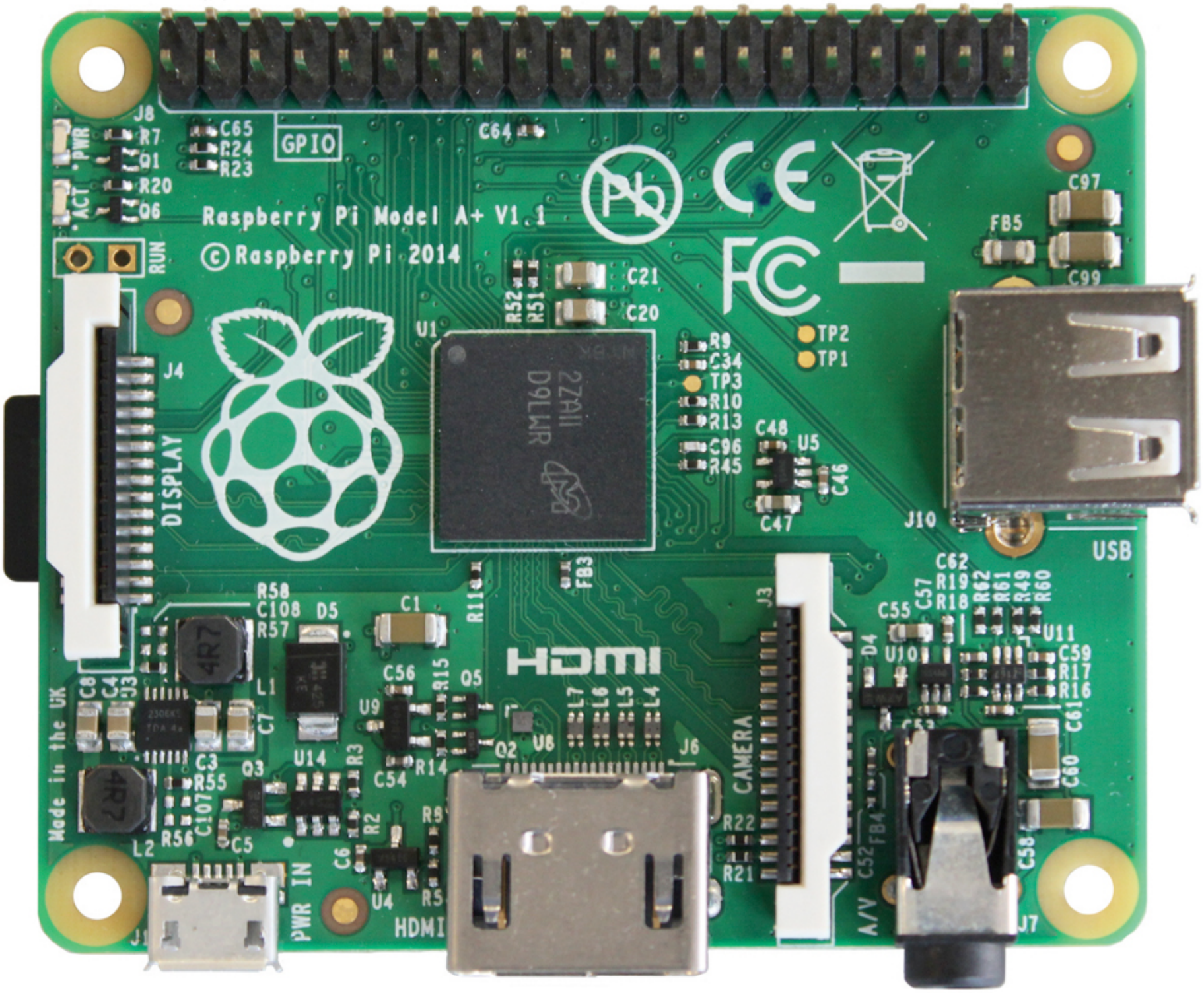
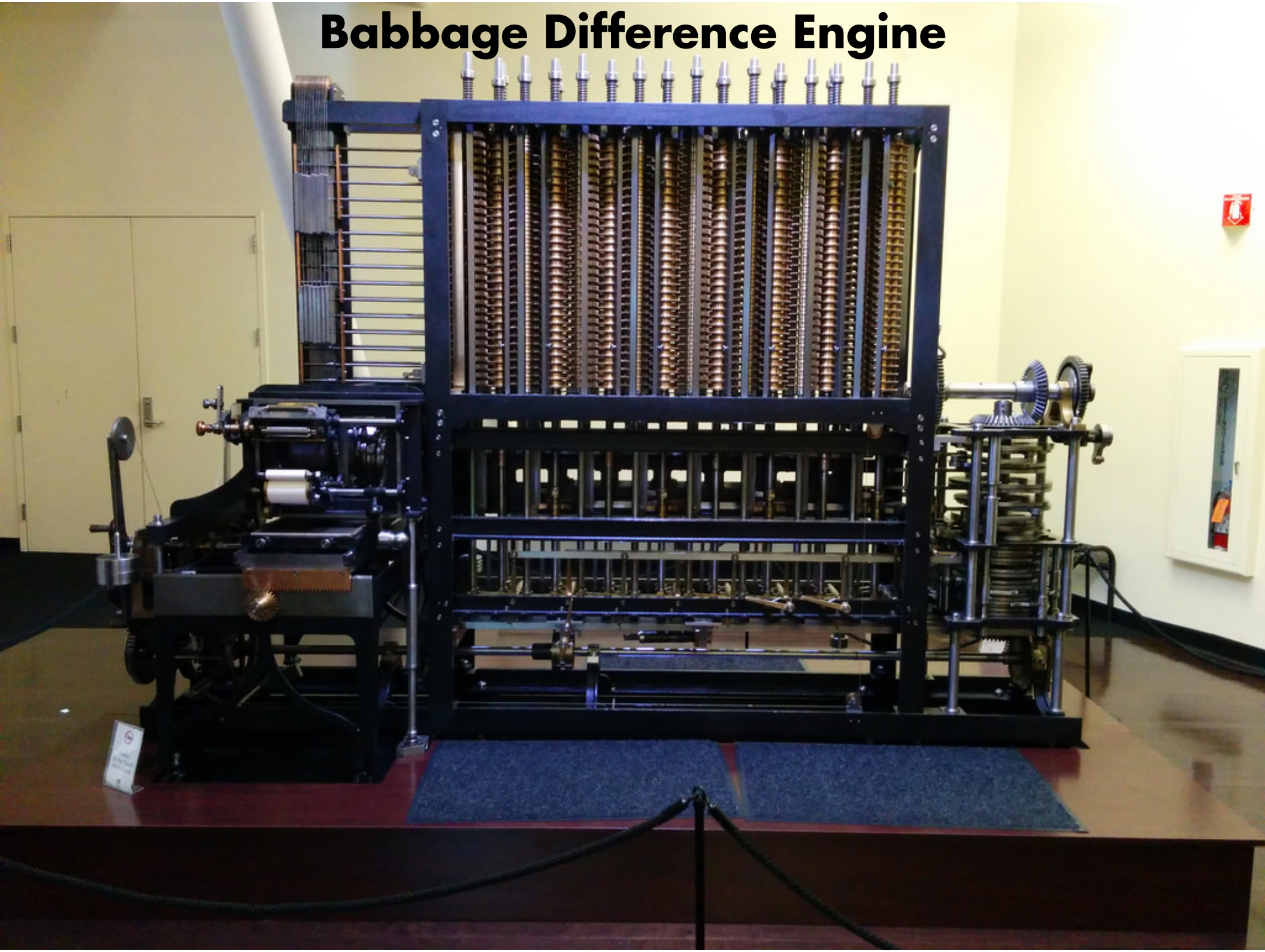
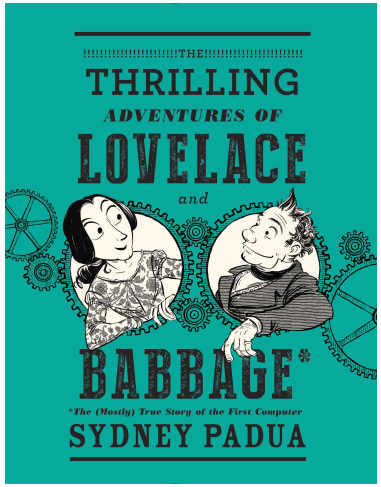
ARM
Processor and Memory Architecture

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

Babbage Difference Engine



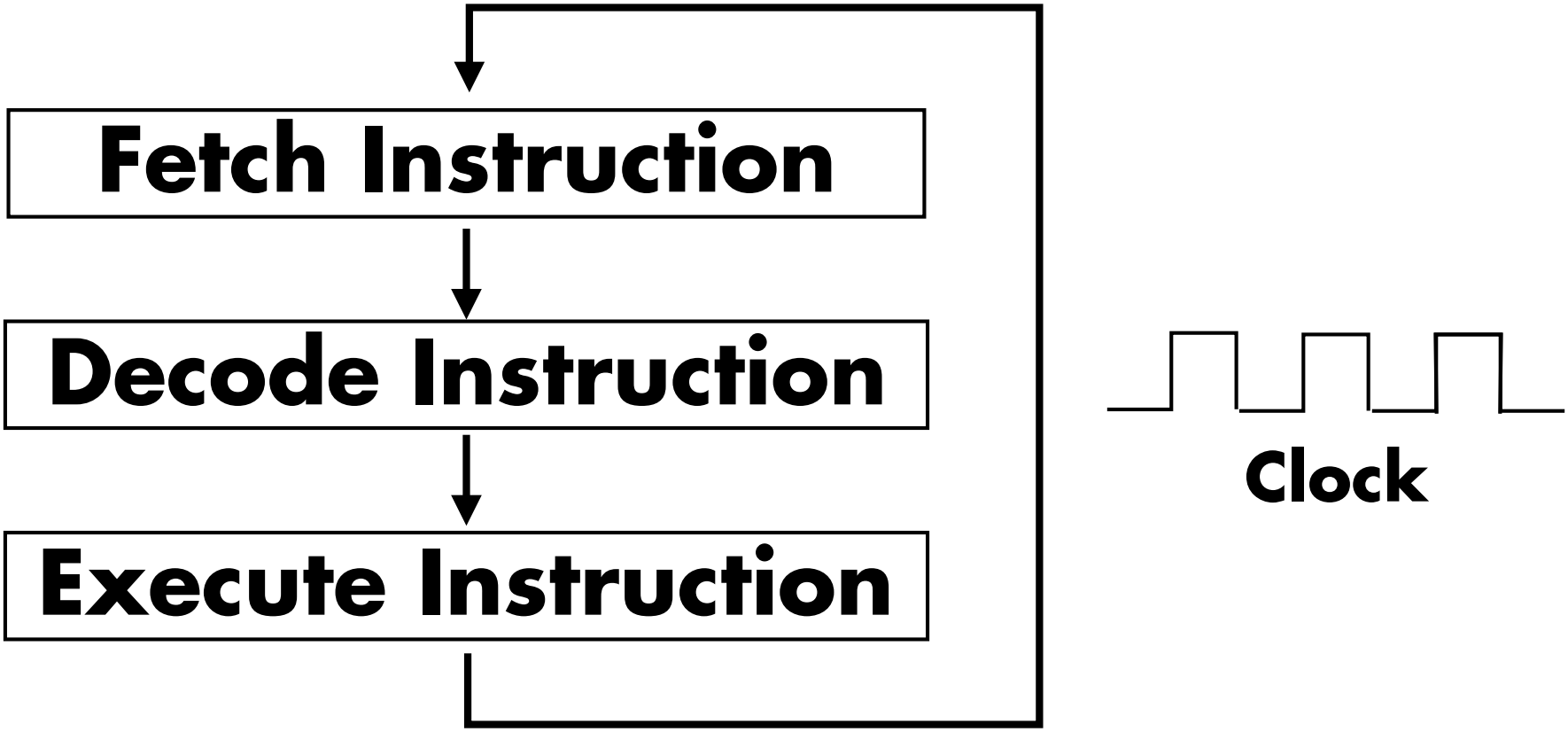


Analytical Engine

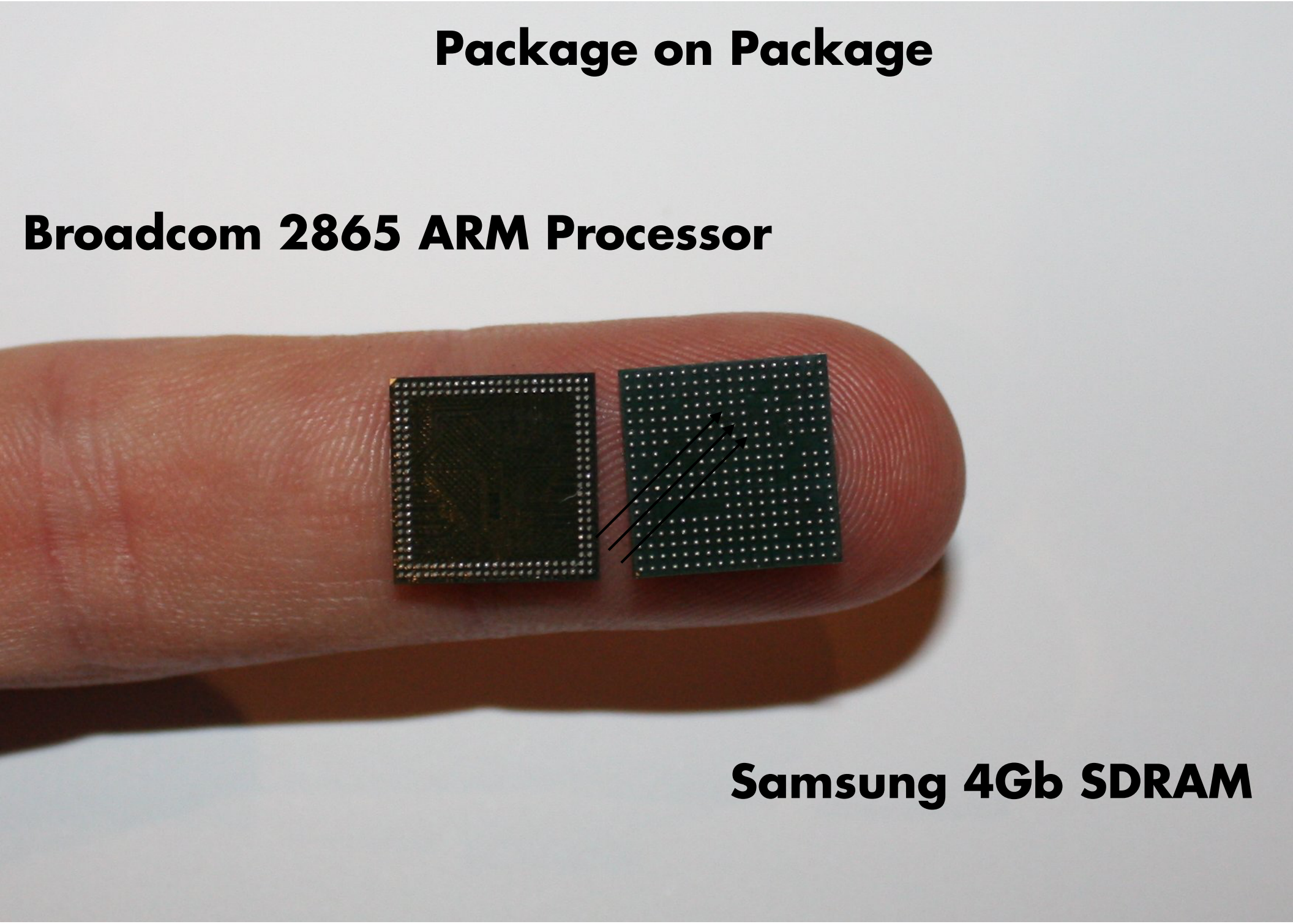
Universal Computer

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

Running a "Program"



Package on Package



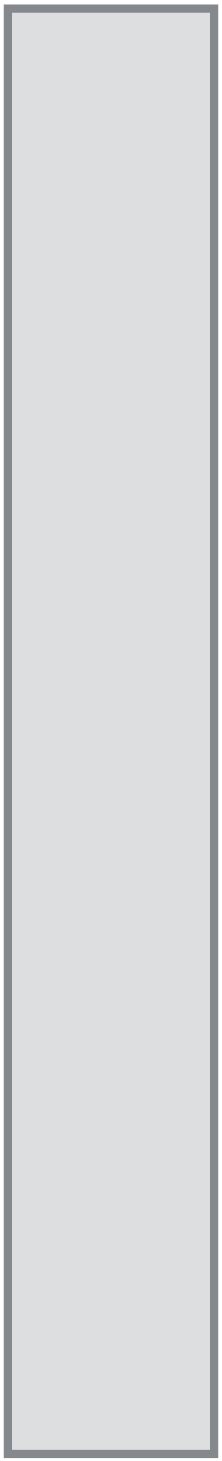
Memory used to store information

Stores both instructions and data

Storage locations are accessed using 32-bit addresses

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

Maximum addressable memory 4 GB



100000000_{16}

Memory Map

00000000_{16}

Memory used to store information

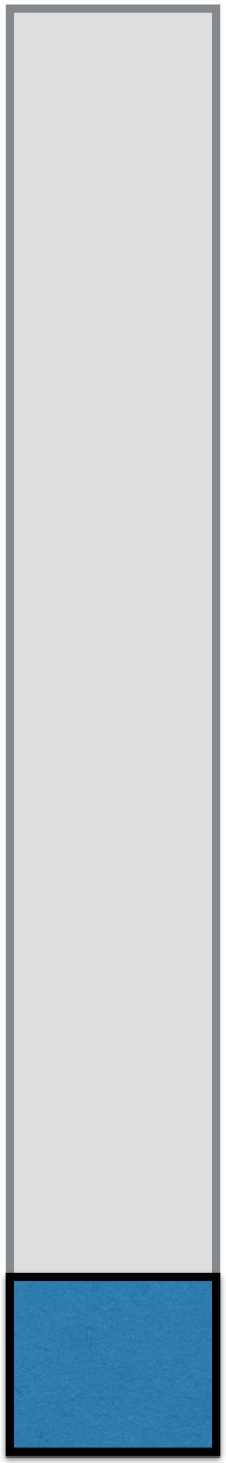
Stores both instructions and data

Storage locations are accessed using 32-bit addresses

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

Maximum addressable memory 4 GB

Actual memory is 512 MB



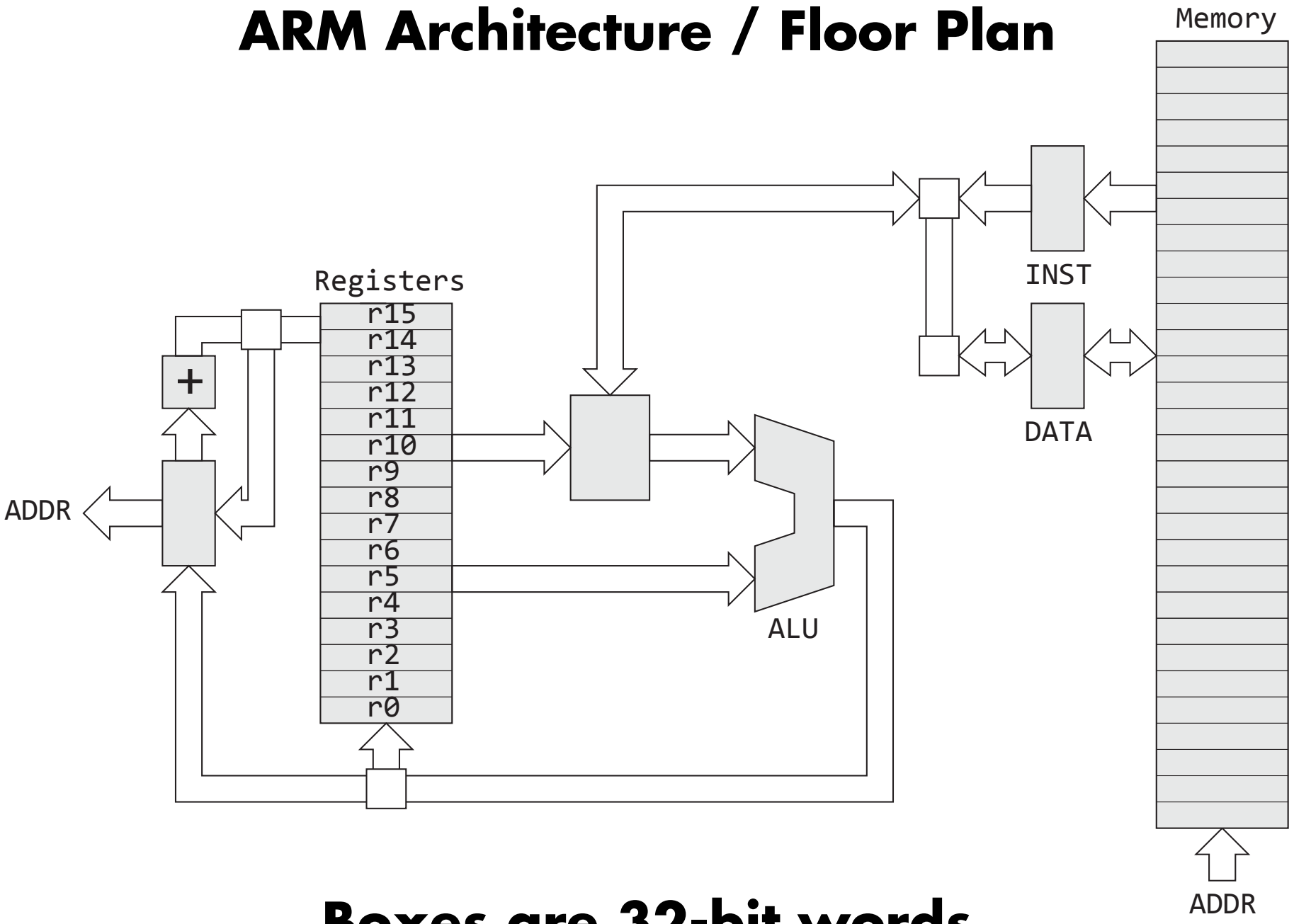
100000000_{16}

Memory Map

020000000_{16}

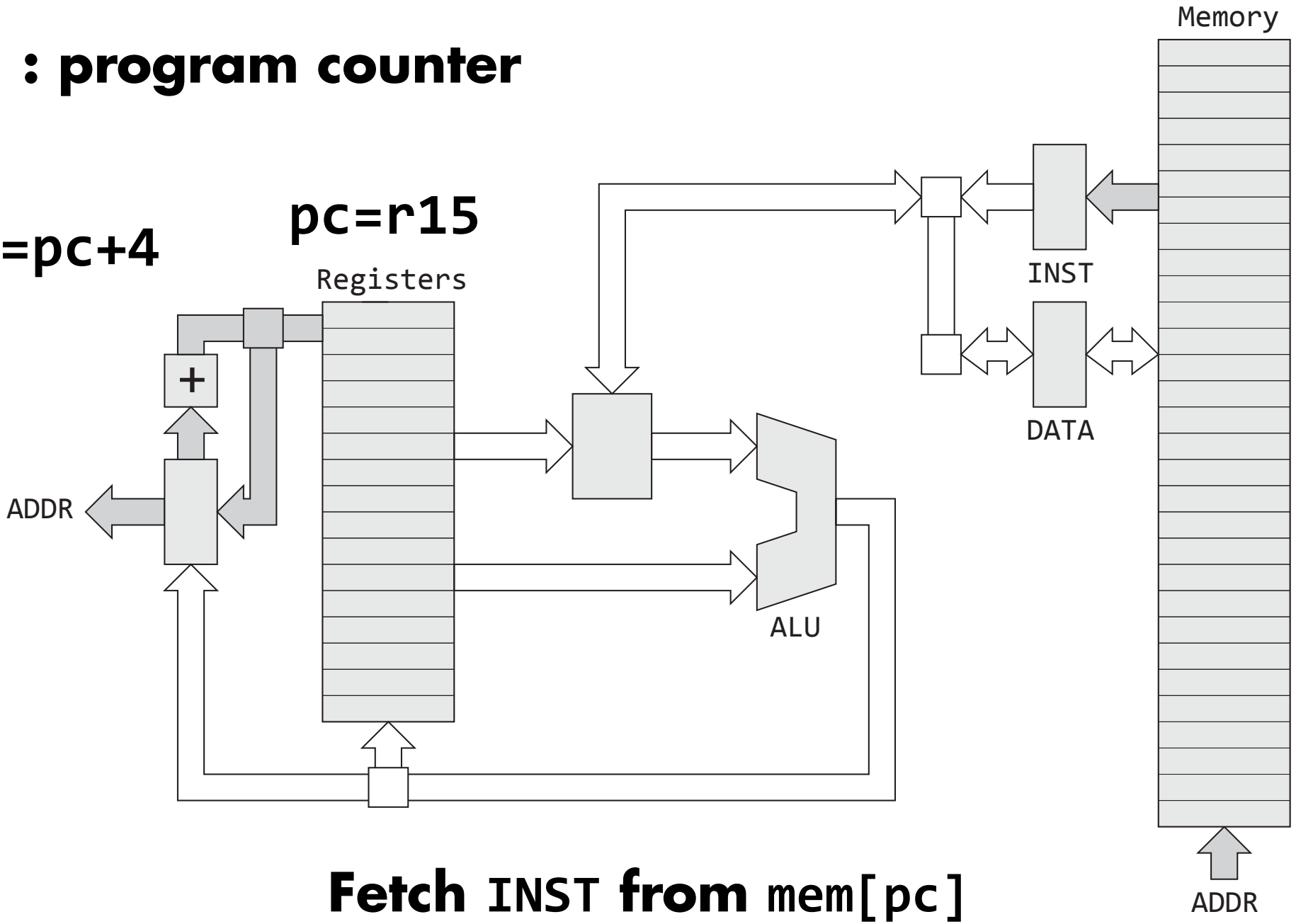
512 MB

ARM Architecture / Floor Plan



Boxes are 32-bit words

pc : program counter



Fetch INST from mem[pc]

Decode

ALU Instructions

Add Instruction

Meaning (defined as math or code)

```
r0 = r1 + r2
```

Assembly language

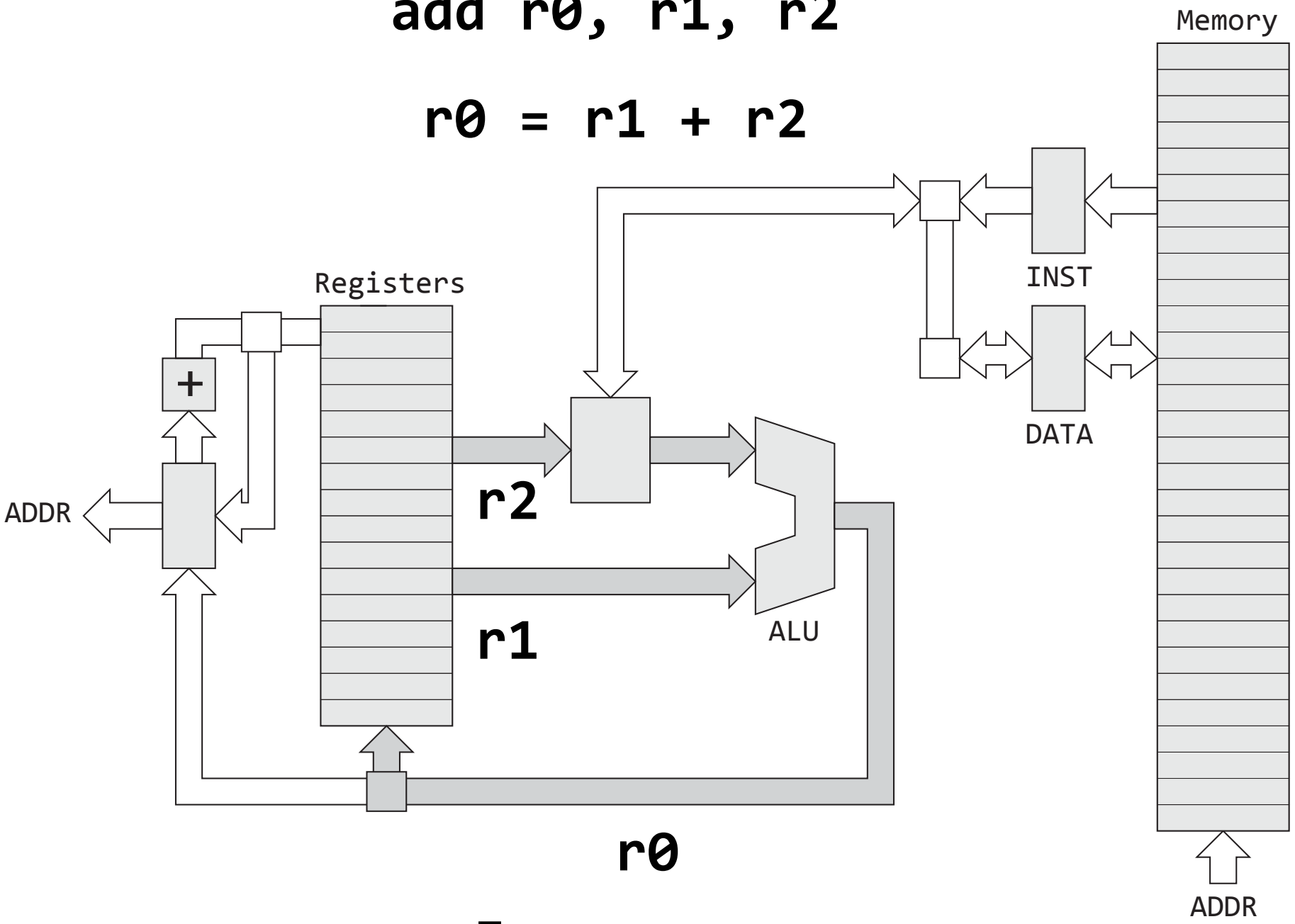
```
add r0, r1, r2
```

Machine code

```
E0 81 00 02
```

add r0, r1, r2

r0 = r1 + r2



Execute INST

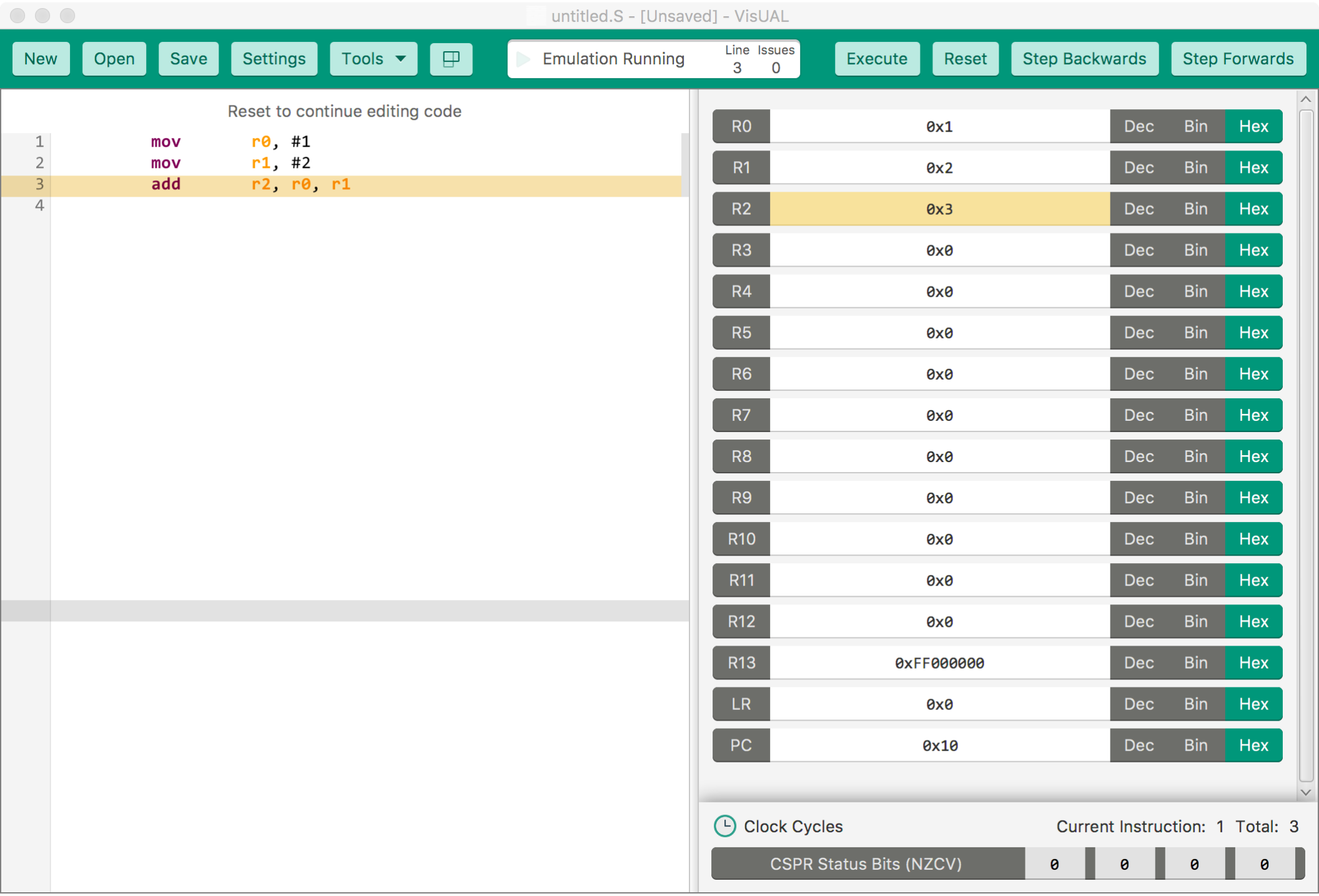
```
# Assemble (.s) into 'object' file (.o)
% arm-none-eabi-as add.s -o add.o

# Create binary (.bin)
% arm-none-eabi-objdump 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
```

VisUAL

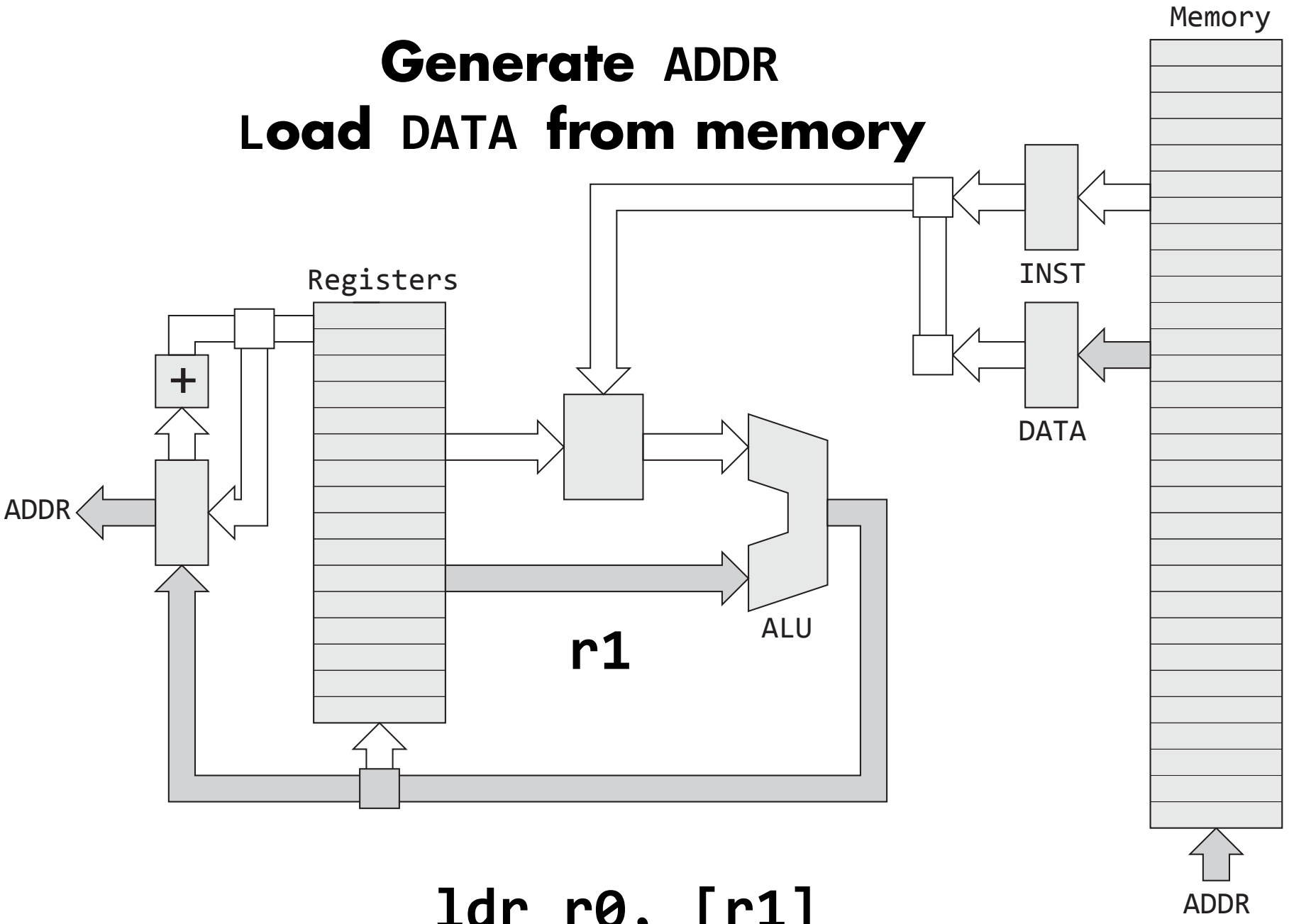

untitled.S - [Unsaved] - VisUAL
New
Open
Save
Settings
Tools
Emulation Running
Line 3
Issues 0
Execute
Reset
Step Backwards
Step Forwards
Reset to continue editing code
1 mov r0, #1
2 mov r1, #2
3 add r2, r0, r1
4
R0 0x1 Dec Bin Hex
R1 0x2 Dec Bin Hex
R2 0x3 Dec Bin Hex
R3 0x0 Dec Bin Hex
R4 0x0 Dec 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

Load and Store Instructions

r0 = mem[r1]

Generate ADDR

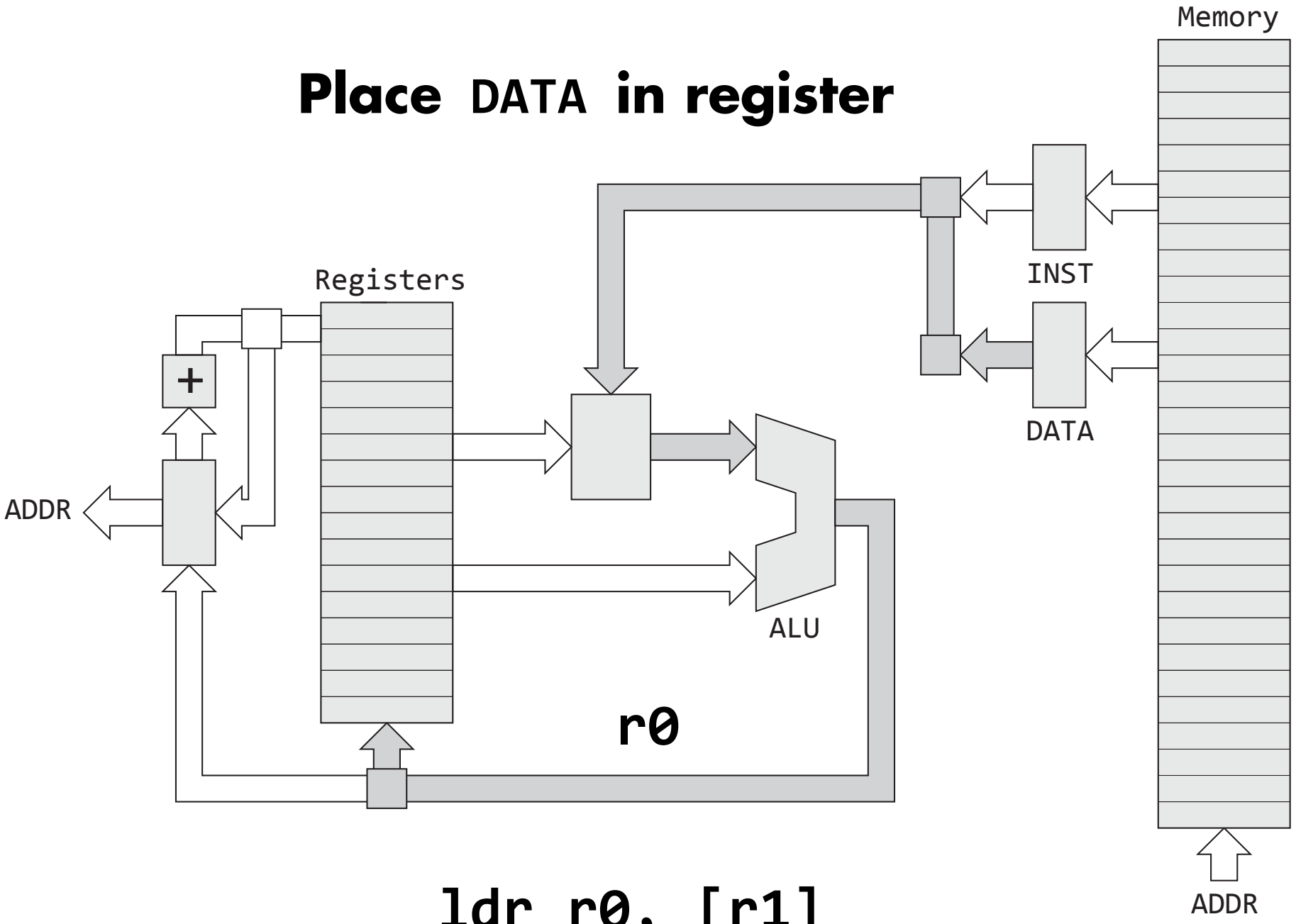
Load DATA from memory



ldr r0, [r1]

r0 = mem[r1]

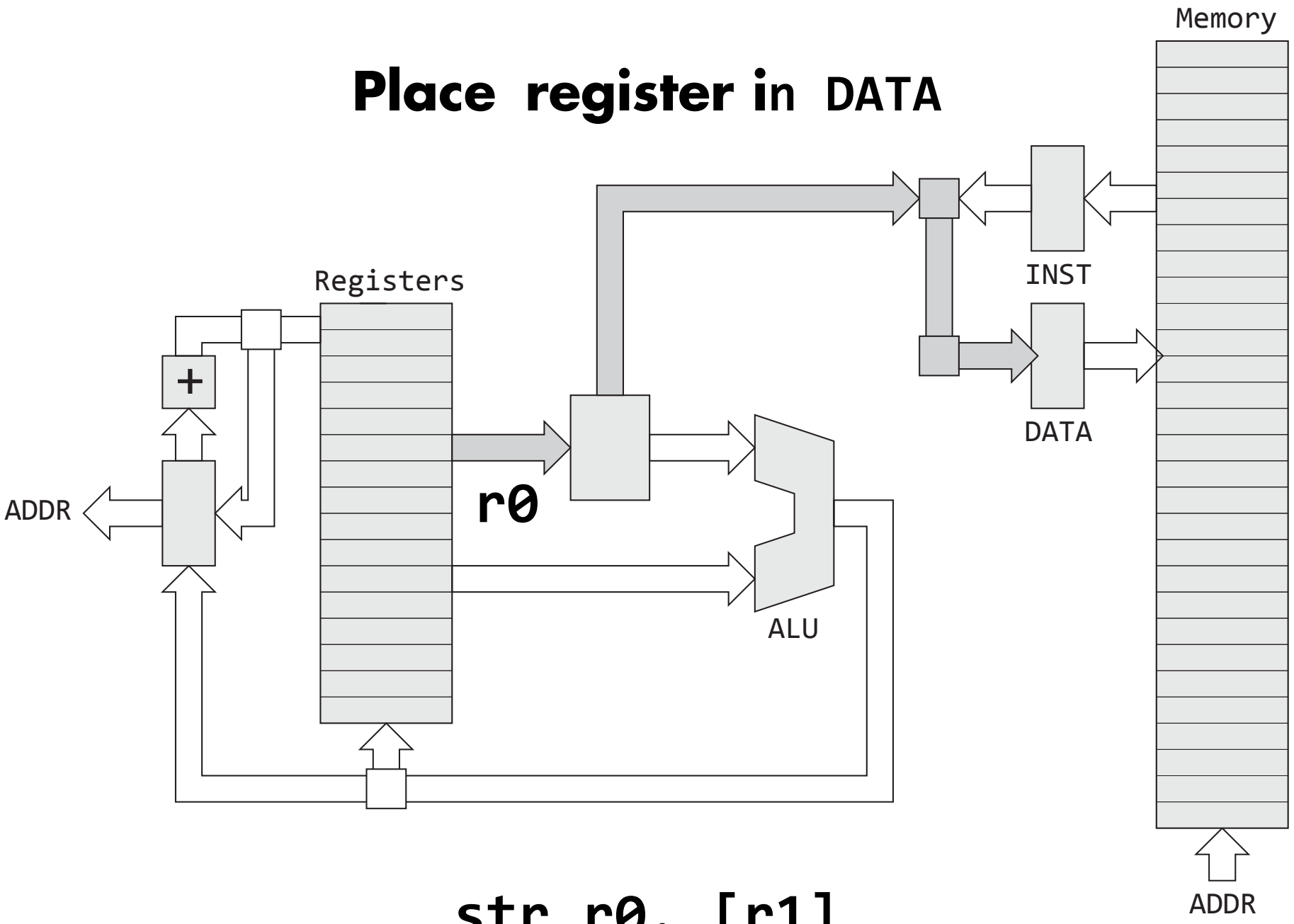
Place DATA in register



ldr r0, [r1]

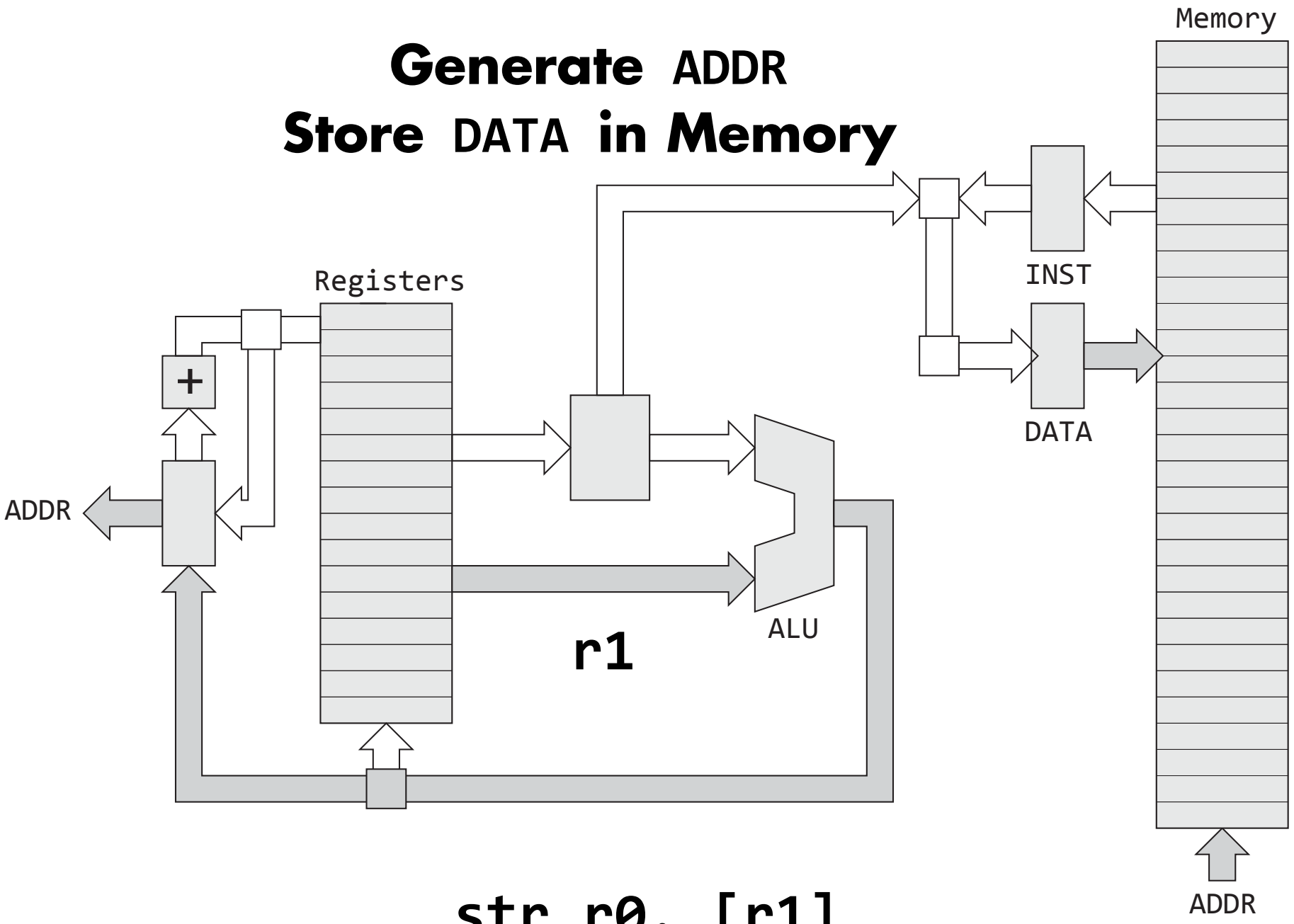
mem[r1] = r0

Place register in DATA

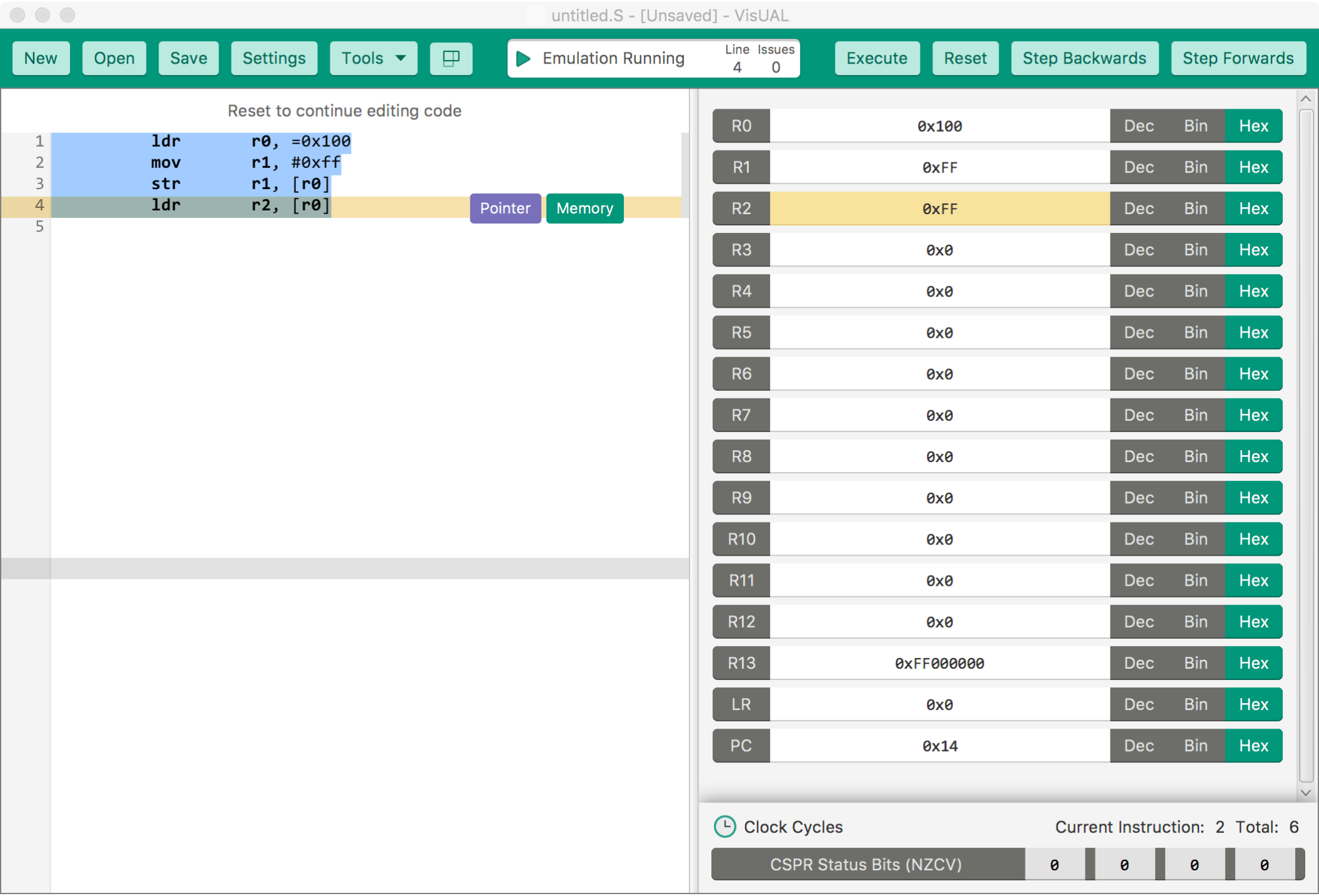


str r0, [r1]

mem[r1] = r0



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

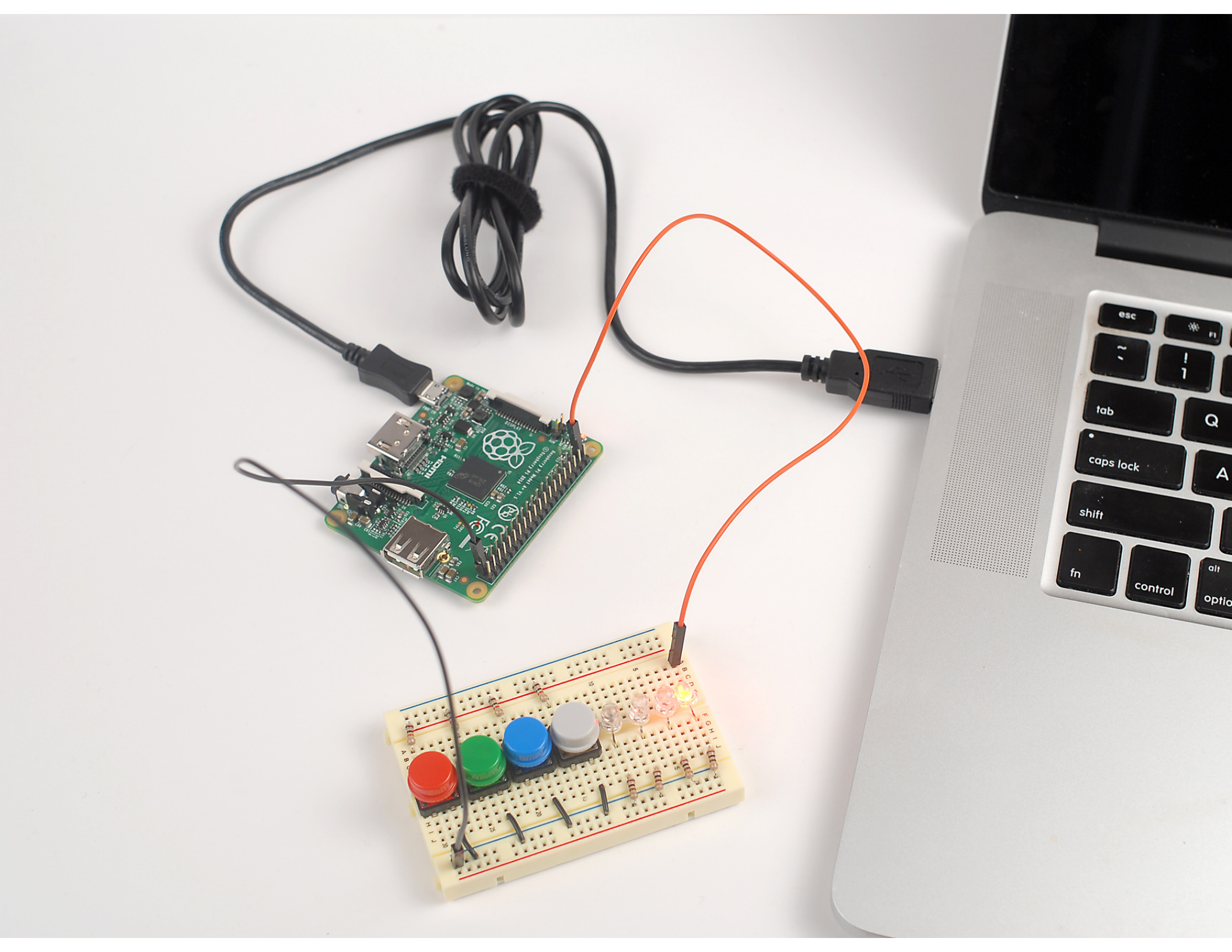
Conceptual Questions

1. Suppose your program starts at `0x8000`, how could you jump and start executing instructions at that location?

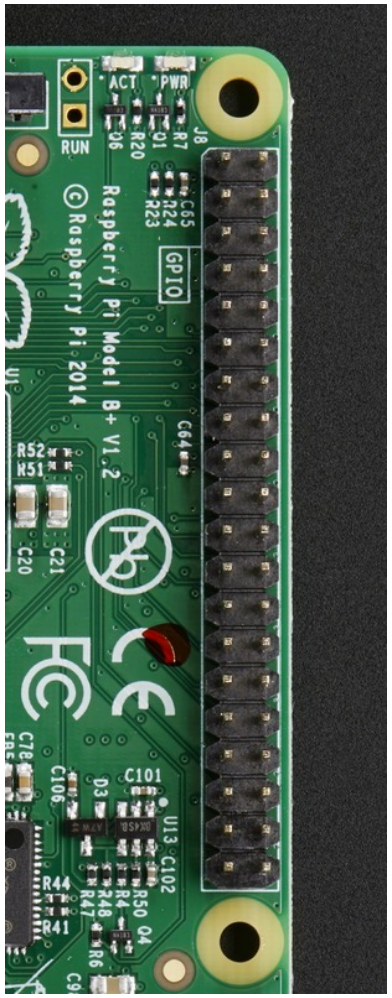
2. All instructions are 32-bits. Can you `mov` any 32-bit immediate constant to a register using the `mov` instruction?

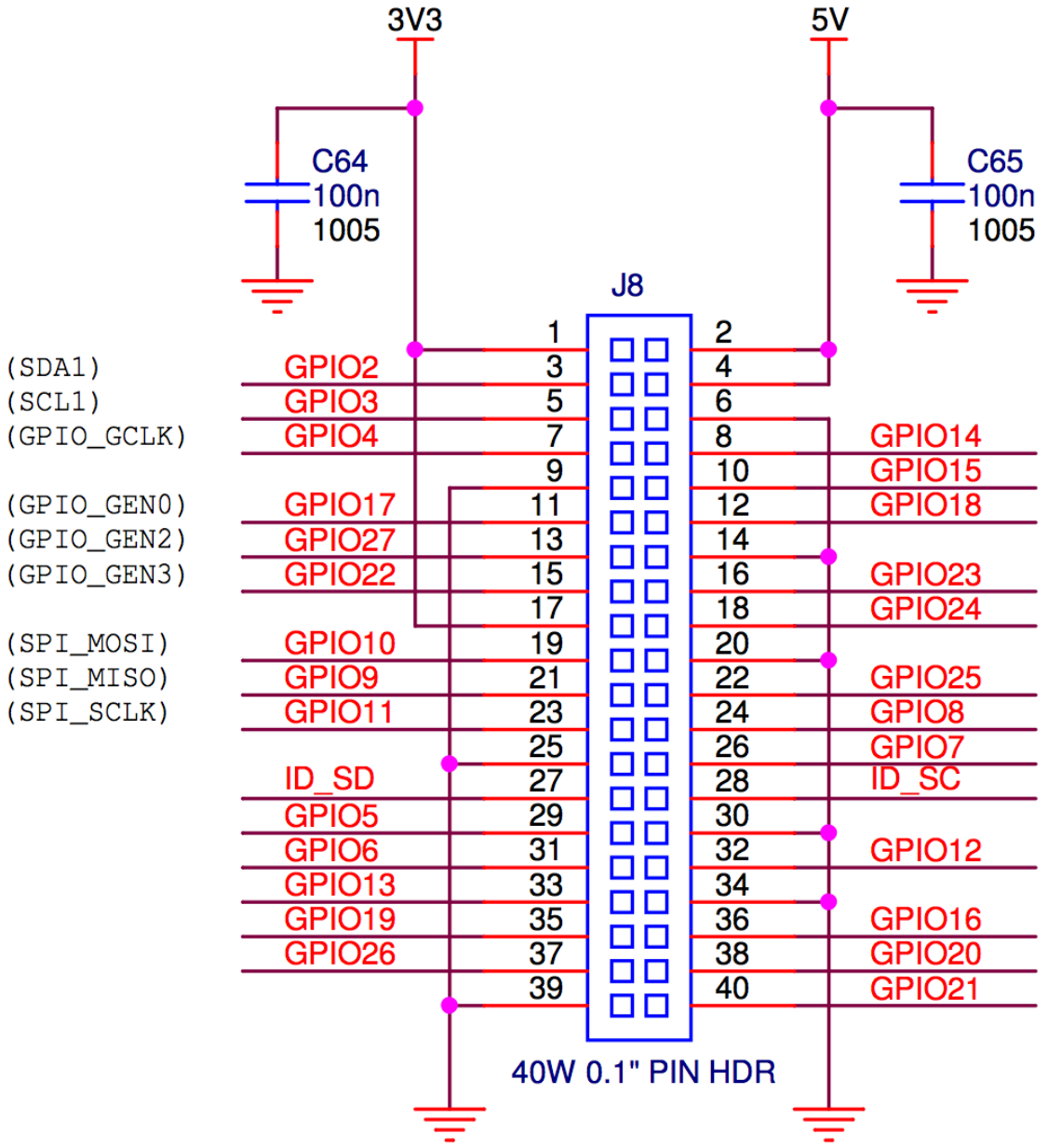
3. What instruction do you think takes longer to execute, `ldr` or `add`?

Turning on an LED


esc
tab
caps lock
shift
fn
control

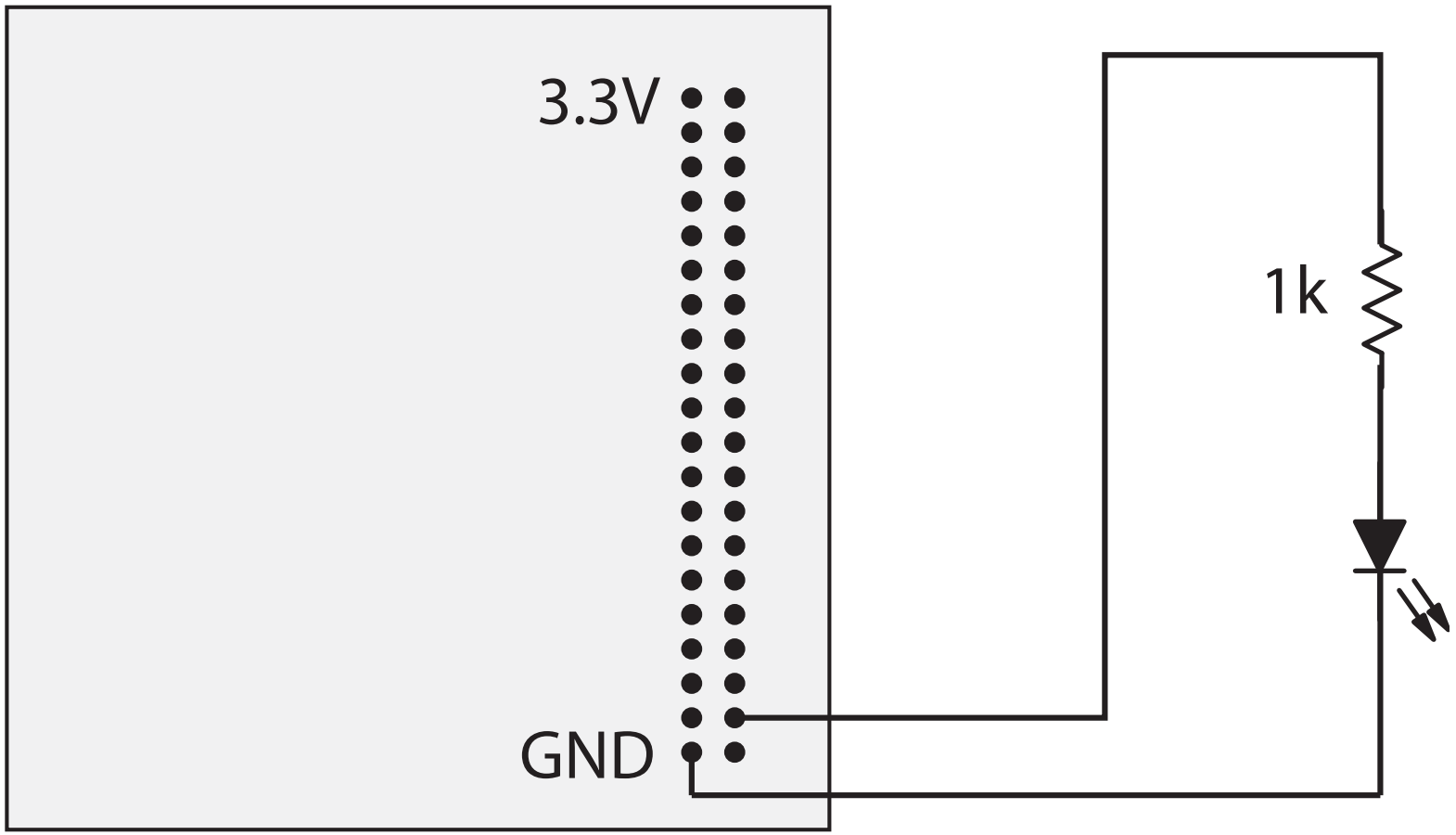
General-Purpose Input/Output (GPIO) Pins





54 GPIO Pins

Connect LED to GPIO 20

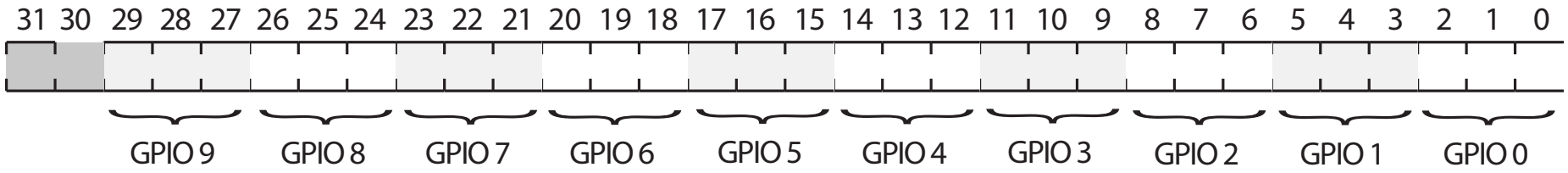


Logic 1 -> 3.3V
Logic 0 -> 0.0V (GND)

How to Control GPIO Pins?

Peripheral Registers!

GPIO Function Select Register

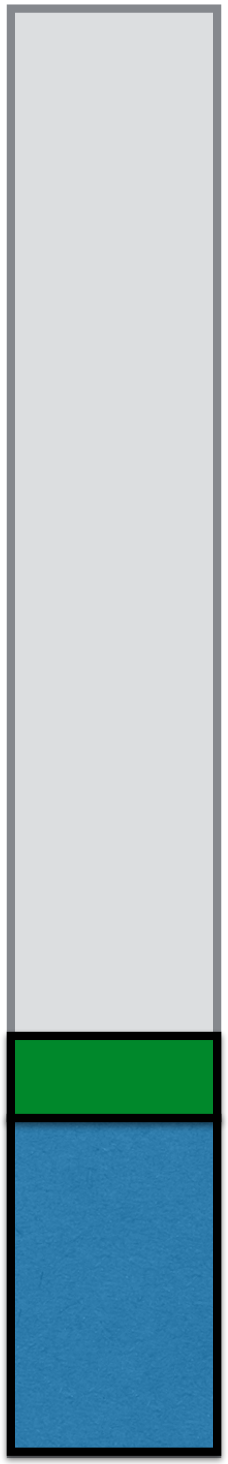


3 bits per GPIO pin

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

Max of 10 pins per 32-bit register

Memory Map



100000000_{16}

4 GB

Memory-Mapped IO (MMIO)

Peripheral Registers

020000000_{16}

Ref: BCM2835-ARM-Peripherals.pdf

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	-	-

Gotcha

Manual says: 0x7E200000

Replace 7E with 20: 0x20200000

Ref: BCM2835-ARM-Peripherals.pdf

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

// FSEL2=0x20200008 controls pins 20-29

// load r0 with GPIO FSEL2 address
ldr r0, =0x20200008

// GPIO 20 function select is bits 0-2
// The value of 1 indicates OUTPUT
// load r1 with 1
mov r1, #1

// store value in r1 to address in r0
str r1, [r0]
```

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

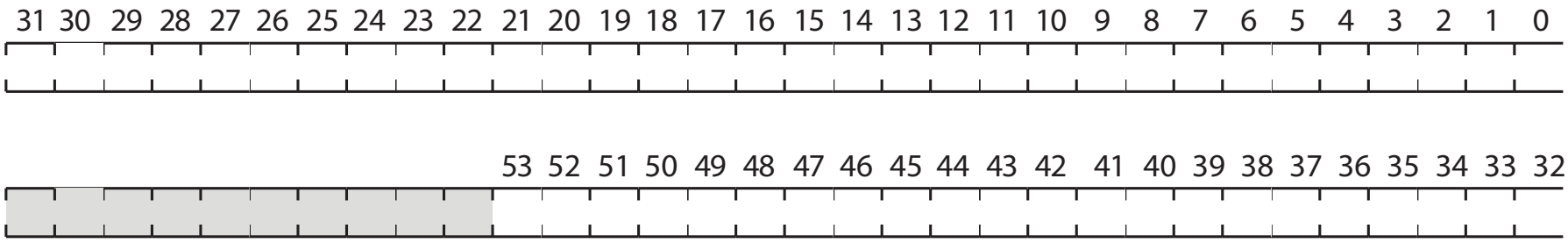
Table 6-8 – GPIO Output Set Register 0

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

```
…

// load r0 with GPIO SET0 register addr
ldr r0, =0x2020001C

// set bit 20 in r1
mov r1, #0x100000 // 0x100000 = 1 << 20

// store bit in GPIO SET0 register
str r1, [r0]
```

```
…

// load r0 with GPIO SET0 register addr
ldr r0, =0x2020001C

// set bit 20 in r1
mov r1, #0x100000 // 0x100000 = 1 << 20

// store bit in GPIO SET0 register
str r1, [r0]

// loop forever
hang: b hang
```

```
# 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!!
#
```

Next Lecture

More Instructions in Detail