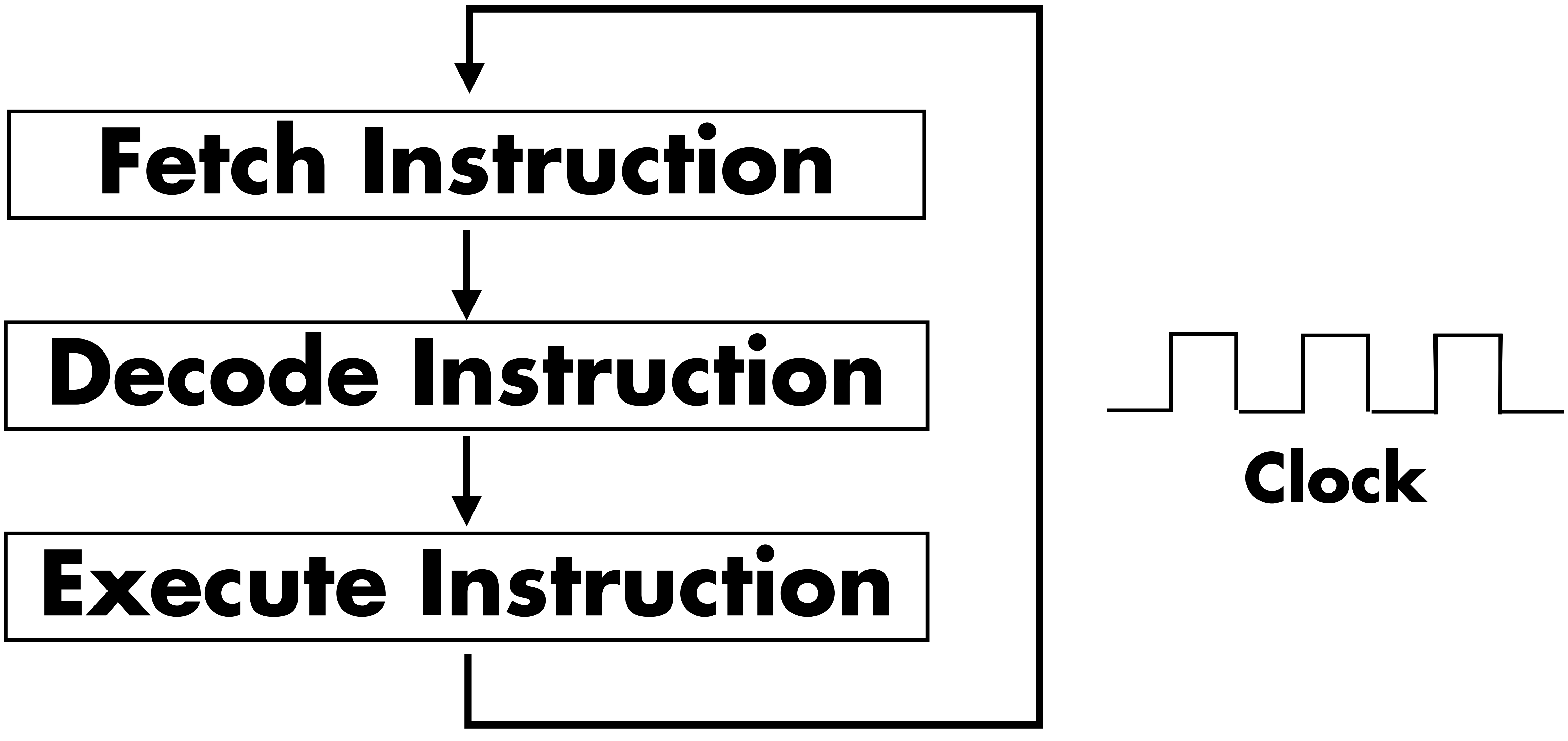
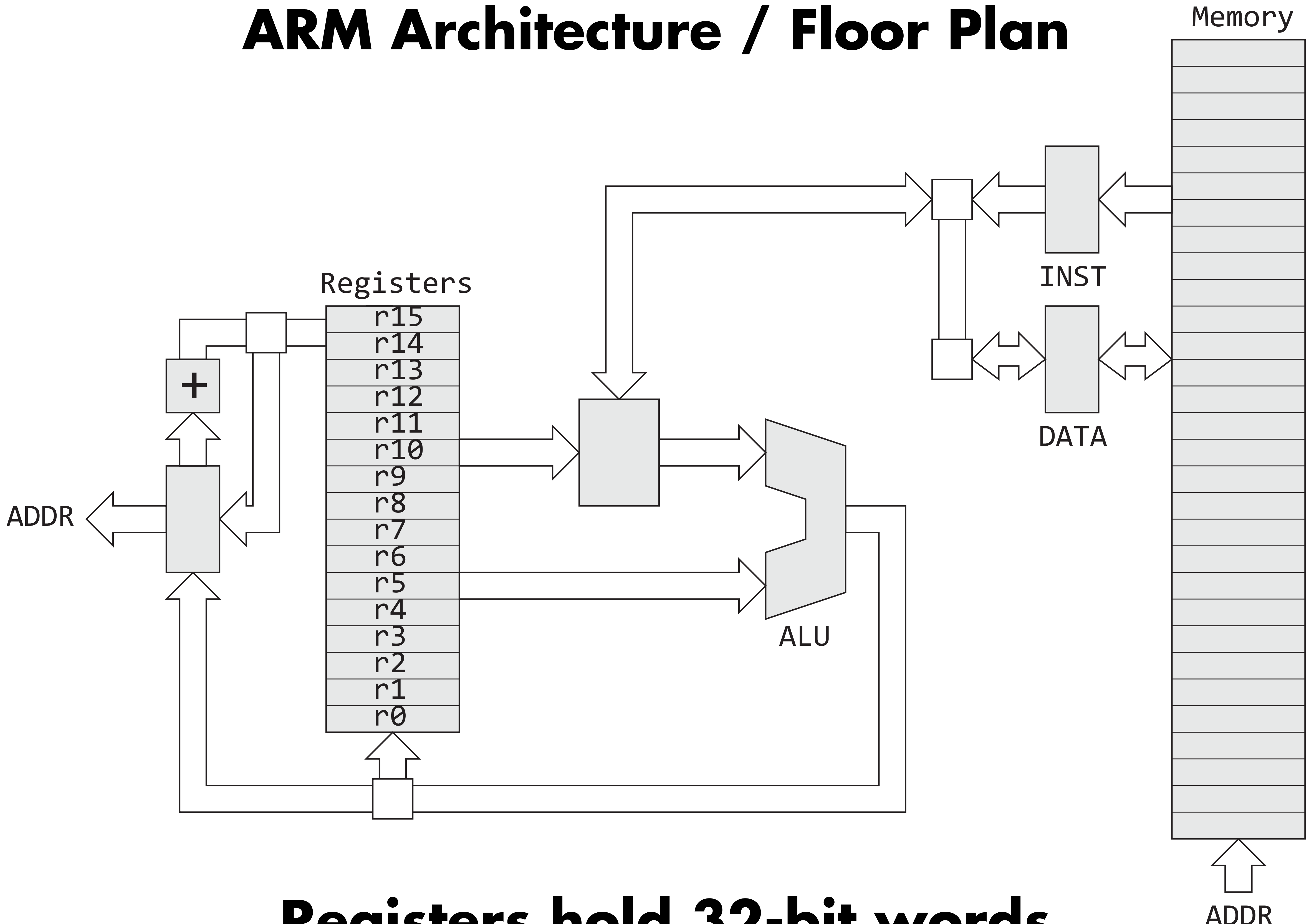
ARM
Processor and Memory Architecture

Goal: Turn on an LED

Running a "Program"



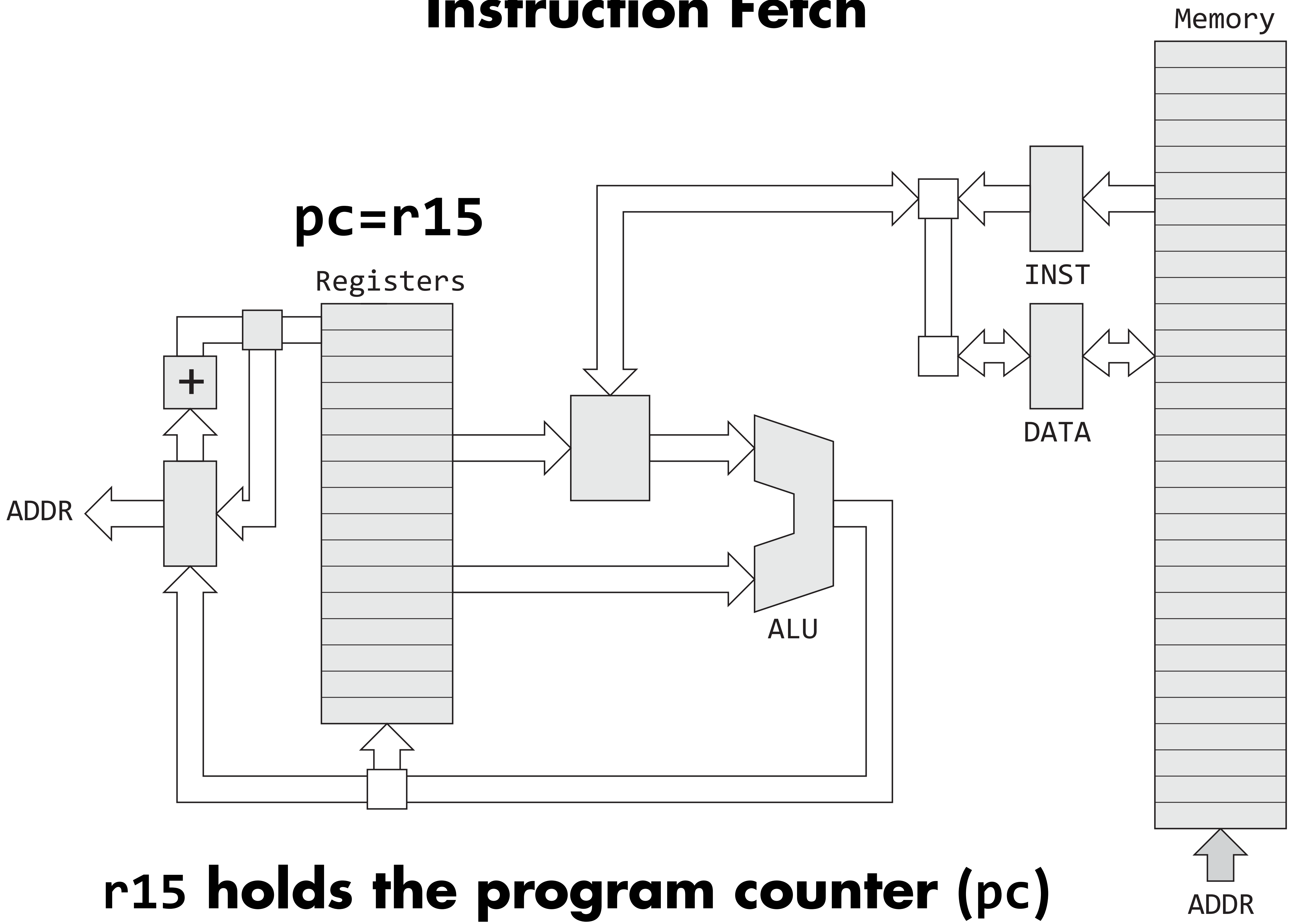
ARM Architecture / Floor Plan



Registers hold 32-bit words

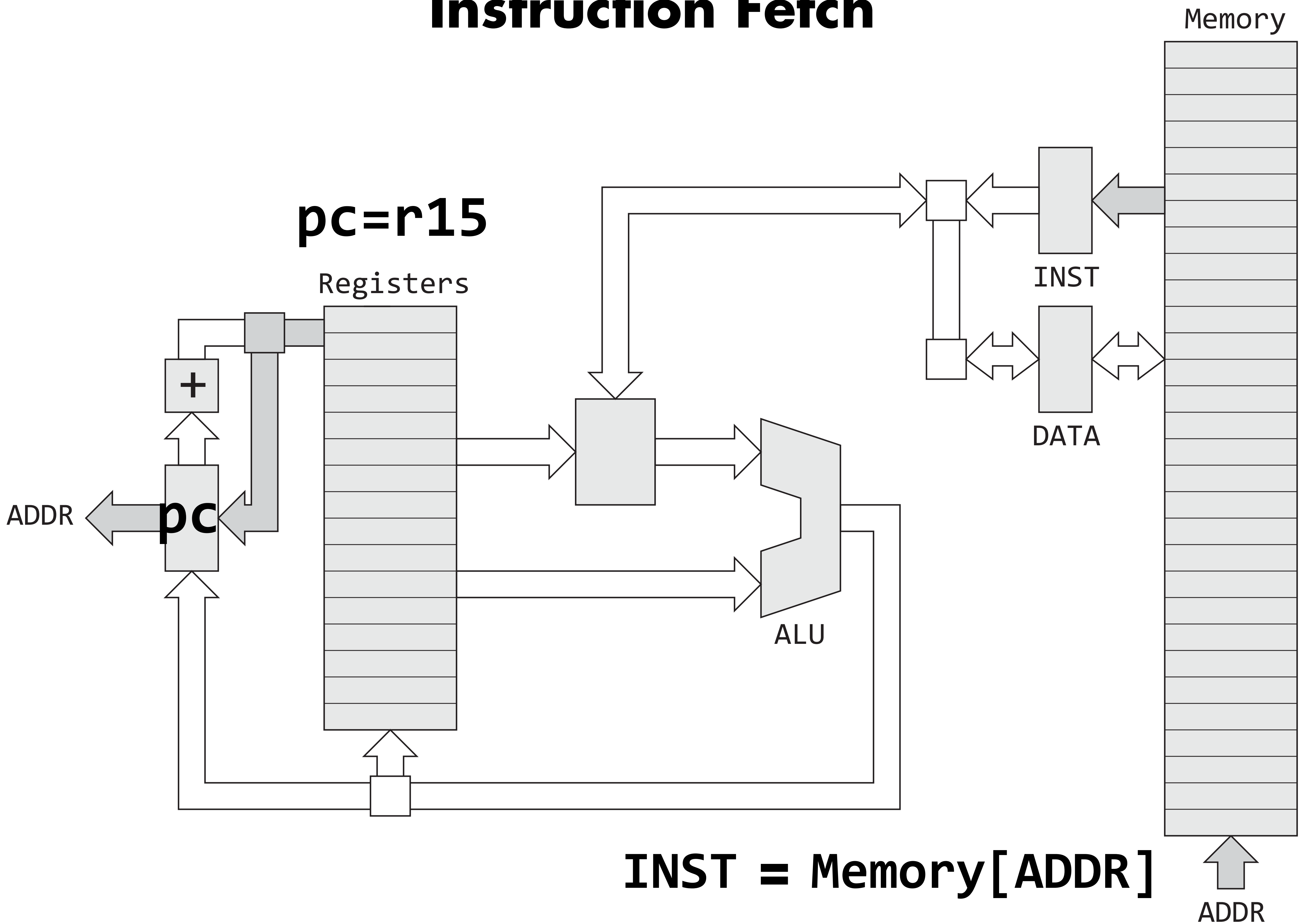
Arithmetic-Logic Unit (ALU) operates on 32-bit words

Instruction Fetch



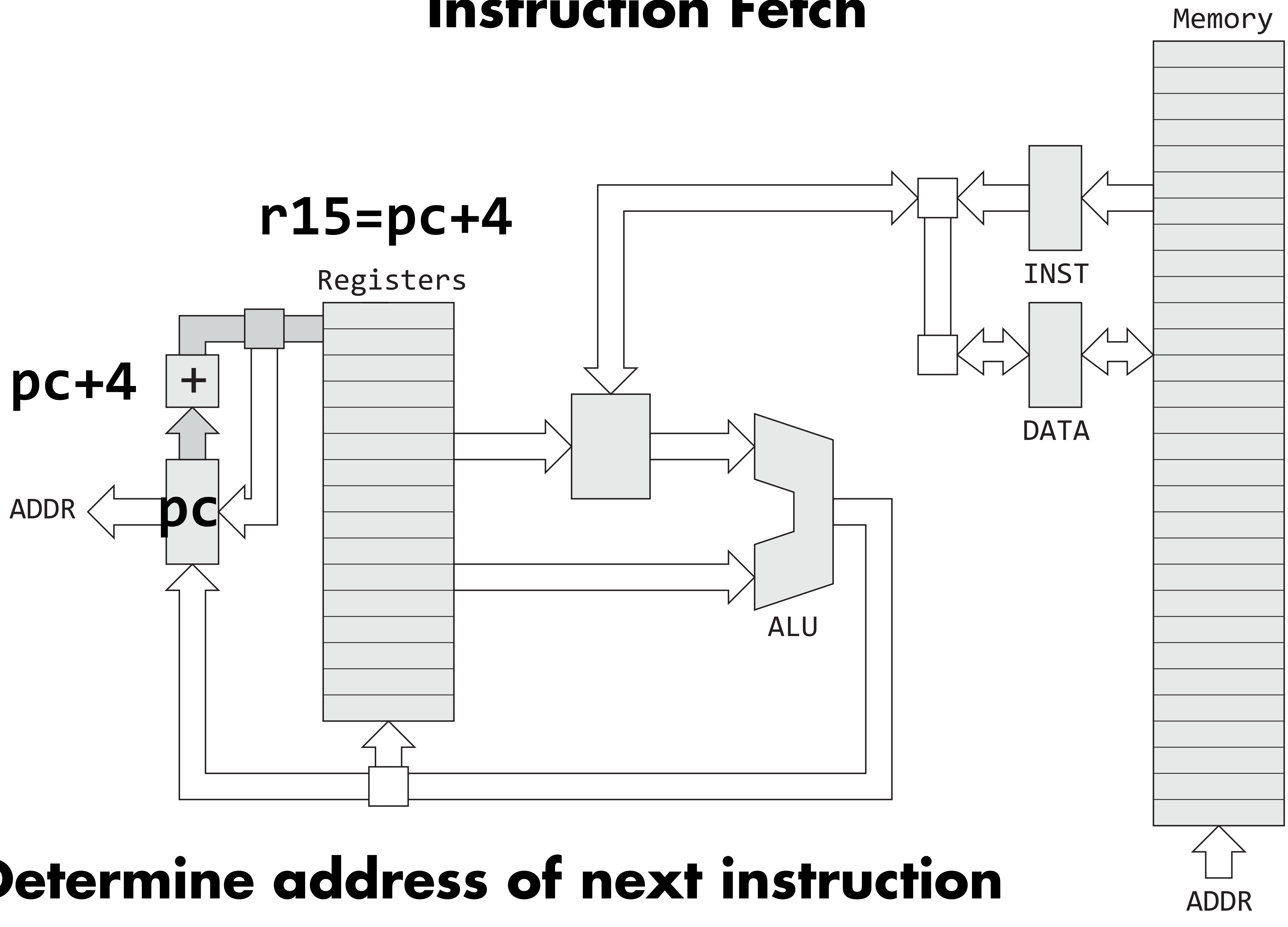
r15 holds the program counter (pc)

Instruction Fetch



Addresses and instructions are 32-bit words

Instruction Fetch



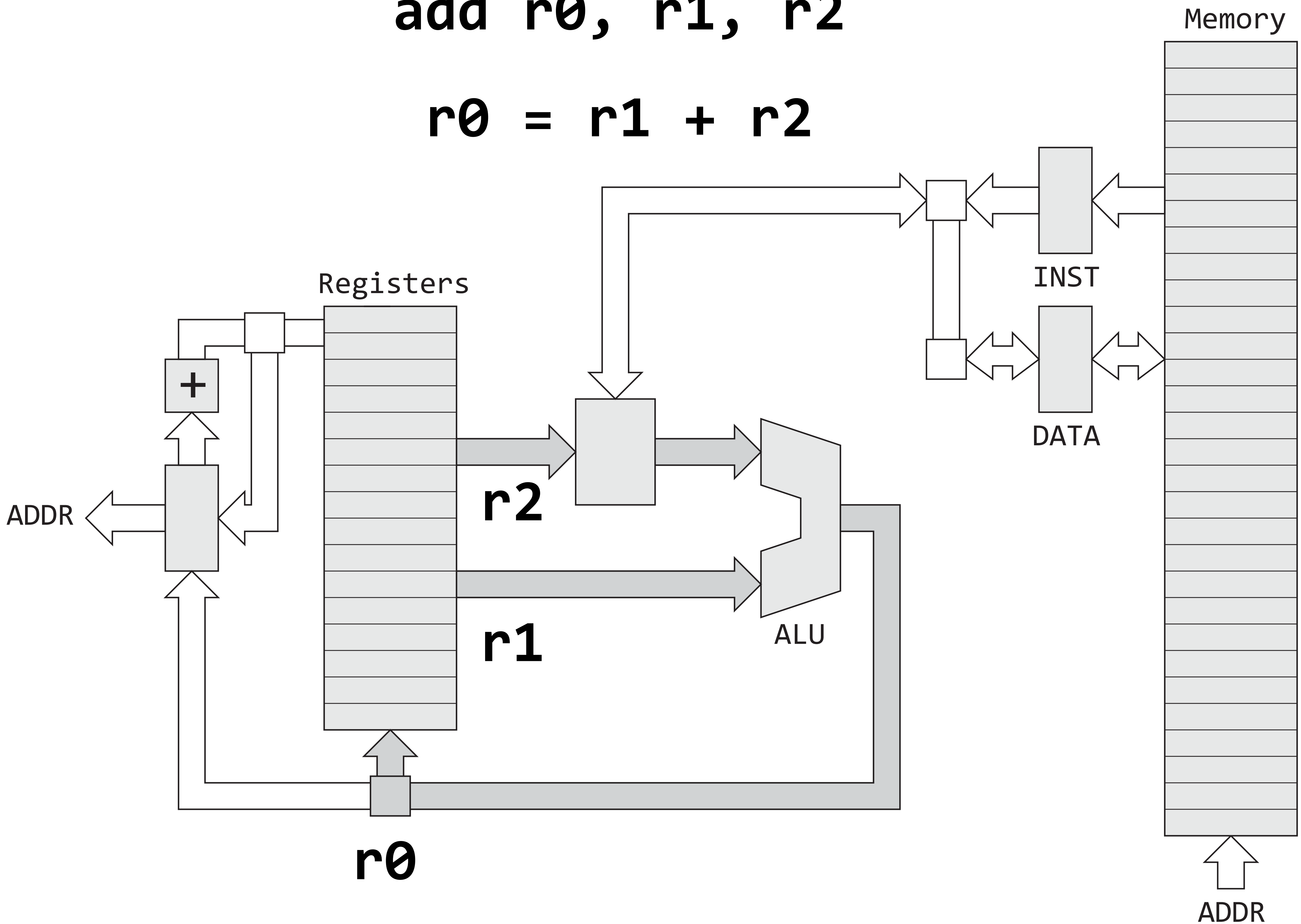
Determine address of next instruction

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)

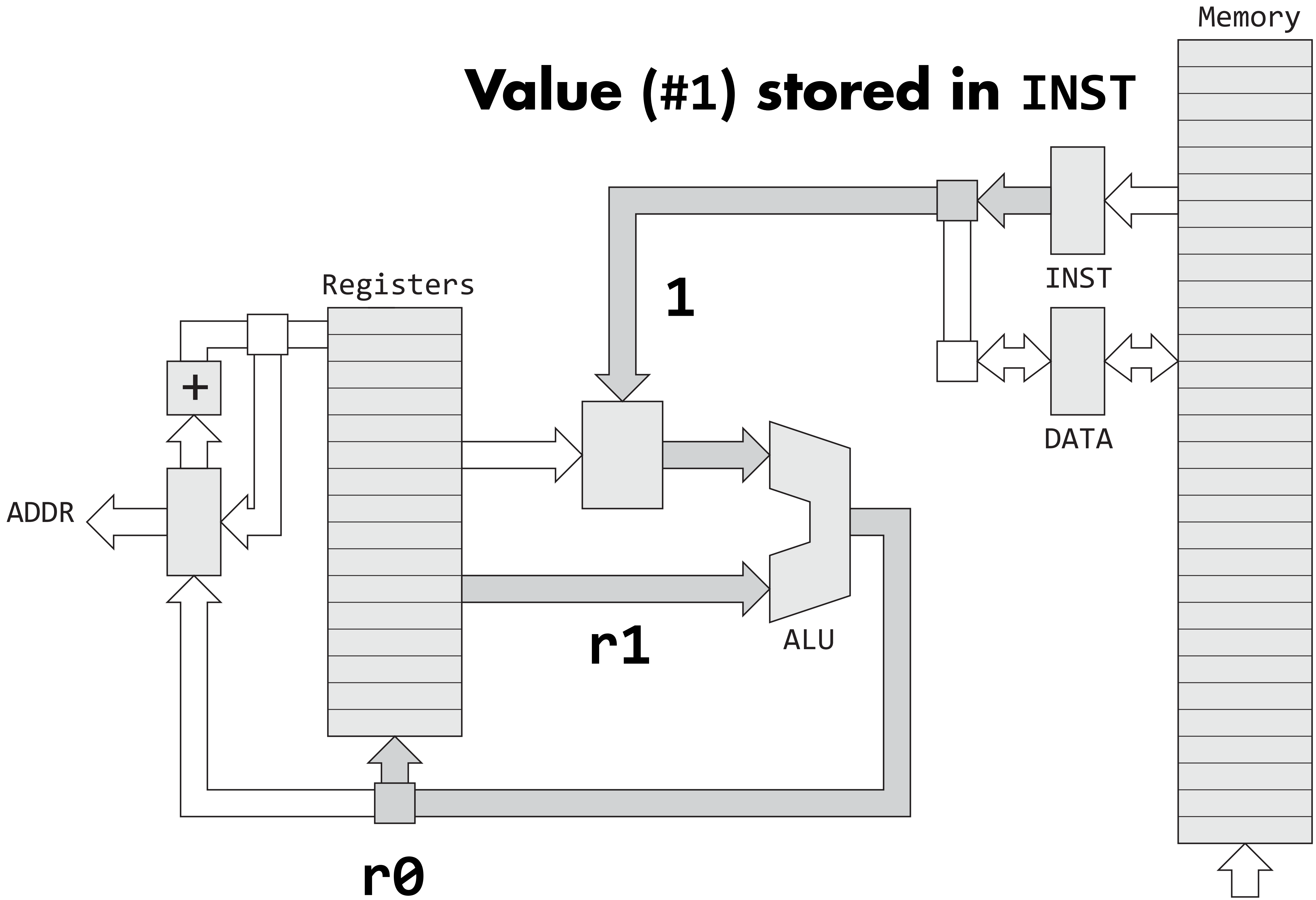
```
add r0, r1, r2
```

Machine code (more on this later)

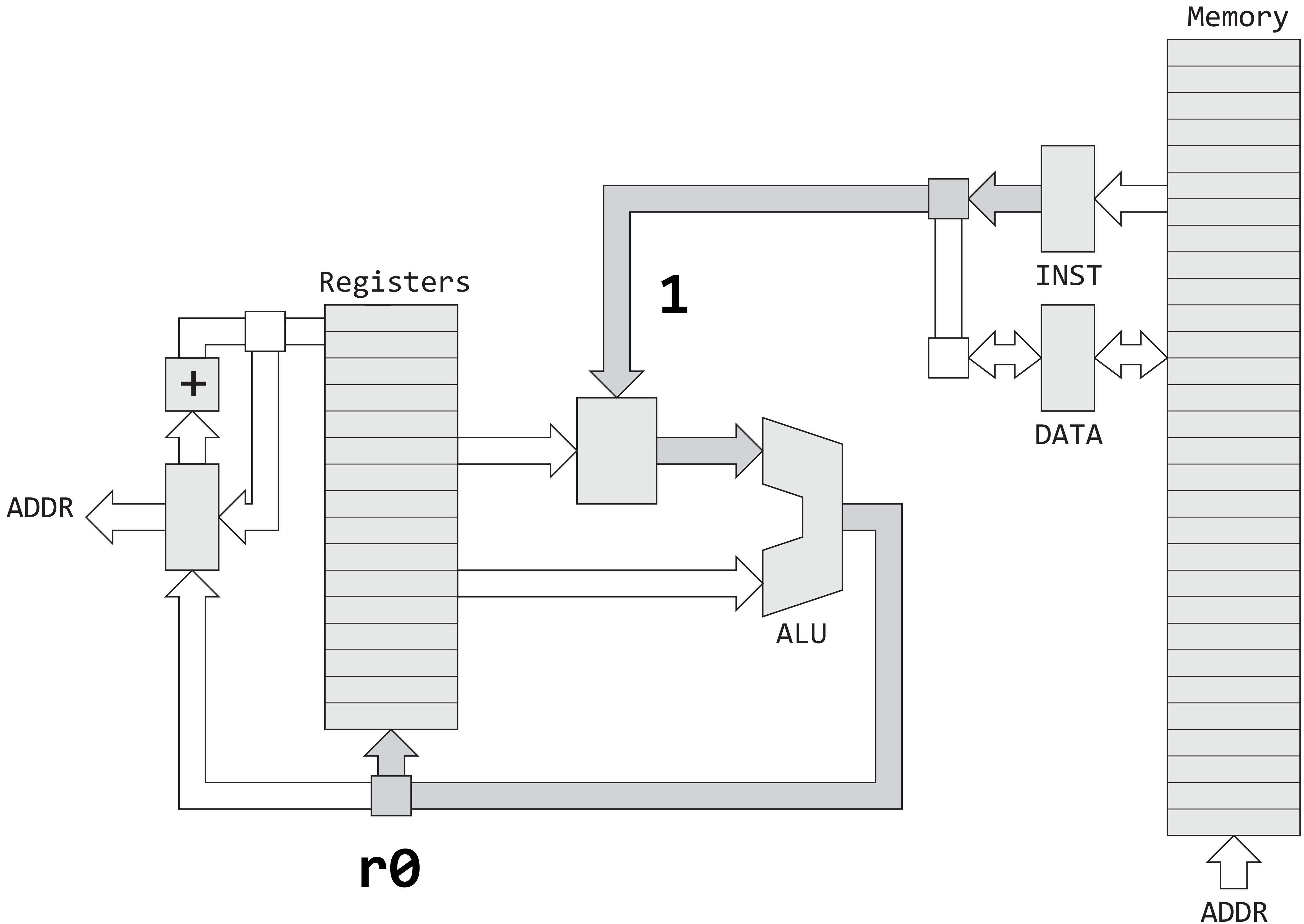
```
E0 81 00 02
```

```
# 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 cgregg  staff  4 add.bin

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

# Look at ARM Dissassembly:
% objdump -d add.o

add.o:   file format elf32-littlearm
Disassembly of section .text:
00000000 <$a>:
       0: 02 00 81 e0  add   r0, r1, r2
```

Value (#1) stored in INST

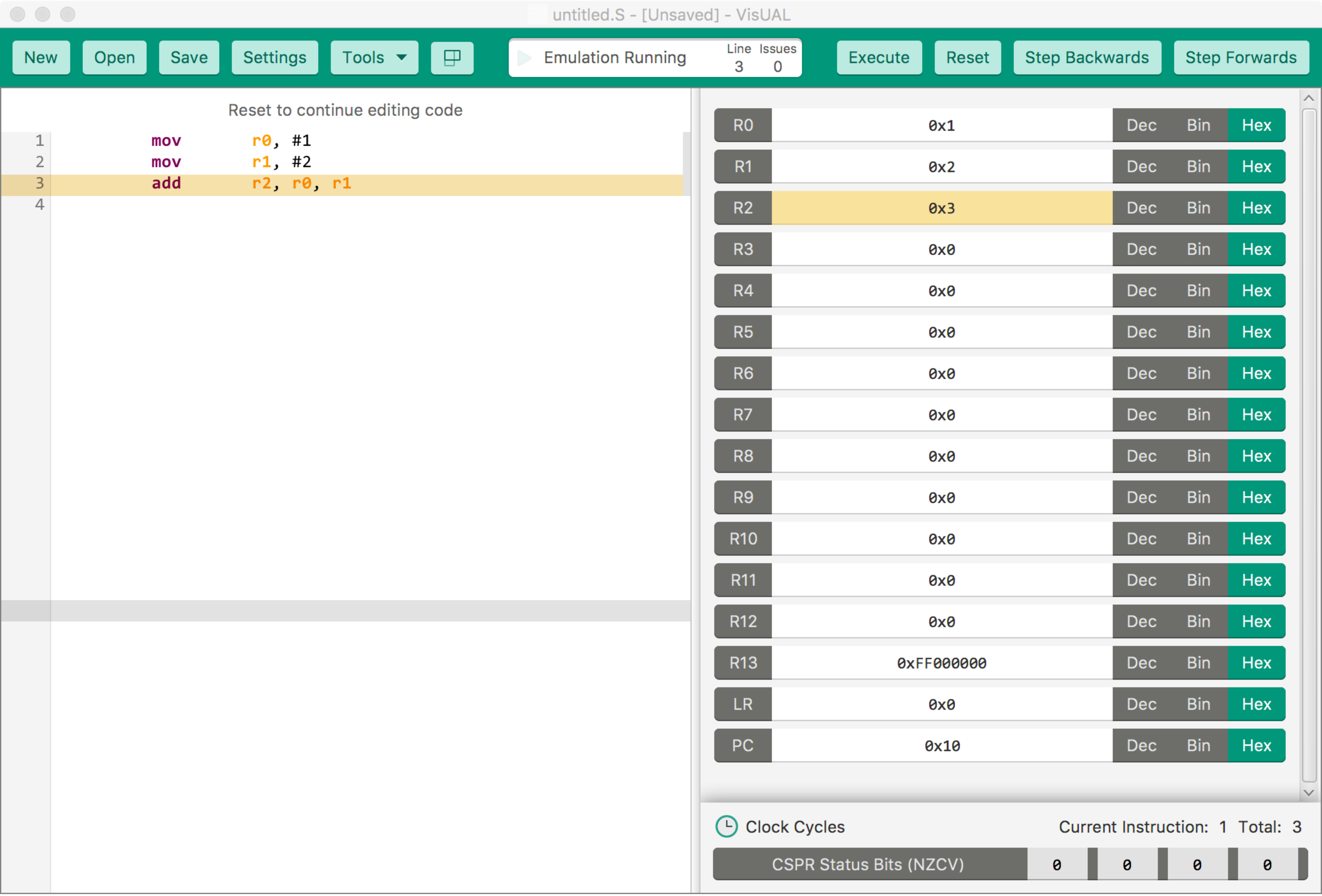


add r0, r1, #1



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
R1 0x2
R2 0x3
R3 0x0
R4 0x0
R5 0x0
R6 0x0
R7 0x0
R8 0x0
R9 0x0
R10 0x0
R11 0x0
R12 0x0
R13 0xFF000000
LR 0x0
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.**

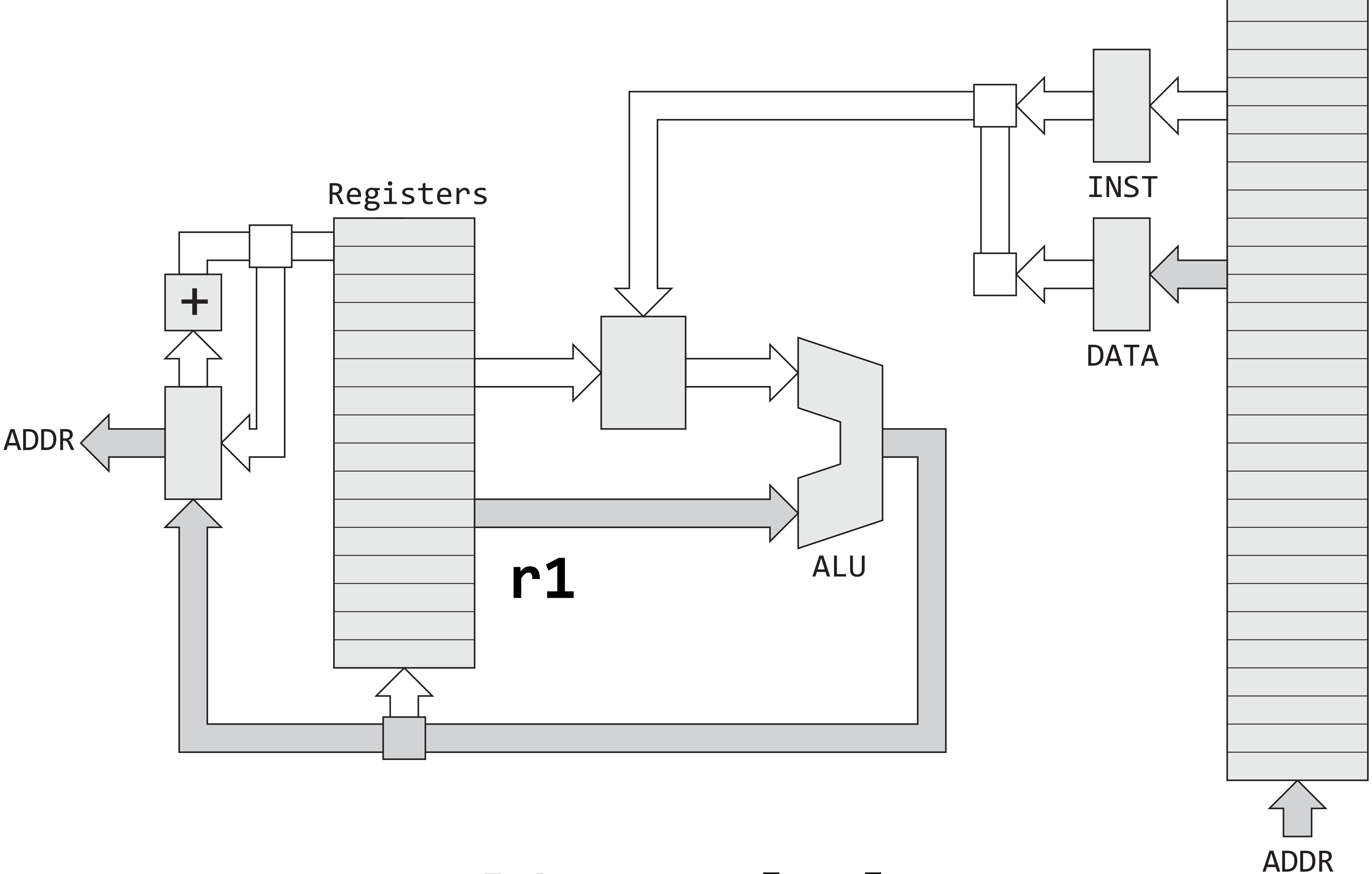
2. **All instructions are 32-bits. Can you `mov` any 32-bit constant value to a register using the `mov` instruction?**

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

Load and Store Instructions

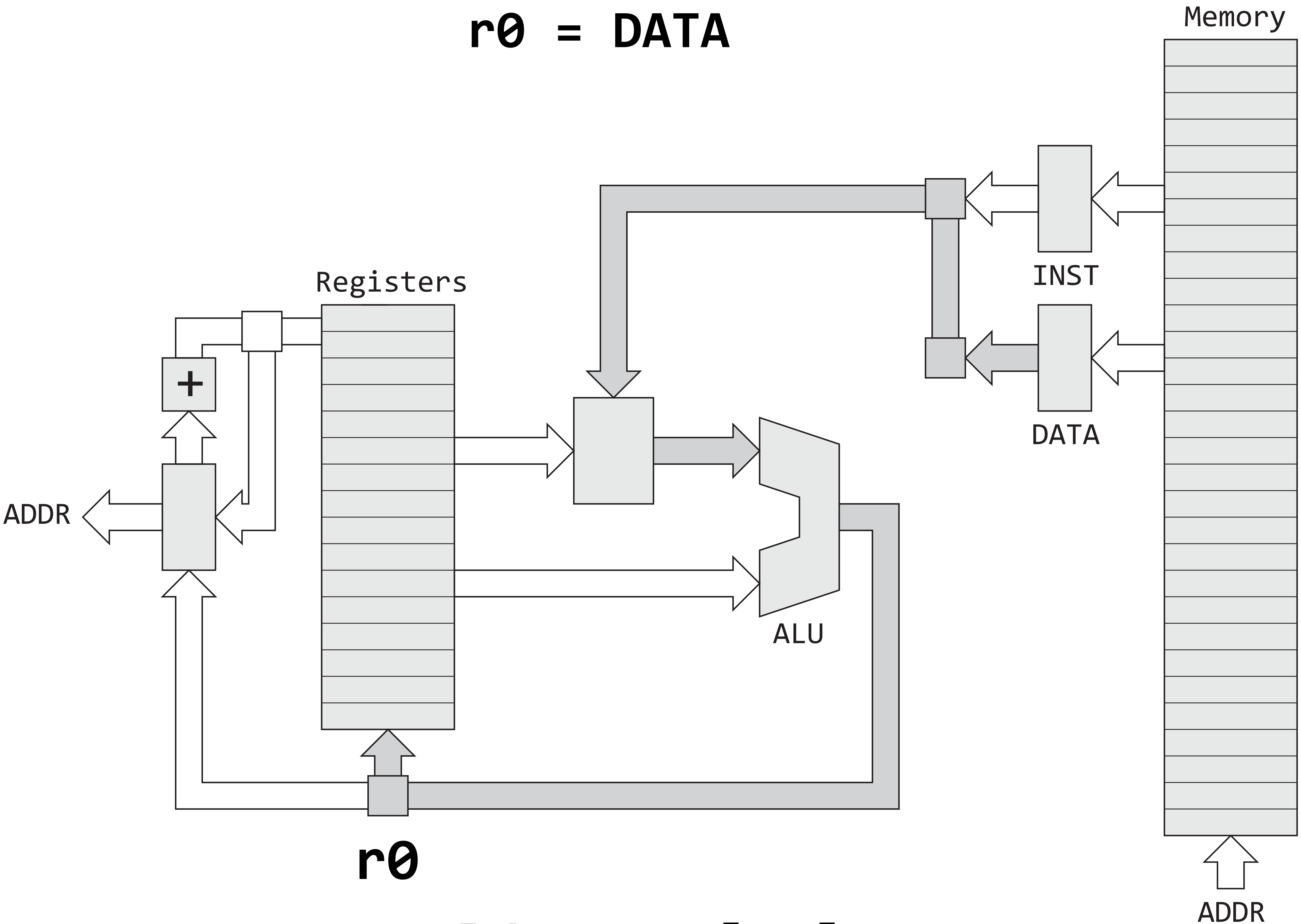
ADDR = r1

DATA = Memory[ADDR]



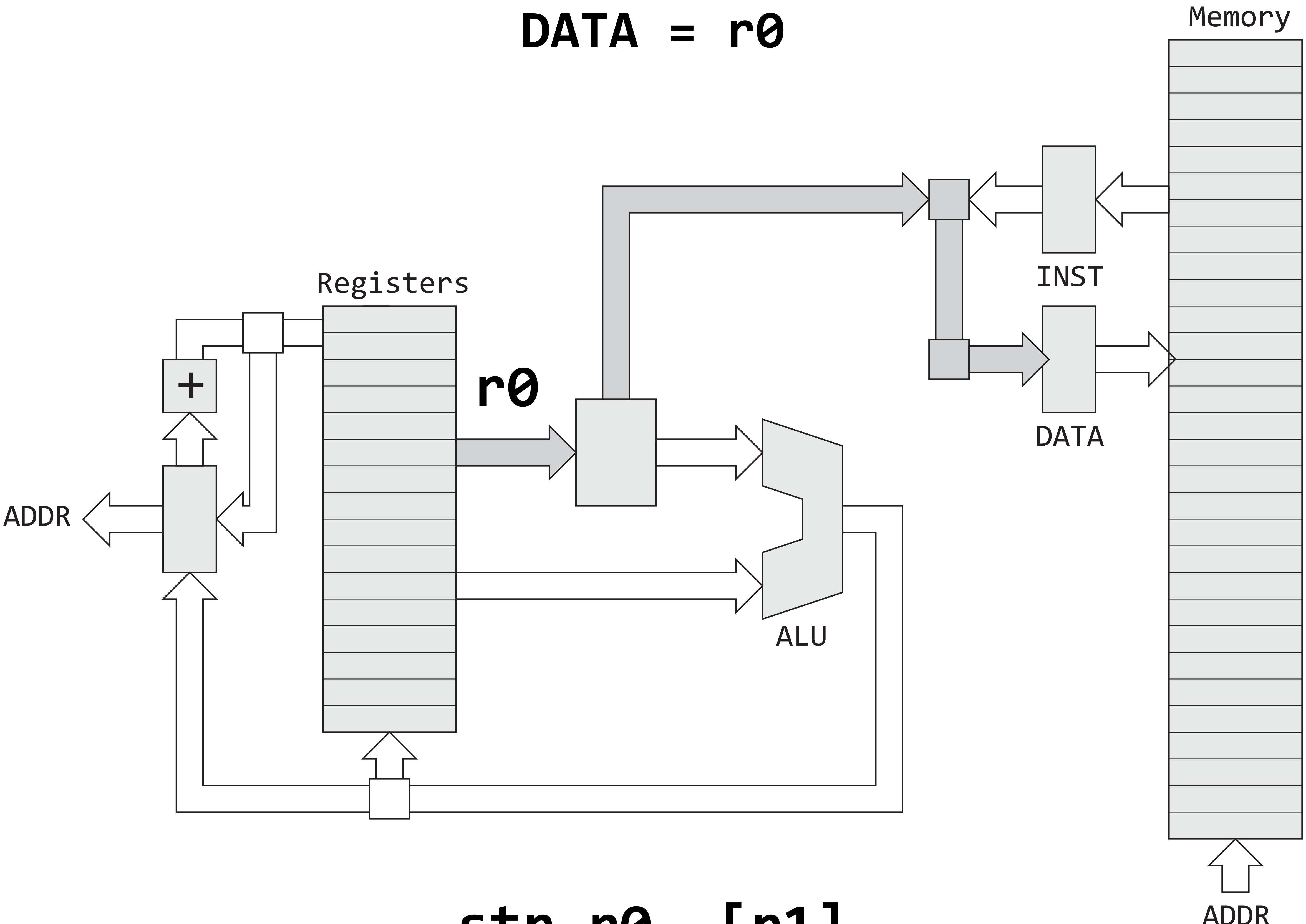
ldr r0, [r1]

r0 = DATA



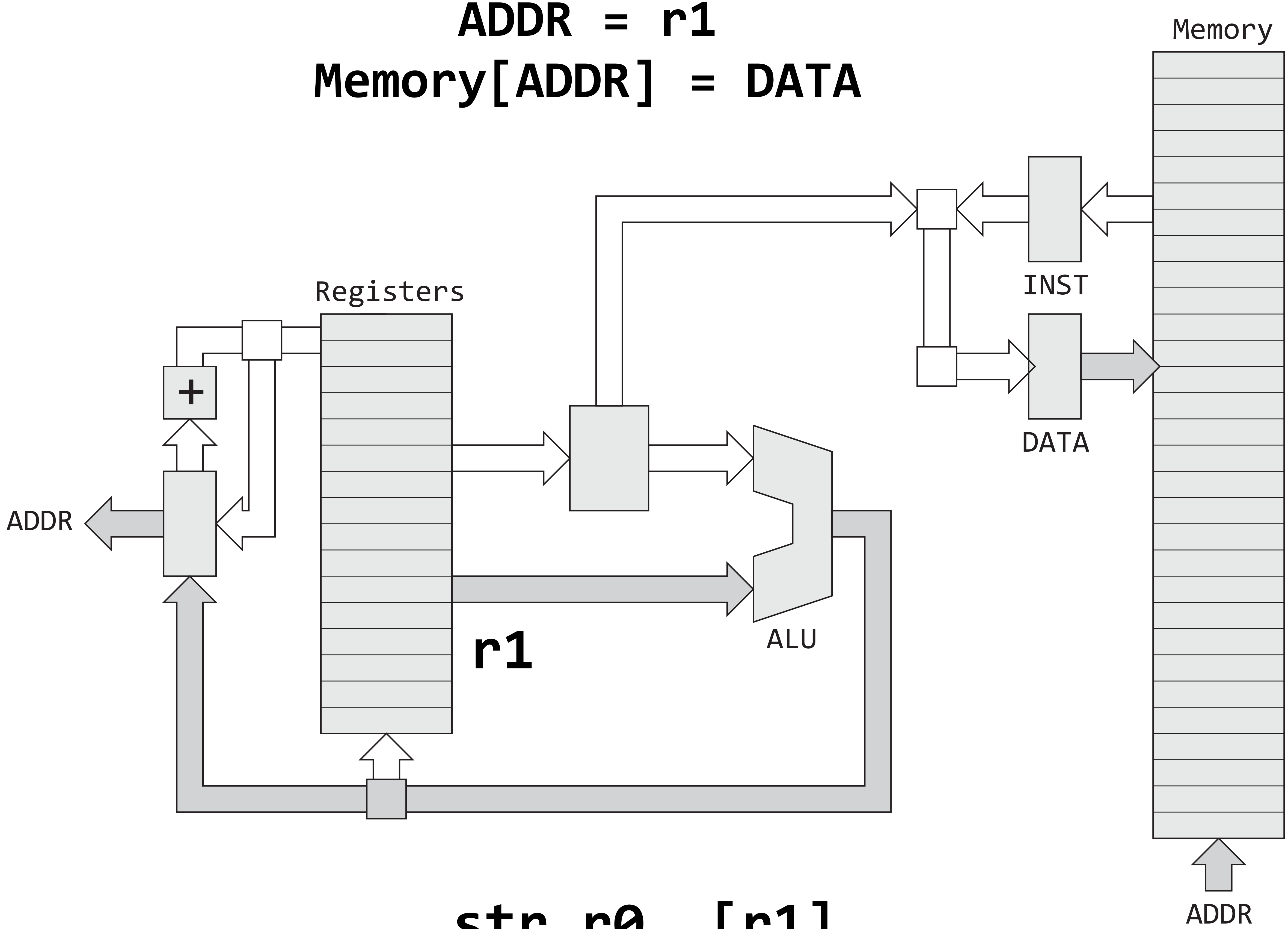
ldr r0, [r1]

DATA = r0

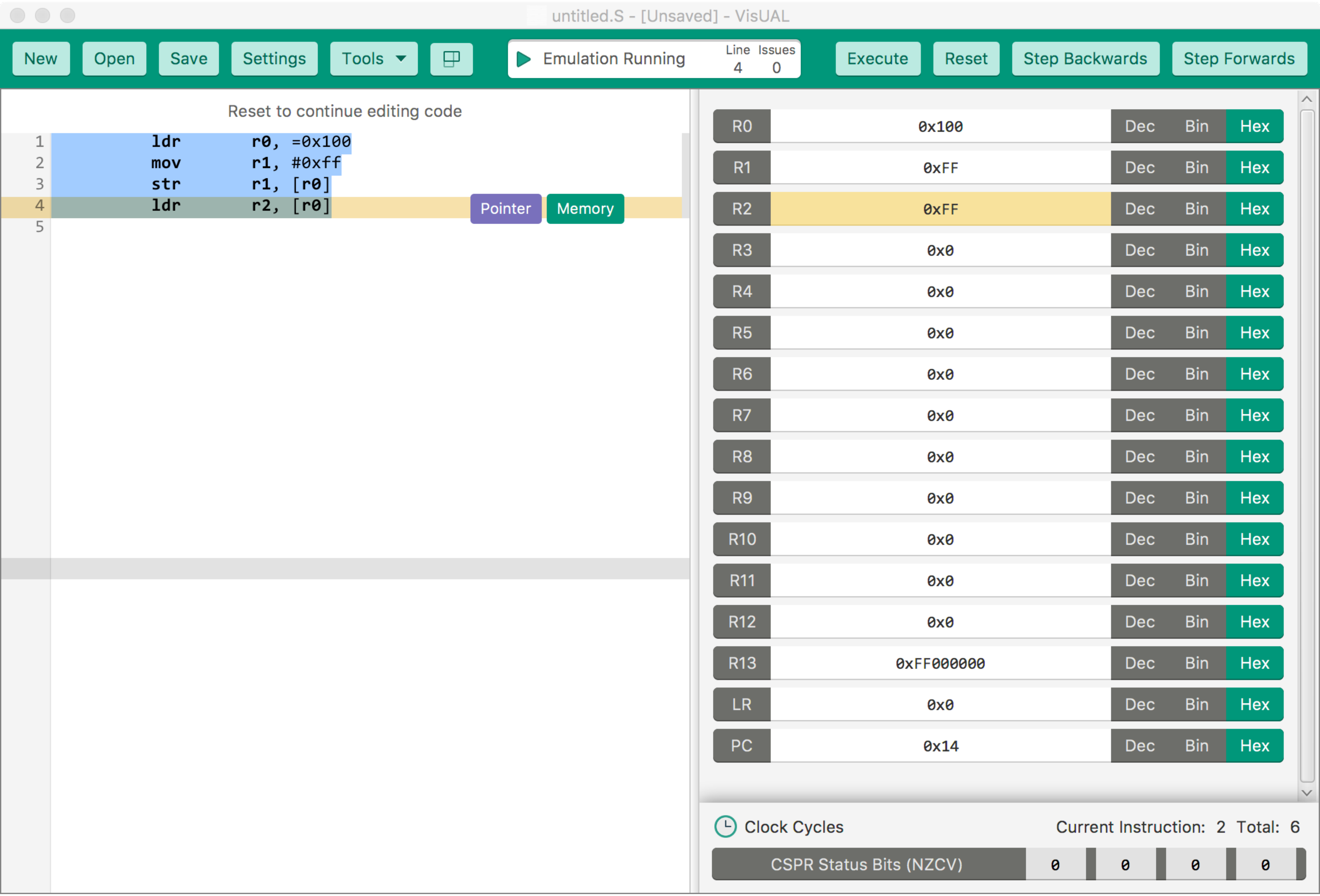


str r0, [r1]

ADDR = r1
Memory[ADDR] = DATA

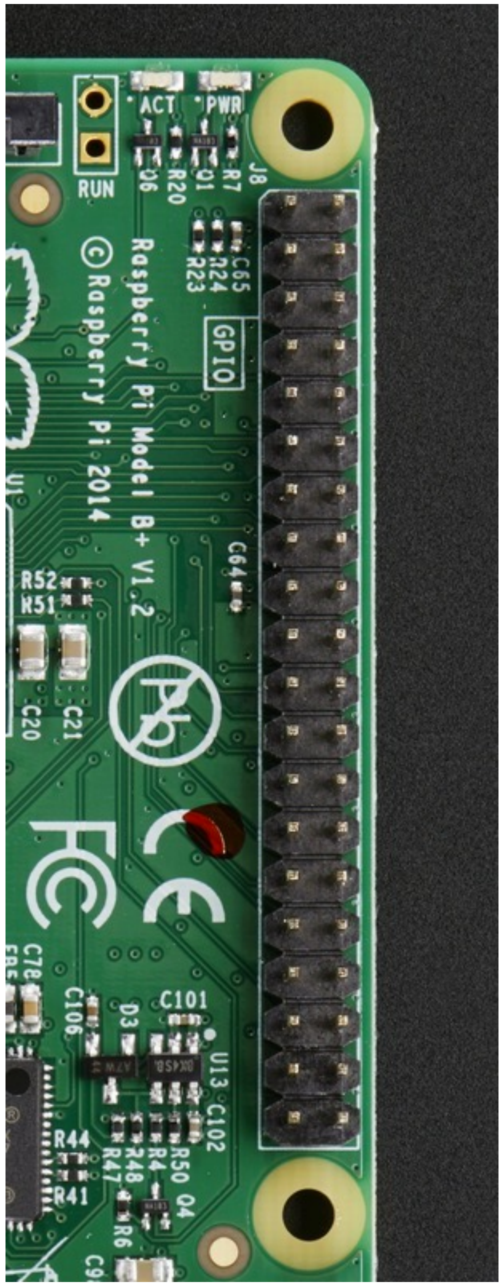


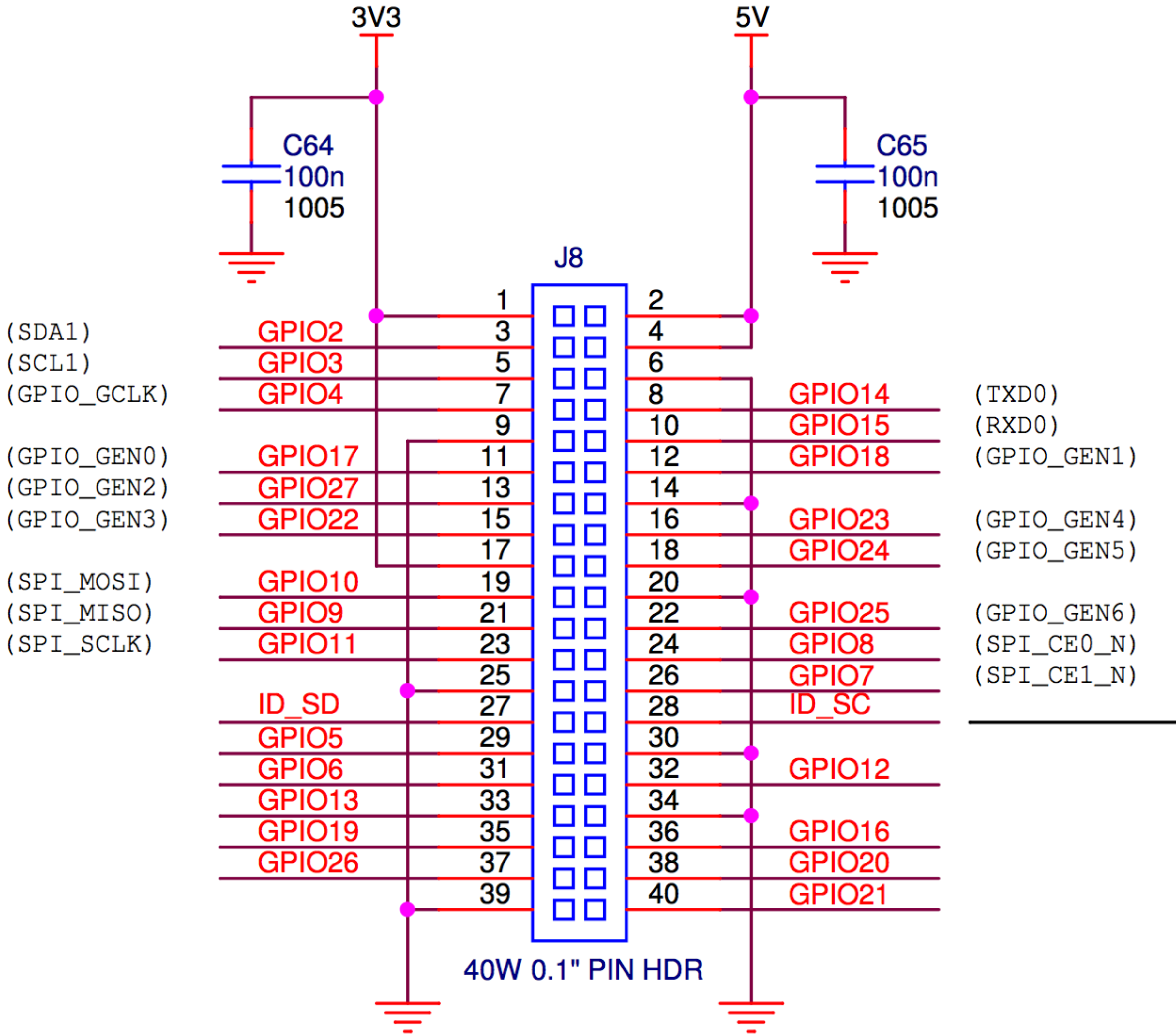
str r0, [r1]


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
ldr r0, =0x100
mov r1, #0xff
str r1, [r0]
ldr r2, [r0]
Pointer
Memory
R0 0x100
R1 0xFF
R2 0xFF
R3 0x0
R4 0x0
R5 0x0
R6 0x0
R7 0x0
R8 0x0
R9 0x0
R10 0x0
R11 0x0
R12 0x0
R13 0xFF000000
LR 0x0
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

Computers have Peripherals that Interface to the World

GPIO Pins are Peripherals

Raspberry Pi Pinout

5v Power | SDIO | JTAG | 3v3 Power | UART | DPI | PCM | 1-WIRE | WiringPi | GPCLK | Ground | I2C | PWM | SPI

Browse pinouts for HATs, pHATs and add-ons »

3v3 Power	1	2	5v Power
GPIO 2 (I2C1 SDA)	3	4	5v Power
GPIO 3 (I2C1 SCL)	5	6	Ground
GPIO 4 (GPCLK0)	7	8	GPIO 14 (UART TX)
Ground	9	10	GPIO 15 (UART RX)
GPIO 17	11	12	GPIO 18 (PCM CLK)
GPIO 27	13	14	Ground
GPIO 22	15	16	GPIO 23
3v3 Power	17	18	GPIO 24
GPIO 10 (SPI0 MOSI)	19	20	Ground
GPIO 9 (SPI0 MISO)	21	22	GPIO 25
GPIO 11 (SPI0 SCLK)	23	24	GPIO 8 (SPI0 CE0)
Ground	25	26	GPIO 7 (SPI0 CE1)
GPIO 0 (EEPROM SDA)	27	28	GPIO 1 (EEPROM SCL)
GPIO 5	29	30	Ground
GPIO 6	31	32	GPIO 12 (PWM0)
GPIO 13 (PWM1)	33	34	Ground
GPIO 19 (PCM FS)	35	36	GPIO 16
GPIO 26	37	38	GPIO 20 (PCM DIN)
Ground	39	40	GPIO 21 (PCM DOUT)

GPIO 20 (PCM Data-In)

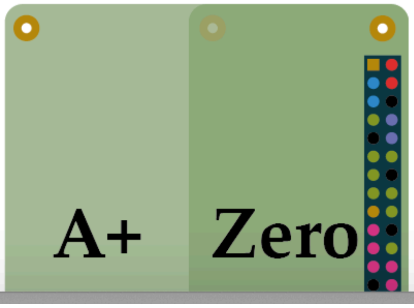
Alt0	Alt1	Alt2	Alt3	Alt4	Alt5
PCM DIN	SMI SD12	DPI D16	I2CSL MISO	SPI1 MOSI	GPCLK0

- Physical/Board pin 38
- GPIO/BCM pin 20
- Wiring Pi pin 28

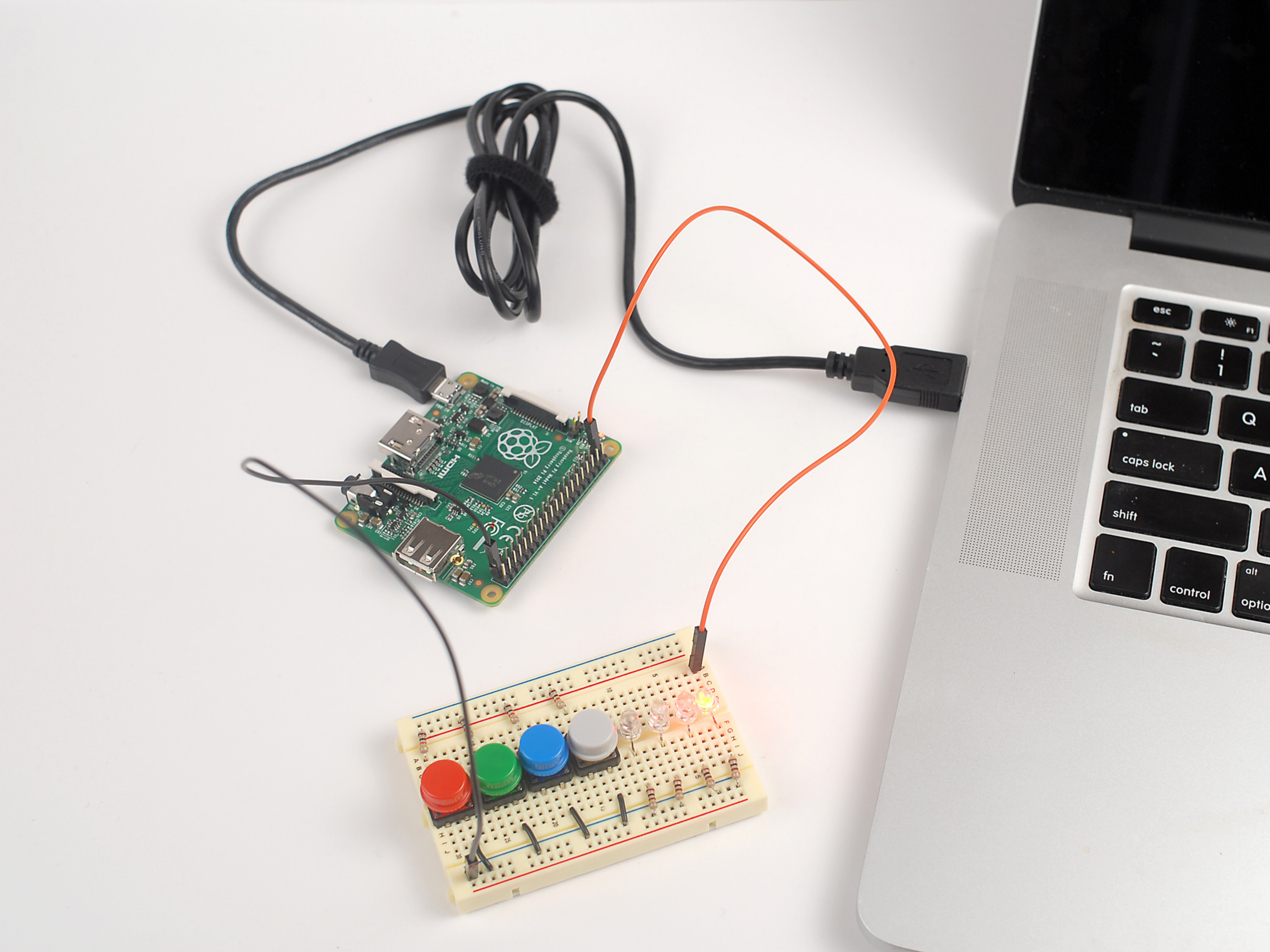
GPIO 20 is used by PCM to as a data input from an audio device such as an I2C microphone.

Legend

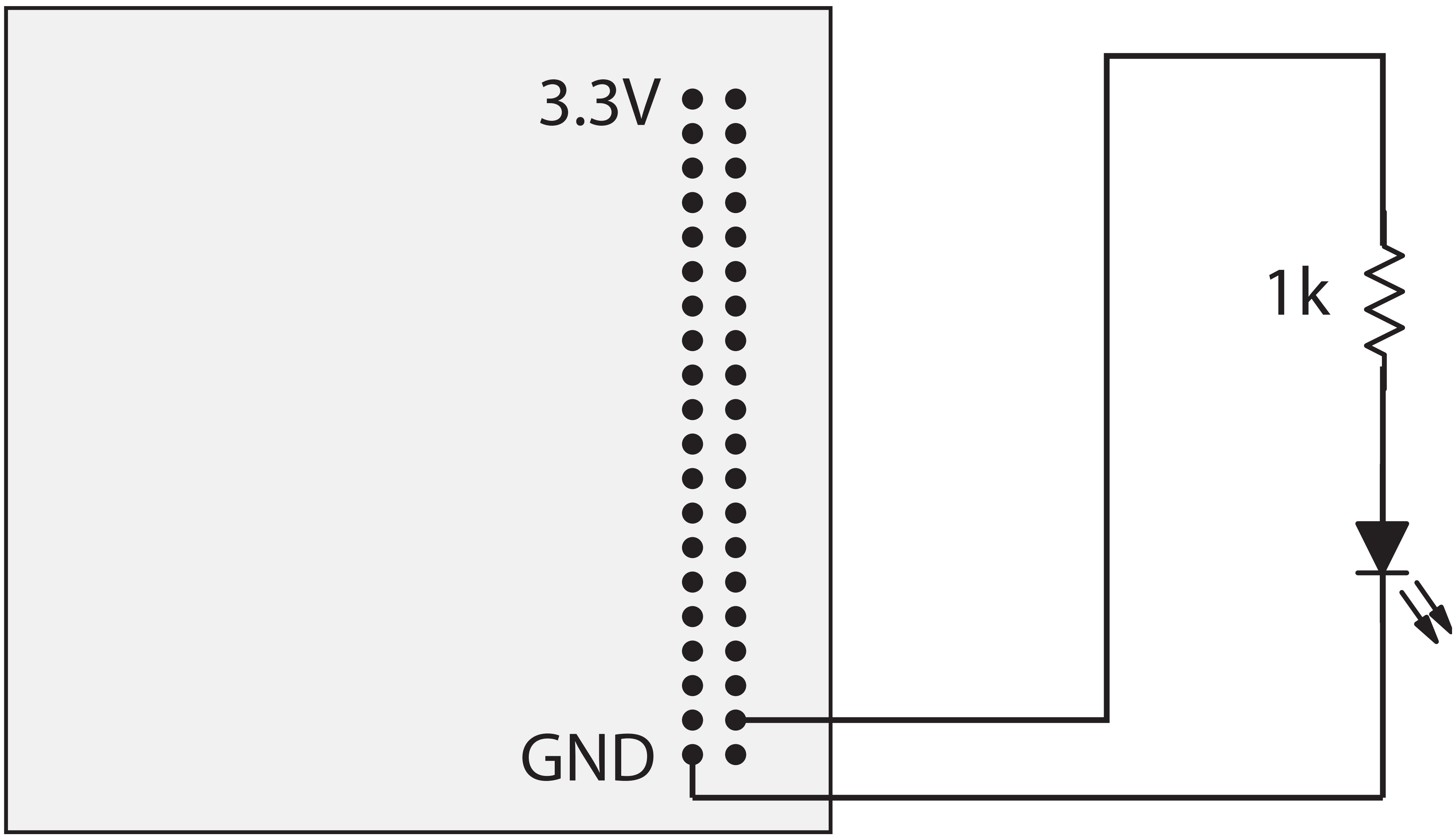
Orientate your Pi with the GPIO on the right and the HDMI port(s) on the left.



- GPIO (General Purpose IO)
- SPI (Serial Peripheral Interface)


esc
tab
caps lock
shift
fn
control
alt

Connect LED to GPIO 20



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

GPIO Pins are called Peripherals

Peripherals are Controlled by Special Registers

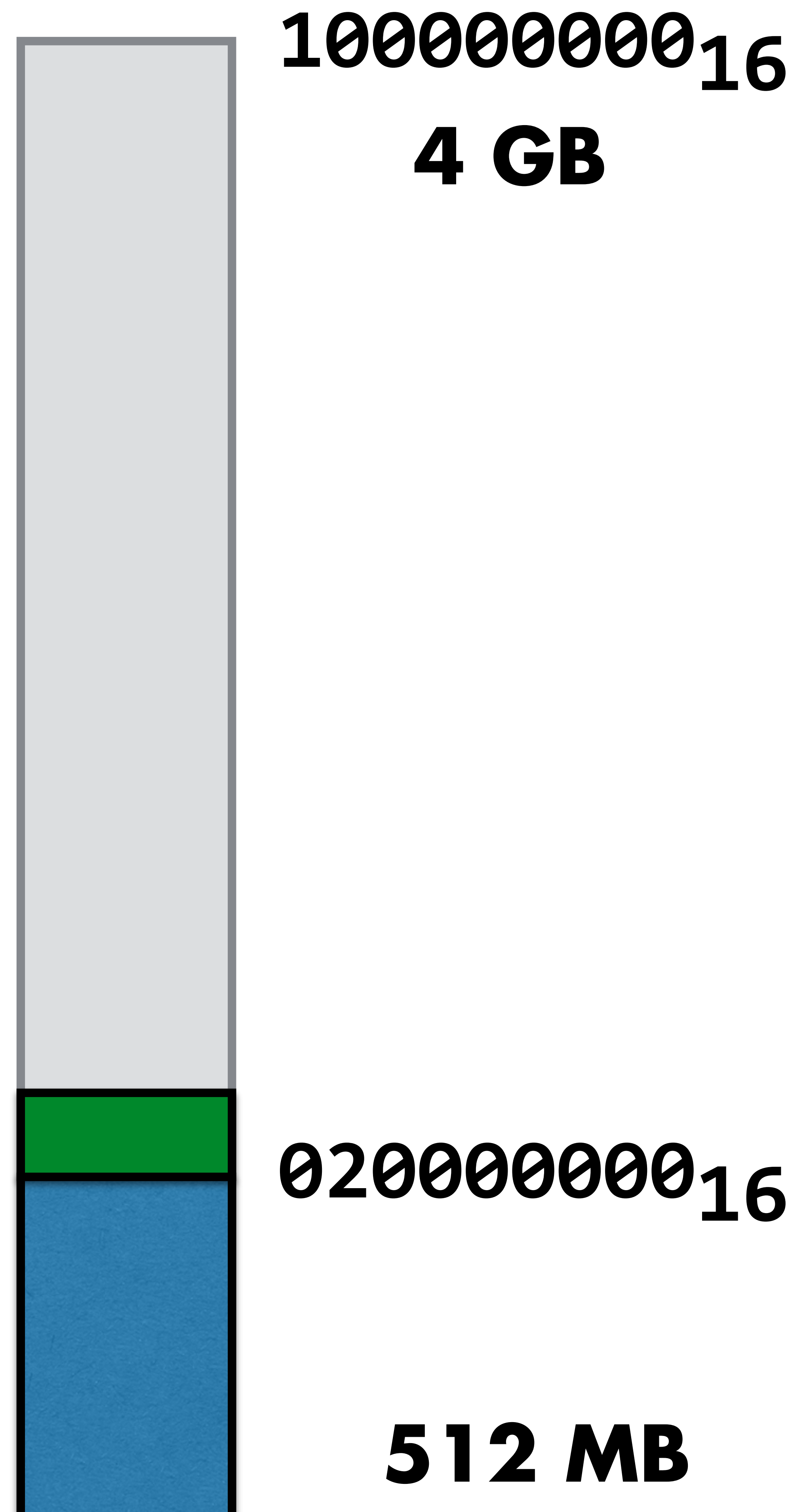
"Peripheral Registers"

Memory Map

Peripheral registers are mapped into address space

Memory-Mapped IO (MMIO)

MMIO space is above physical memory



Ref: BCM2835-ARM-Peripherals.pdf

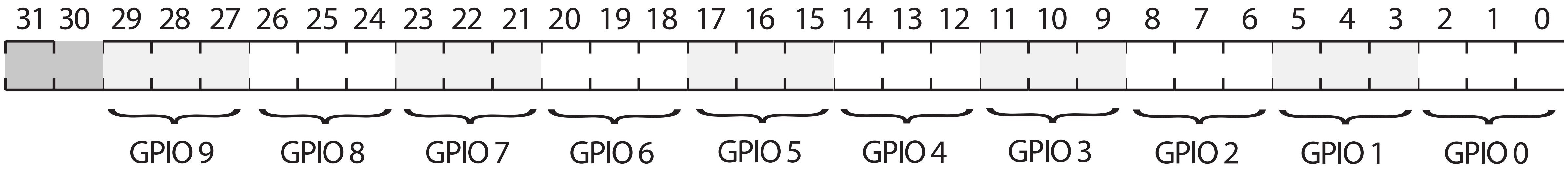
General-Purpose IO Function

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

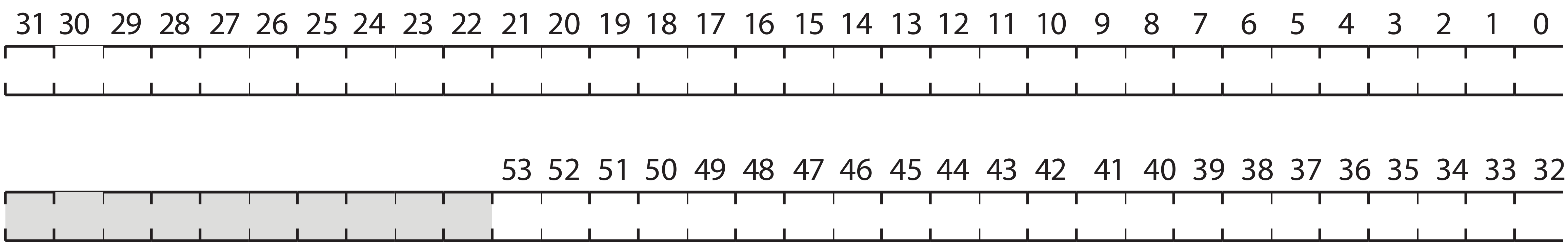
Table 6-8 – GPIO Output Set Register 0

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

```
…

//  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
```

```
…

//  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

// loop forever
loop:
b loop
```

```
# 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