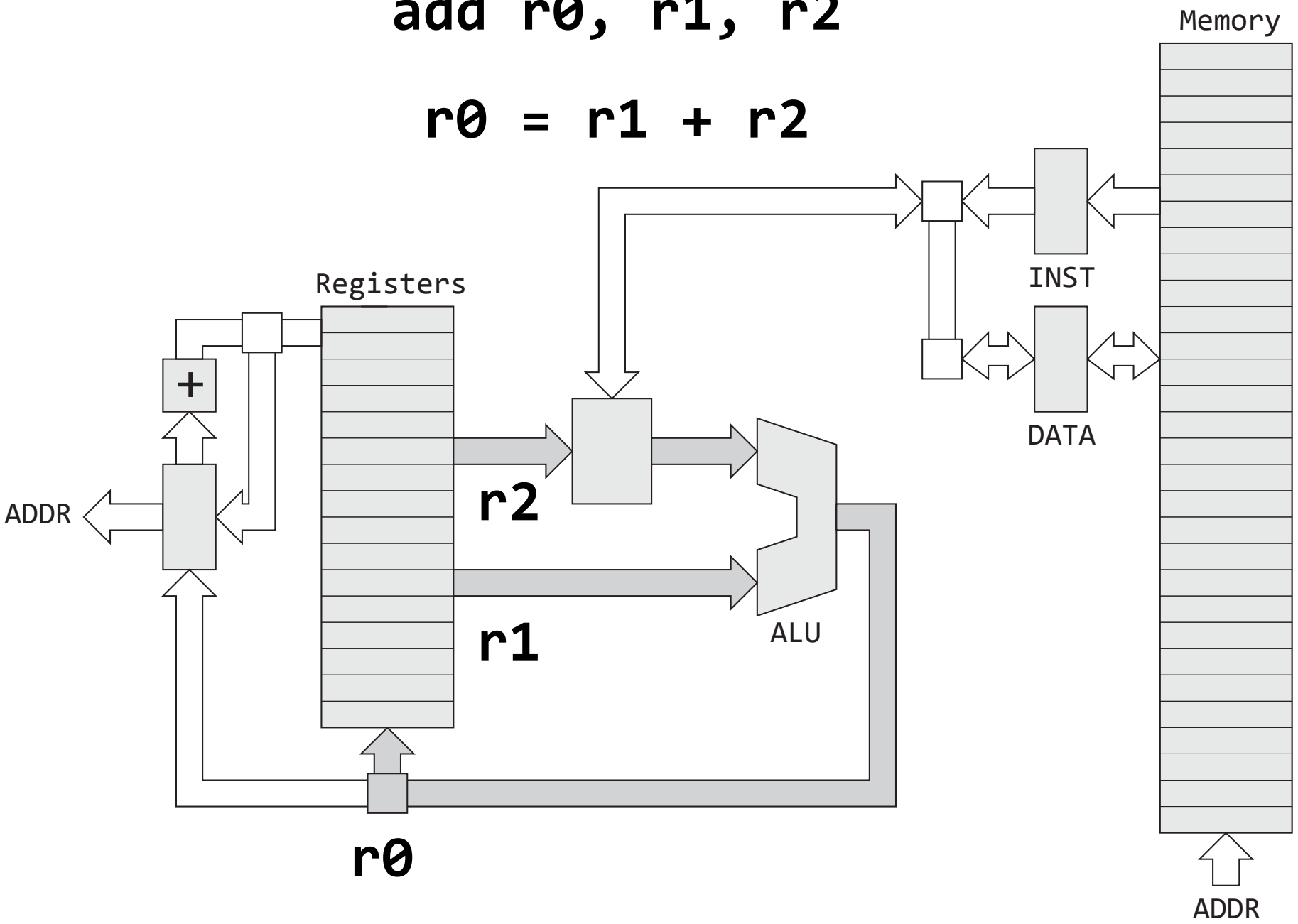


Determine address of next instruction

Why pc+4?

Arithmetic-Logic Unit (ALU)

```
add r0, r1, r2

r0 = r1 + r2
```



ALU operates on 32-bit words

Add Instruction

Meaning (defined as math or C code)

```
r0 = r1 + r2
```

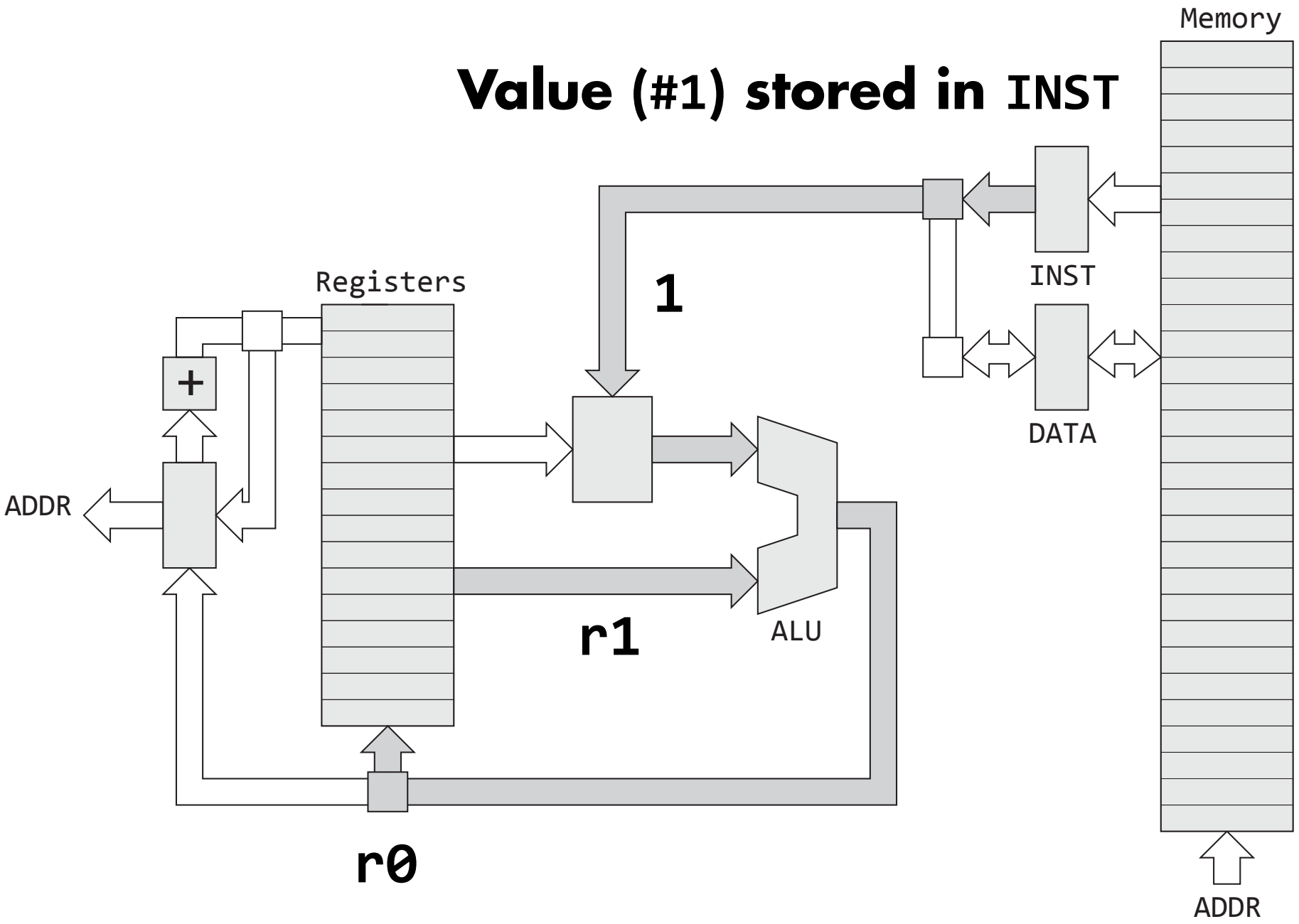
Assembly language (result is leftmost register)

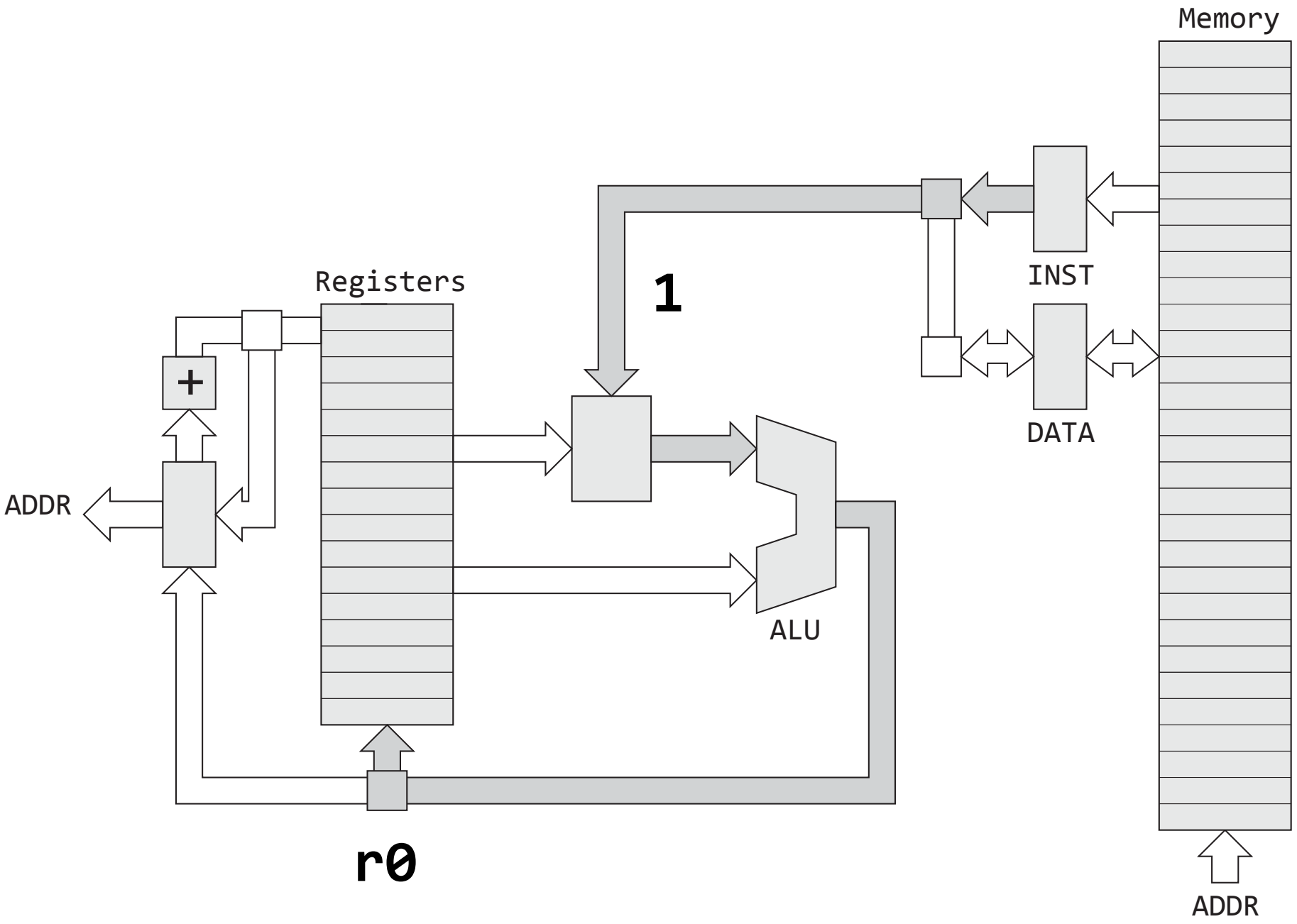
```
add r0, r1, r2
```

Machine code (more on this later)

```
E0 81 00 02
```

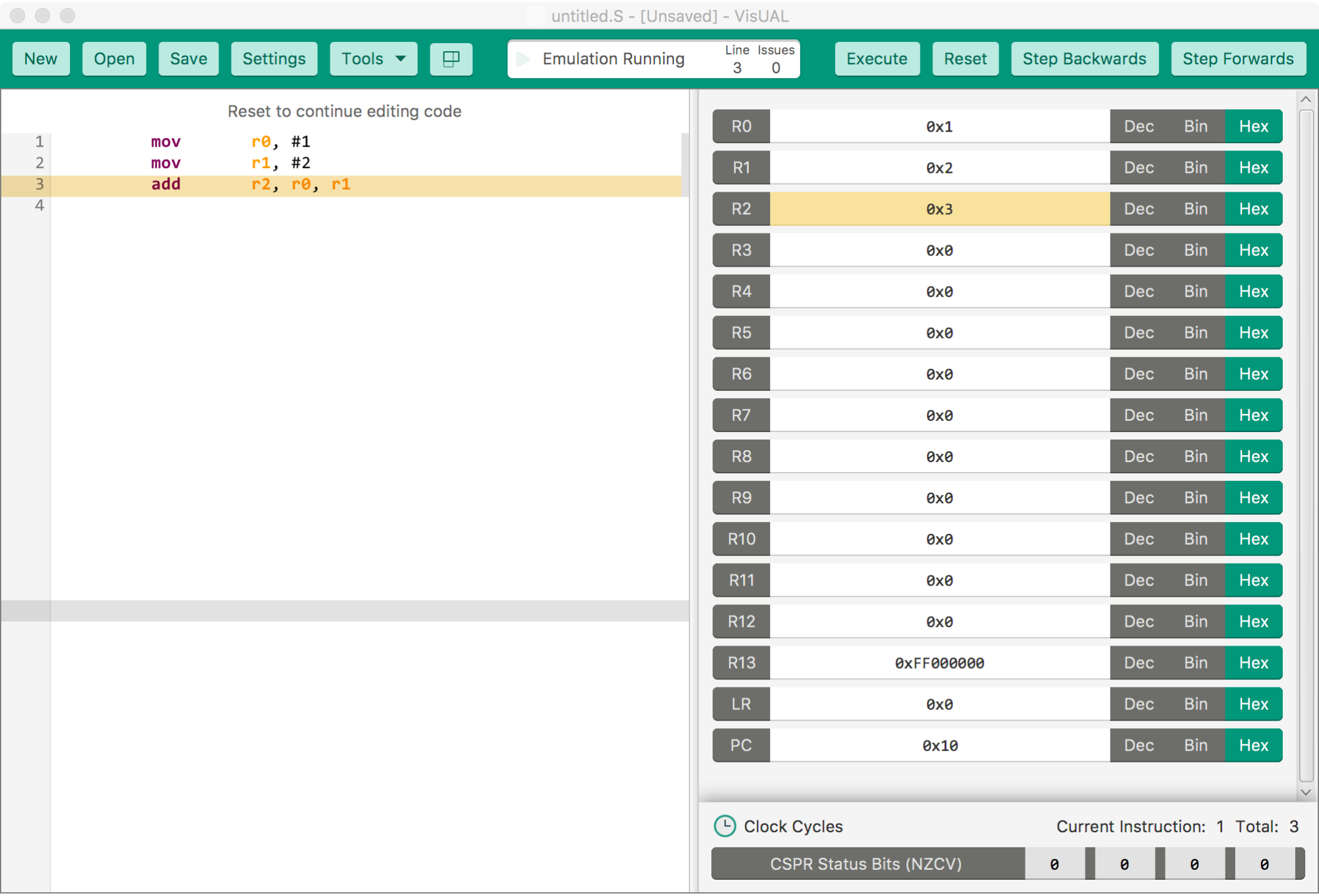
```
# Assemble (.s) into 'object' file (.o)
% arm-none-eabi-as add.s -o add.o

# Create binary (.bin)
% arm-none-eabi-objcopy add.o -O binary add.bin

# Find size (in bytes)
% ls -l add.bin
-rw-r--r--+ 1 hanrahan  staff  4 add.bin

# Dump binary in hex
% hexdump add.bin
0000000: 02 00 81 e0
```


Memory
Value (#1) stored in INST
INST
DATA
Registers
1
+
ADDR
r1
ALU
r0
ADDR
add r0, r1, #1



mov r0, #1

VisUAL


untitled.S - [Unsaved] - VisUAL
New
Open
Save
Settings
Tools
Emulation Running
Line 3
Issues 0
Execute
Reset
Step Backwards
Step Forwards
Reset to continue editing code
1 mov r0, #1
2 mov r1, #2
3 add r2, r0, r1
4
R0 0x1 Dec Bin Hex
R1 0x2 Dec Bin Hex
R2 0x3 Dec Bin Hex
R3 0x0 Dec Bin Hex
R4 0x0 Dec Bin Hex
R5 0x0 Dec Bin Hex
R6 0x0 Dec Bin Hex
R7 0x0 Dec Bin Hex
R8 0x0 Dec Bin Hex
R9 0x0 Dec Bin Hex
R10 0x0 Dec Bin Hex
R11 0x0 Dec Bin Hex
R12 0x0 Dec Bin Hex
R13 0xFF000000 Dec Bin Hex
LR 0x0 Dec Bin Hex
PC 0x10 Dec Bin Hex
Clock Cycles
Current Instruction: 1 Total: 3
CSPR Status Bits (NZCV) 0 0 0 0

Conceptual Questions

1. **Suppose your program starts at `0x8000`, what assembly language program will jump to and start executing instructions at that location.**

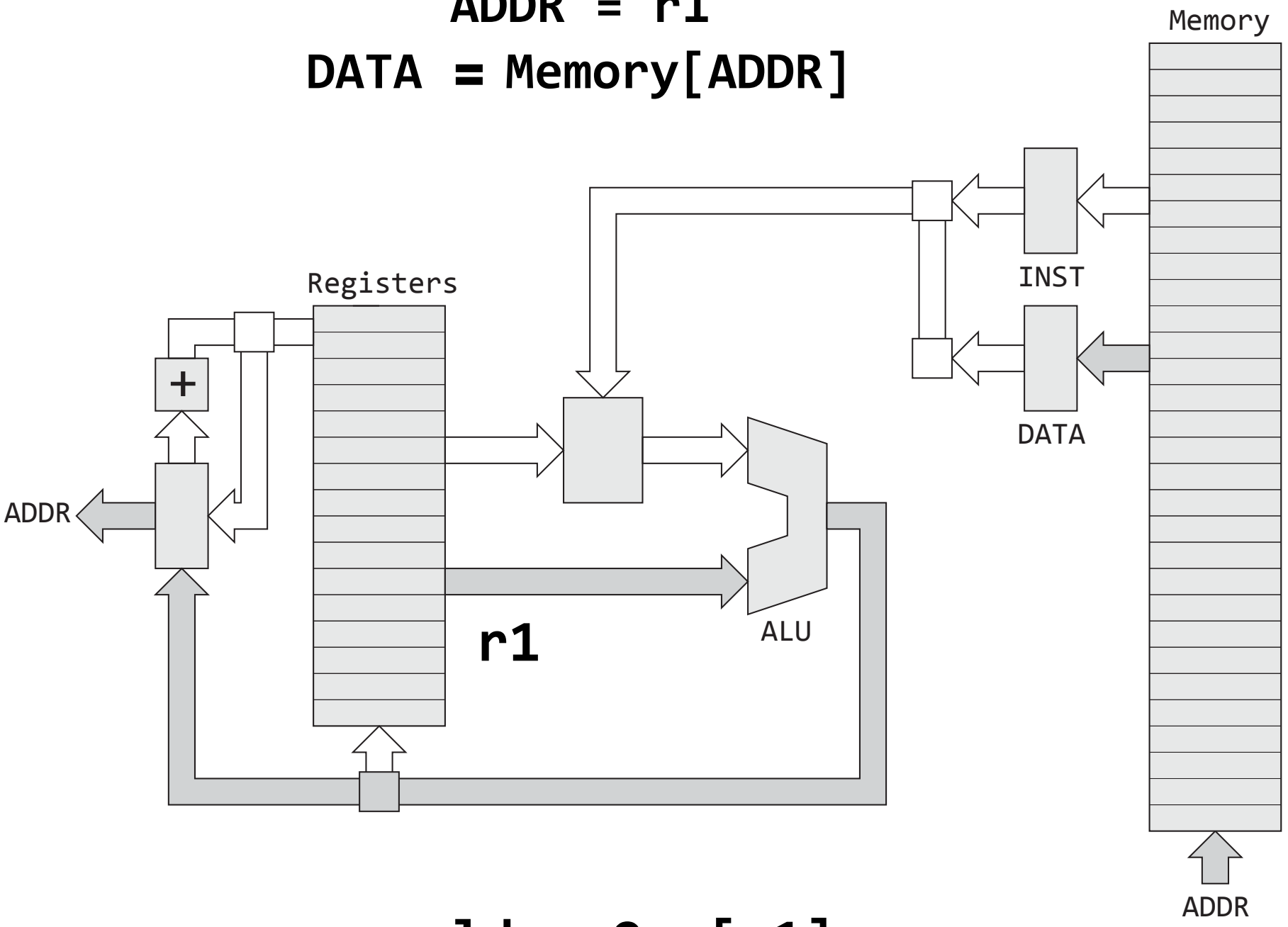
2. **All instructions are 32-bits. Can you `mov` any 32-bit constant value to a register using the `mov` instruction?**

3. **What are some advantages of always using 32-bits for instructions, addresses, and data?**

Load and Store Instructions

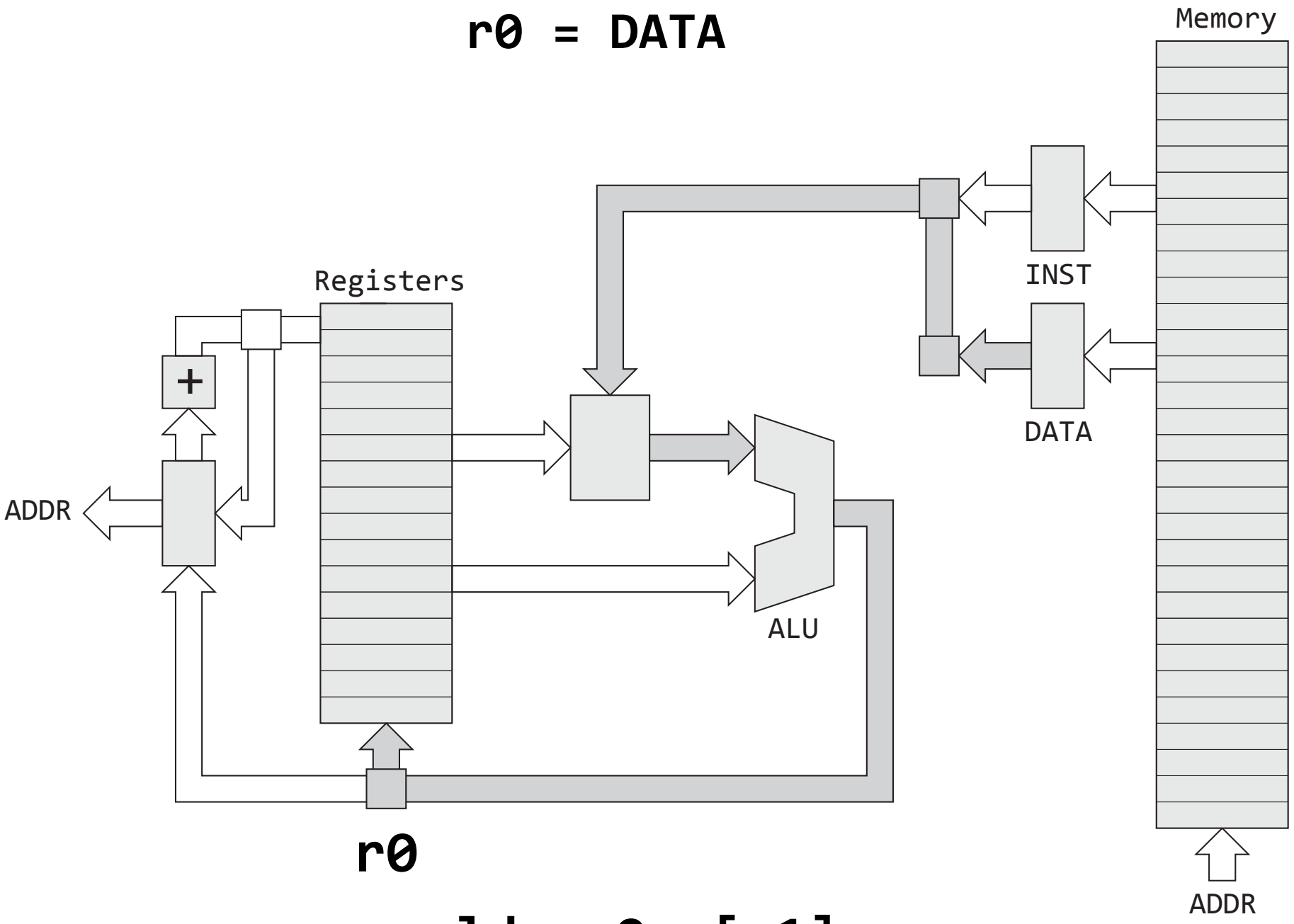
ADDR = r1

DATA = Memory[ADDR]

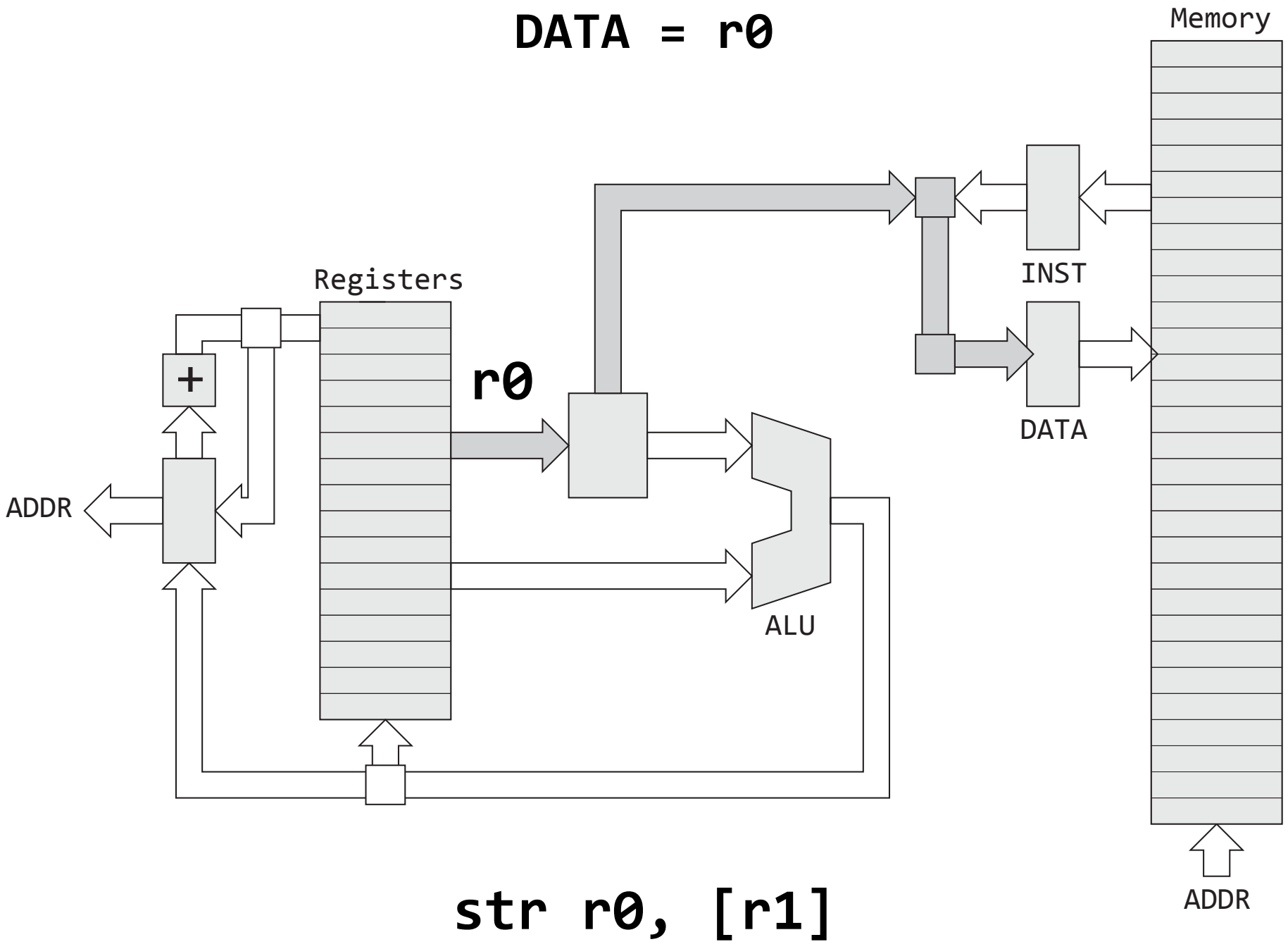


ldr r0, [r1]

r0 = DATA

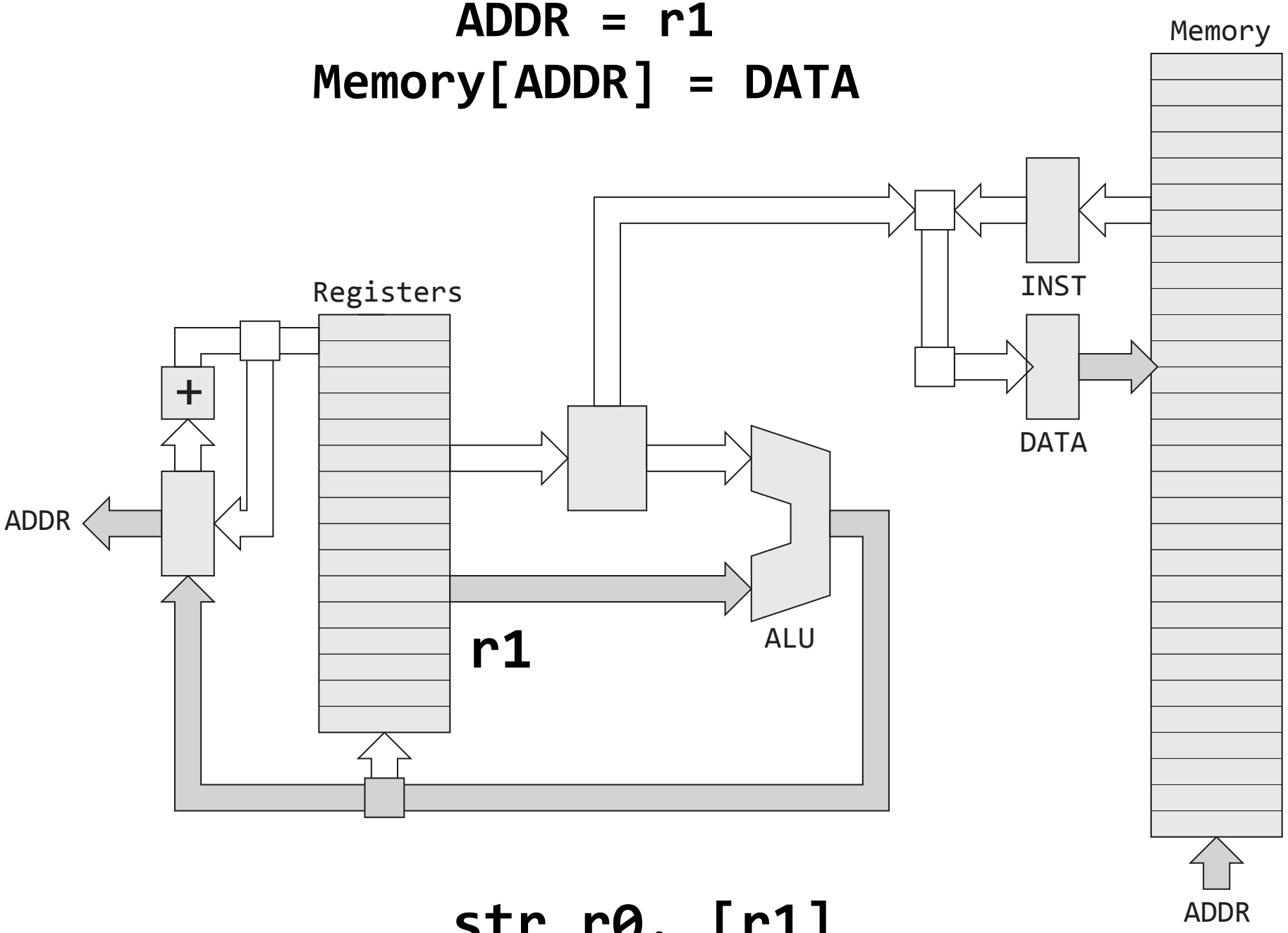


ldr r0, [r1]

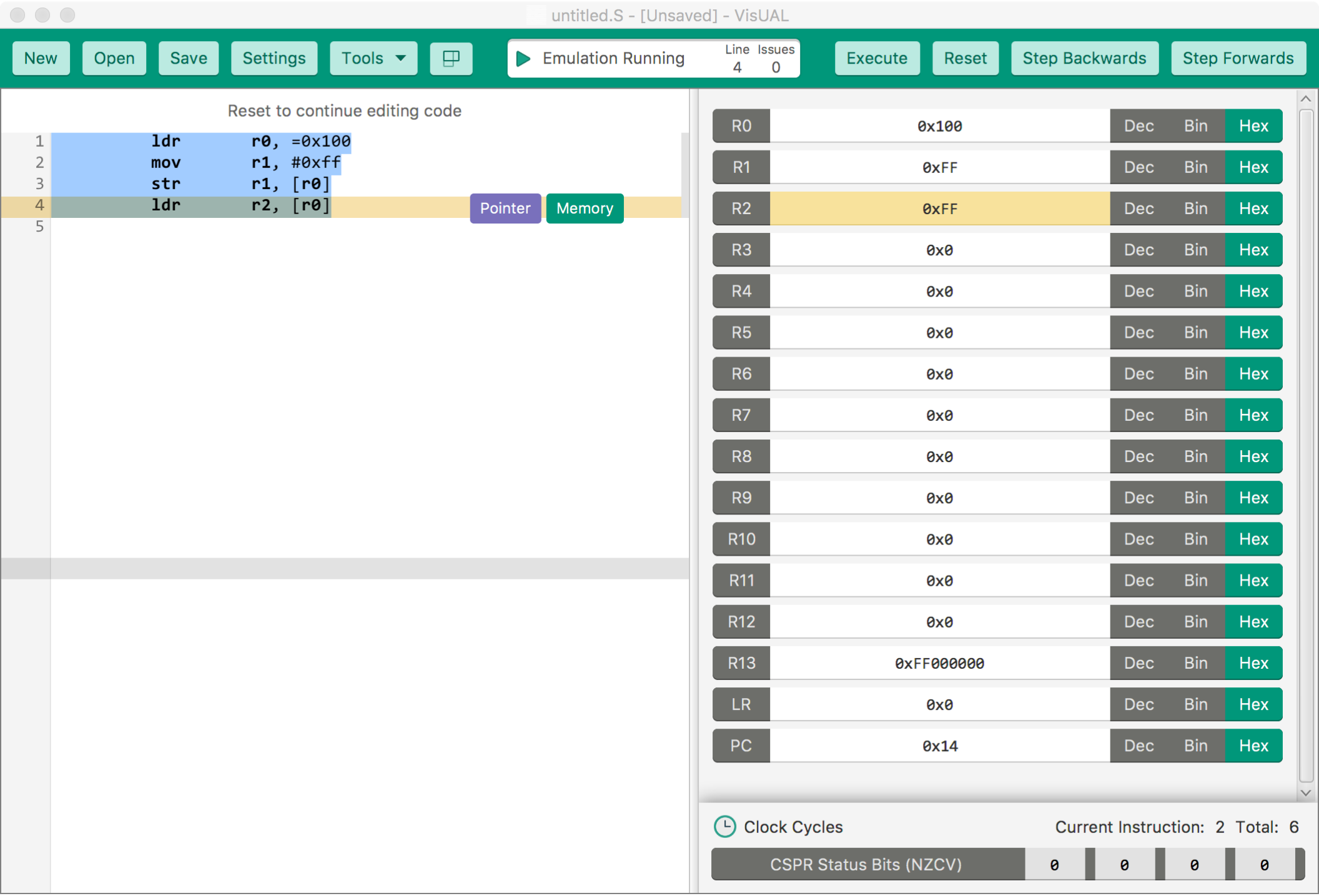

DATA = r0
Memory
INST
DATA
Registers
r0
+
ADDR
ALU
ADDR
str r0, [r1]

ADDR = r1

Memory[ADDR] = DATA

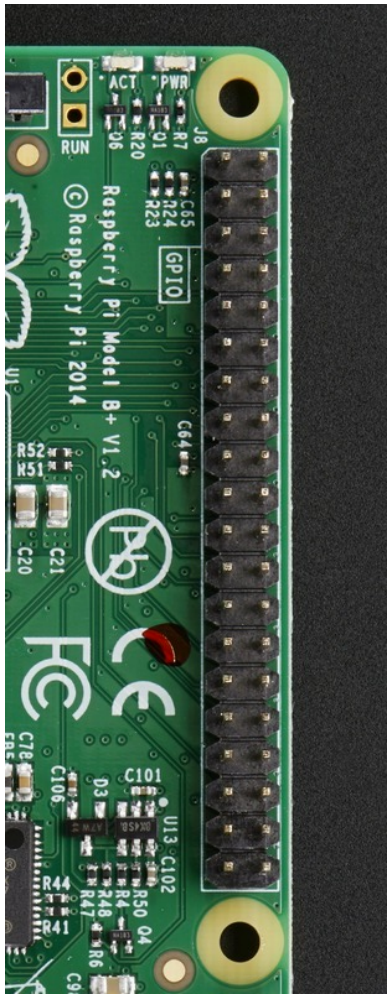


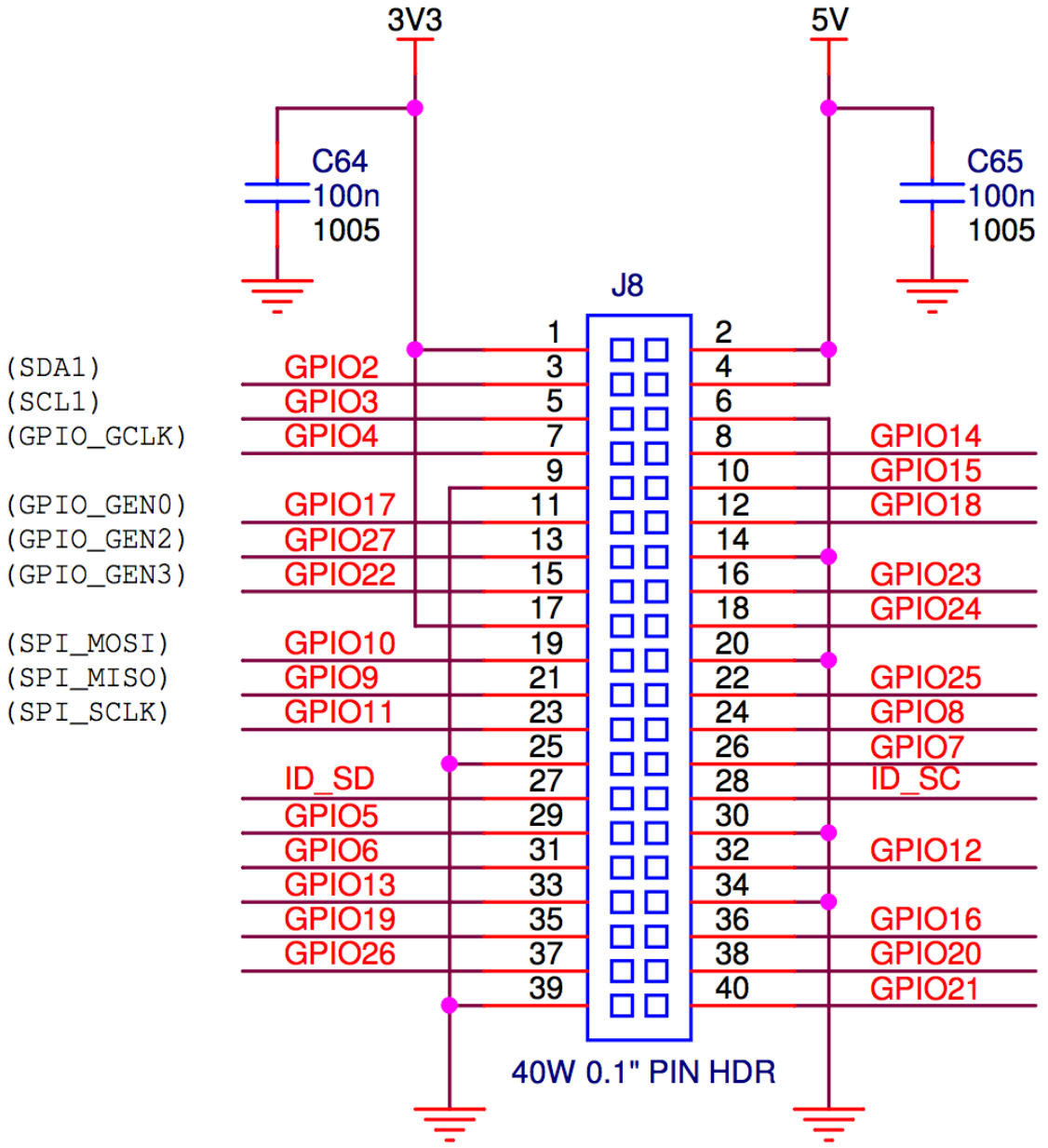
str r0, [r1]


untitled.S - [Unsaved] - VisUAL
New
Open
Save
Settings
Tools
Emulation Running
Line 4
Issues 0
Execute
Reset
Step Backwards
Step Forwards
Reset to continue editing code
1 ldr r0, =0x100
2 mov r1, #0xff
3 str r1, [r0]
4 ldr r2, [r0]
5
Pointer
Memory
R0 0x100 Dec Bin Hex
R1 0xFF Dec Bin Hex
R2 0xFF Dec Bin Hex
R3 0x0 Dec Bin Hex
R4 0x0 Dec Bin Hex
R5 0x0 Dec Bin Hex
R6 0x0 Dec Bin Hex
R7 0x0 Dec Bin Hex
R8 0x0 Dec Bin Hex
R9 0x0 Dec Bin Hex
R10 0x0 Dec Bin Hex
R11 0x0 Dec Bin Hex
R12 0x0 Dec Bin Hex
R13 0xFF000000 Dec Bin Hex
LR 0x0 Dec Bin Hex
PC 0x14 Dec Bin Hex
Clock Cycles
Current Instruction: 2 Total: 6
CSPR Status Bits (NZCV) 0 0 0 0

Turning on an LED

General-Purpose Input/Output (GPIO) Pins





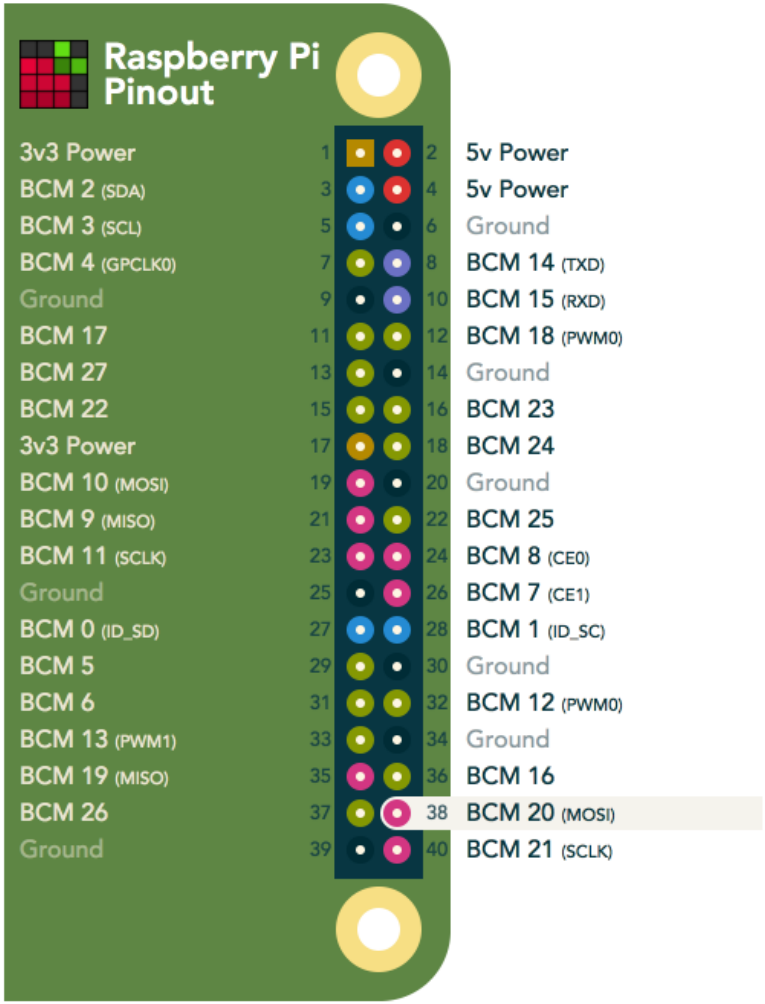
54 GPIO Pins

BCM 20 (SPI Master-Out) at Ra ×

Patrick

Secure | https://pinout.xyz/pinout/pin38_gpio20

Bookmarks | Getting Started | Bookmarks | Tableau | Feedly | Live Ships Map - AIS...



Ground | DPI | GPCLK | JTAG | 1-WIRE | PCM | SDIO | I2C | SPI | UART | WiringPi

Browse more HATs, pHATs and add-ons »

Arcade Bonnet
Connect joystick, buttons and speakers to your Pi

MotoZero
Control 4 motors from your Raspberry Pi

XBee Shield
Use XBee modules with the Raspberry Pi

Score:Zero
A super-simple and stylish soldering kit - makes an NES-style games controller when assembled.

BCM 20 (SPI Master-Out)

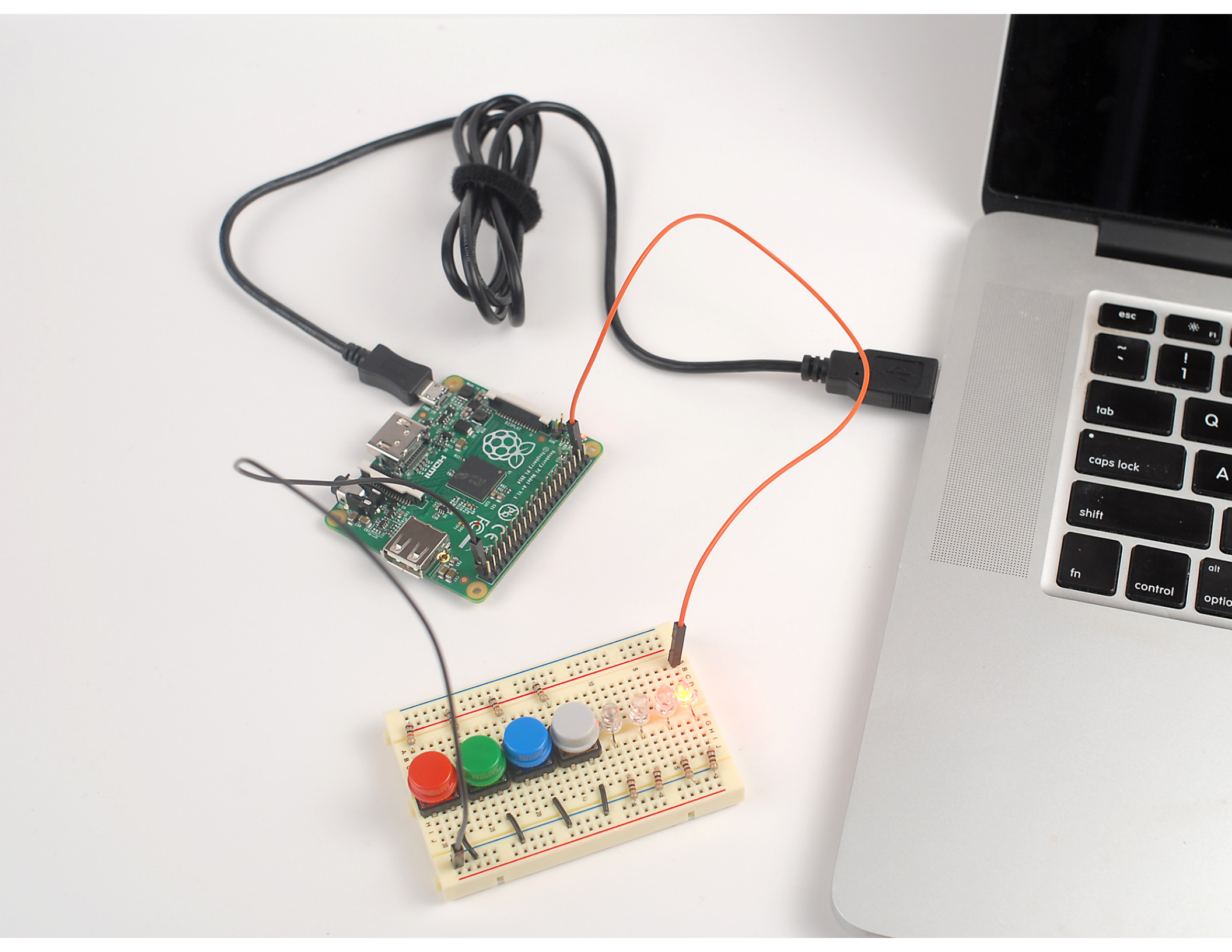
Alt0	Alt1	Alt2	Alt3	Alt4	Alt5
PCM DIN	SMI SD12	DPI D16	I2CSL MISO	SPI1 MOSI	GPCLK0

- Physical pin 38
- BCM pin 20
- Wiring Pi pin 28

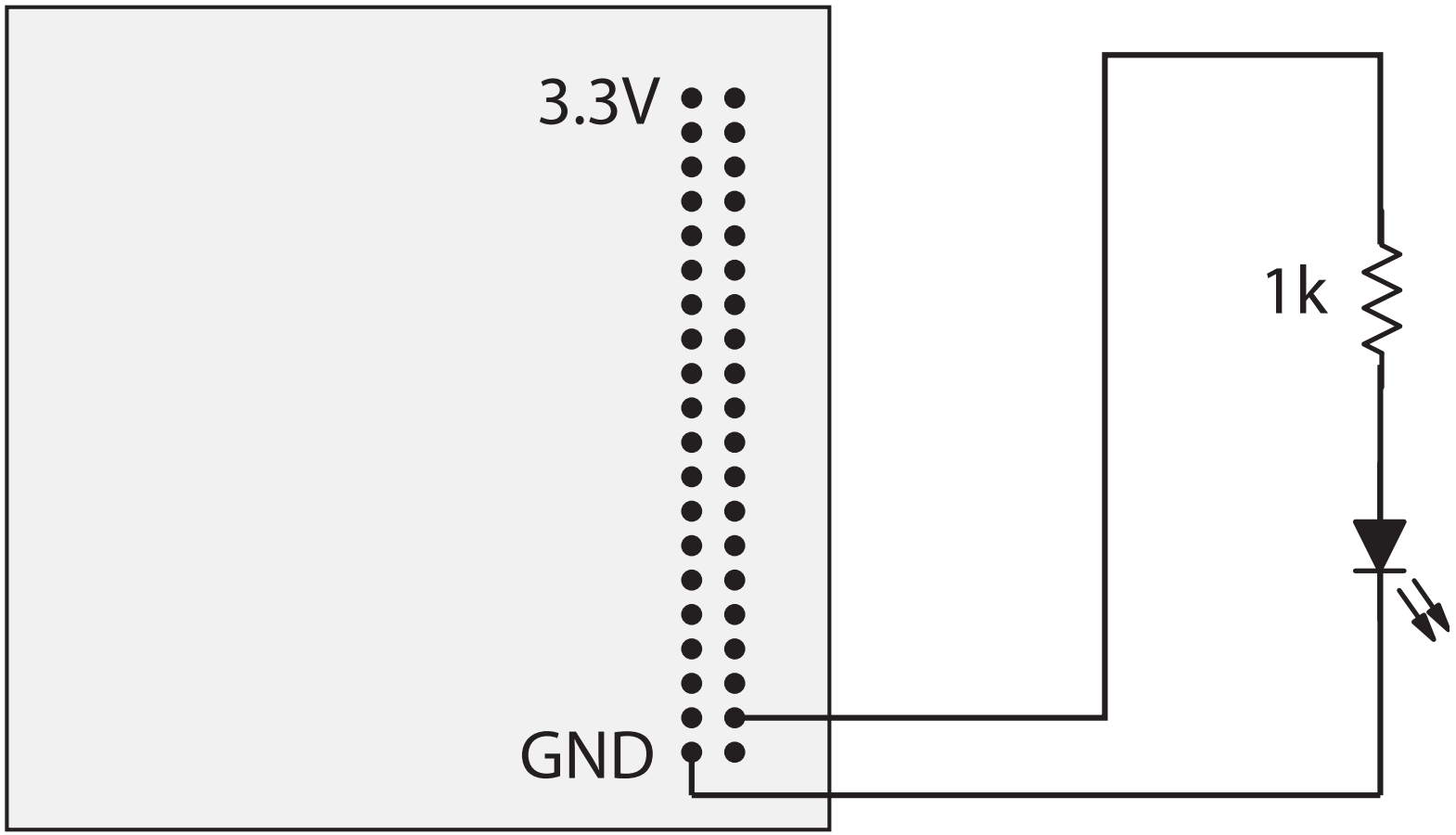
Spotted an error, want to add your board's pinout? Head on over to our GitHub repository and submit an Issue or a Pull Request!

lesson7.html

Show All


esc
tab
caps lock
shift
fn
control

Connect LED to GPIO 20



1 -> 3.3V
0 -> 0.0V (GND)

GPIO Pins are called Peripherals

Peripherals are Controlled by Special Registers

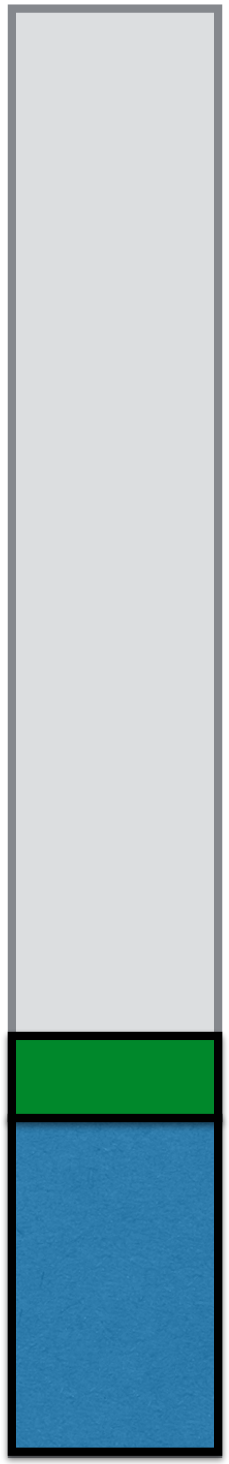
"Peripheral Registers"

Memory Map

Peripheral registers are mapped into address space

Memory-Mapped IO (MMIO)

MMIO space is above physical memory



100000000_{16}

4 GB

020000000_{16}

512 MB

Ref: BCM2835-ARM-Peripherals.pdf

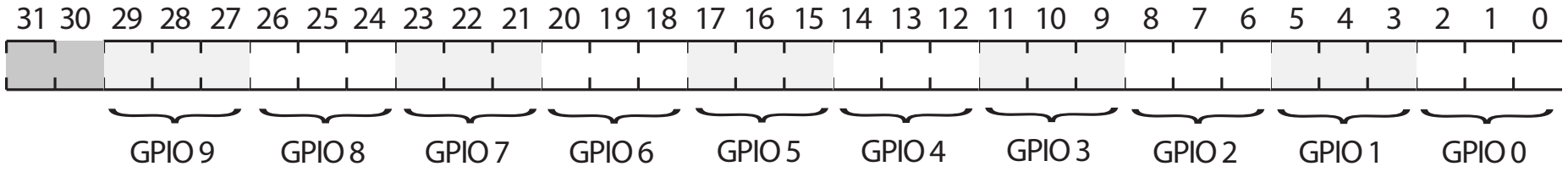
General-Purpose IO Function

GPIO Pins can be configured to be INPUT, OUTPUT, or ALT0-5

Bit pattern	Pin Function
000	The pin in an input
001	The pin is an output
100	The pin does alternate function 0
101	The pin does alternate function 1
110	The pin does alternate function 2
111	The pin does alternate function 3
011	The pin does alternate function 4
010	The pin does alternate function 5

3 bits required to select function

GPIO Function Select Register



Function is INPUT, OUTPUT, or ALT0-5

8 functions requires 3 bits to specify

10 pins per 32-bit register (2 wasted bits)

54 GPIOs pins requires 6 registers

GPIO Function Select Registers Addresses

Address	Field Name	Description	Size	Read/ Write
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0000	GPFSEL0	GPIO Function Select 0	32	R/W
0x 7E20 0004	GPFSEL1	GPIO Function Select 1	32	R/W
0x 7E20 0008	GPFSEL2	GPIO Function Select 2	32	R/W
0x 7E20 000C	GPFSEL3	GPIO Function Select 3	32	R/W
0x 7E20 0010	GPFSEL4	GPIO Function Select 4	32	R/W
0x 7E20 0014	GPFSEL5	GPIO Function Select 5	32	R/W
0x 7E20 0018	-	Reserved	-	-

```
Watch out for …
  Manual says: 0x7E200000
  Replace 7E with 20: 0x20200000
```

Ref: BCM2835-ARM-Peripherals.pdf

```
// Turn on an LED via GPIO 20

// FSEL2 = 0x20200008
mov r0, #0x20000000
orr r0, #0x00200000
orr r0, #0x00000008
mov r1, #1    // 1 indicates OUTPUT
str r1, [r0]  // store 1 to 0x20200008
```

GPIO Pin Output Set Registers (GPSETn)

SYNOPSIS The output set registers are used to set a GPIO pin. The SET{n} field defines the respective GPIO pin to set, writing a "0" to the field has no effect. If the GPIO pin is being used as in input (by default) then the value in the SET{n} field is ignored. However, if the pin is subsequently defined as an output then the bit will be set according to the last set/clear operation. Separating the set and clear functions removes the need for read-modify-write operations

Bit(s)	Field Name	Description	Type	Reset
31-0	SETn (n=0..31)	0 = No effect 1 = Set GPIO pin *n*	R/W	0

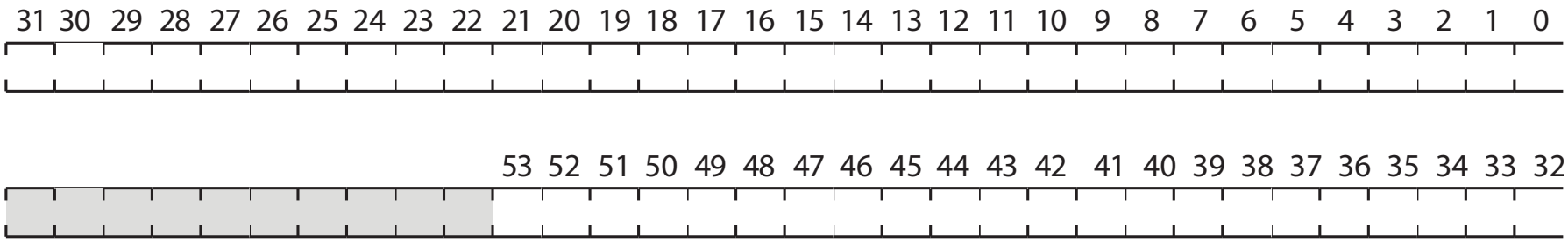
Table 6-8 – GPIO Output Set Register 0

Bit(s)	Field Name	Description	Type	Reset
31-22	-	Reserved	R	0
21-0	SETn (n=32..53)	0 = No effect 1 = Set GPIO pin *n.*	R/W	0

Table 6-9 – GPIO Output Set Register 1

GPIO Function SET Register

```
20 20 00 1C : GPIO SET0 Register
20 20 00 20 : GPIO SET1 Register
```



Notes

1. 1 bit per GPIO pin
2. 54 pins requires 2 registers

```
…

//  SET1 = 0x2020001c
mov r0, #0x20000000
orr r0, #0x00200000
orr r0, #0x0000001c
mov r1, #1
lsl r1, #20  // bit 20 = 1<<20
str r1, [r0] // store 1<<20 to 0x2020001c

// loop forever
loop:
b loop
```

```
…

//  SET0 = 0x2020001c
mov r0, #0x20000000
orr r0, #0x00200000
orr r0, #0x0000001c
mov r1, #1
lsl r1, #20  // bit 20 = 1<<20
str r1, [r0] // store 1<<20 to 0x2020001c
```

```
# What to do on your laptop

# Assemble language to machine code
% arm-none-eabi-as on.s -o on.o

# Create binary from object file
% arm-none-eabi-objcopy on.o -O binary
on.bin
```

```
# What to do on your laptop

# Insert SD card - Volume mounts
% ls /Volumes/
BARE  Macintosh HD

# Copy to SD card
% cp on.bin /Volumes/BARE/kernel.img

# Eject and remove SD card
```

```
#
# Insert SD card into SDHC slot on pi
#
# Apply power using usb console cable.
# Power LED (Red) should be on.
#
# Raspberry pi boots. ACT LED (Green)
# flashes, and then is turned off
#
# LED connected to GPIO20 turns on!!
#
```

Concepts

Memory stores both instructions and data

Bits, bytes, and words; bitwise operations

Different types of ARM instructions

- ALU
- Loads and Stores
- Branches

GPIOs, peripheral registers, and MMIO