

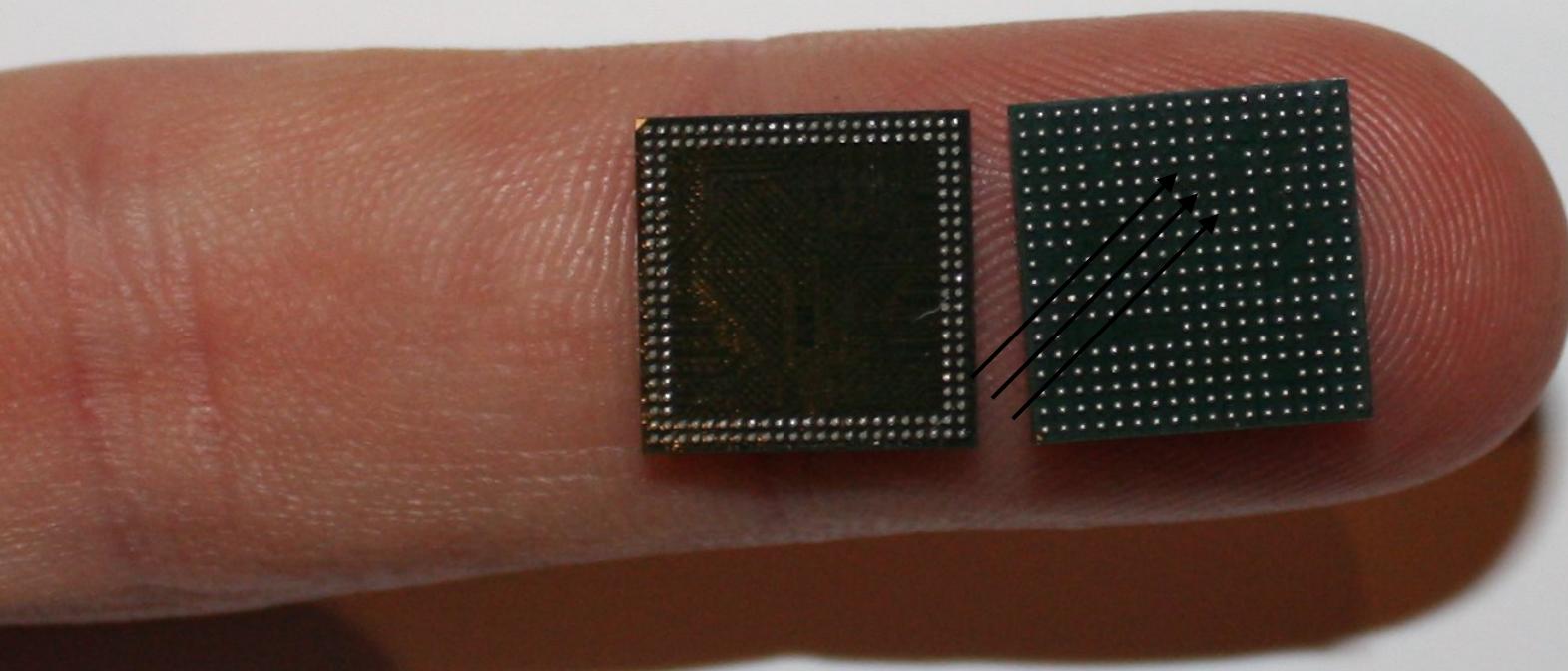
# **ARM**

## **Architecture and Assembly**

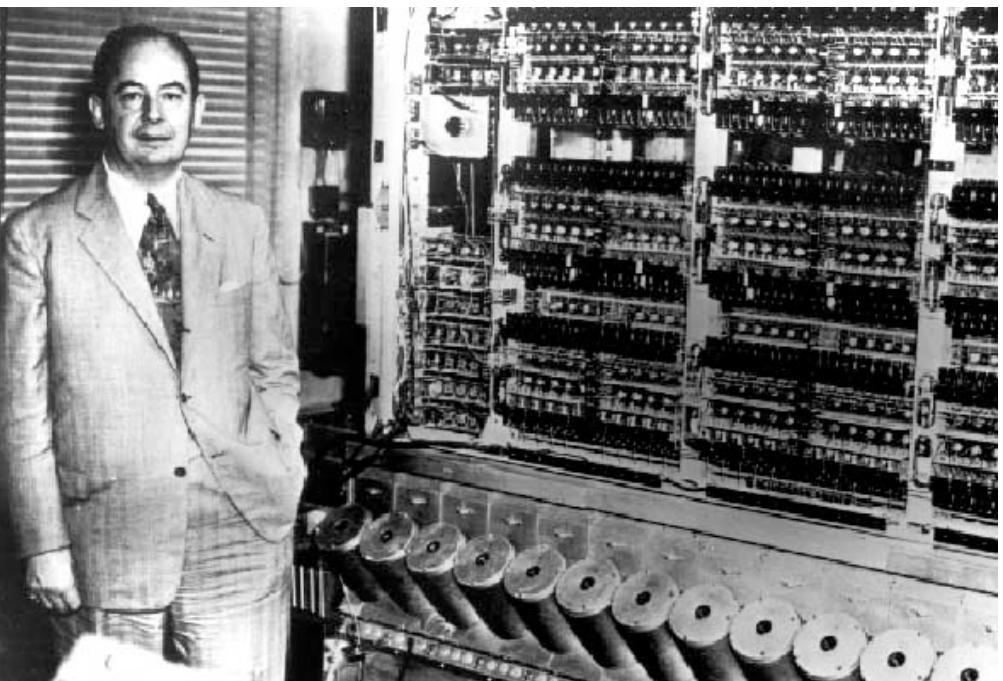
**Modest Goal: Turn on an LED**

# **Package on Package**

**Broadcom 2865 ARM Processor**

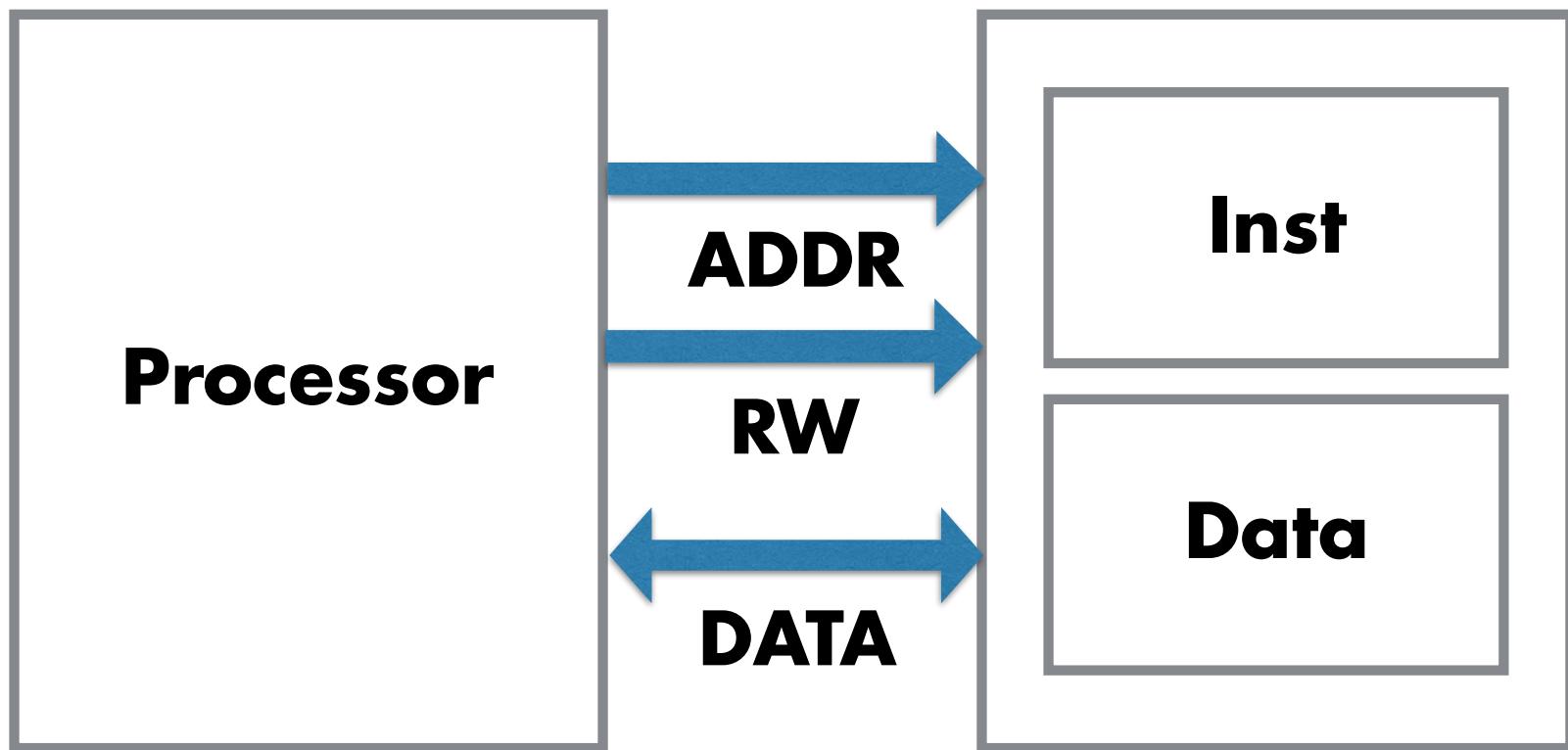


**Samsung 2Gb SDRAM**



## (John) von Neumann Architecture

**Instructions and data stored in the same memory**



$1000000000_{16}$

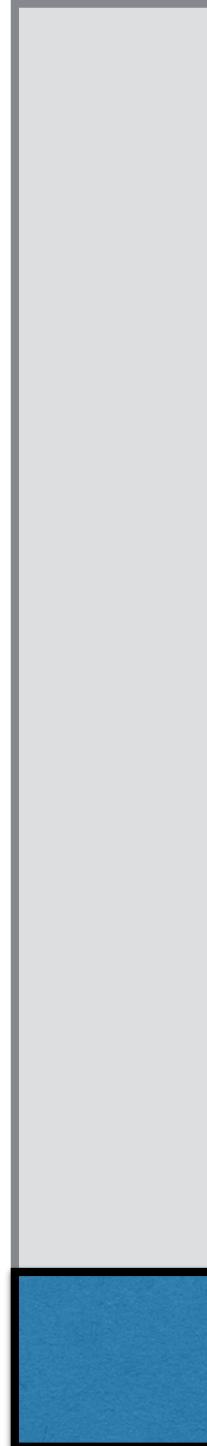
**Memory used to store information**

**Stores both instructions and data**

**Storage locations are named using 32-bit addresses**

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

**Maximum memory 4 GB  
Actual memory is 256 MB**



**Memory Map**

$010000000_{16}$   
**256 MB**

# **ARM 32-bit Architecture**

**Processor designed around 32-bit “words”**

**Registers are 32-bits**

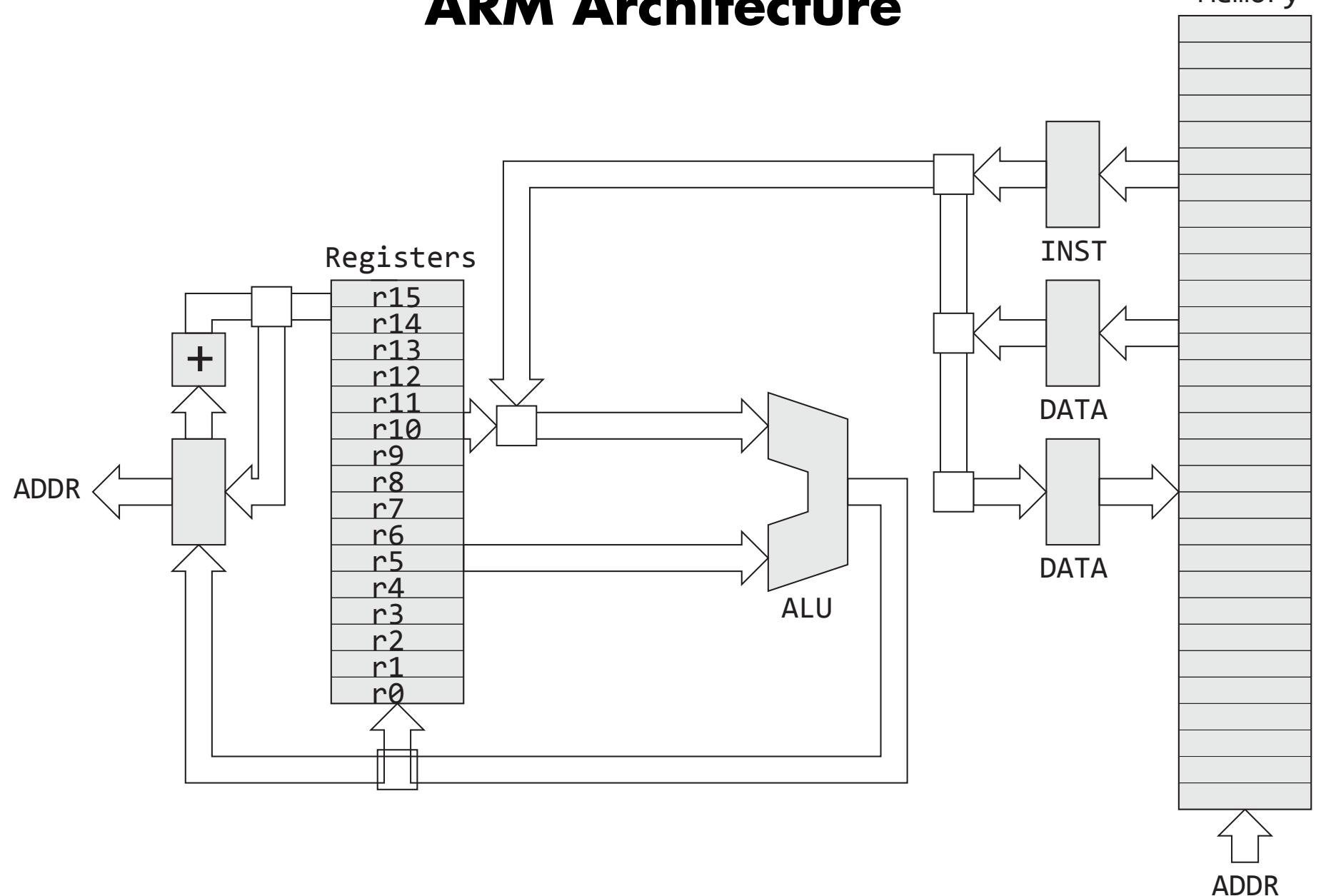
**Arithmetic-Logic Unit (ALU) works on 32-bits**

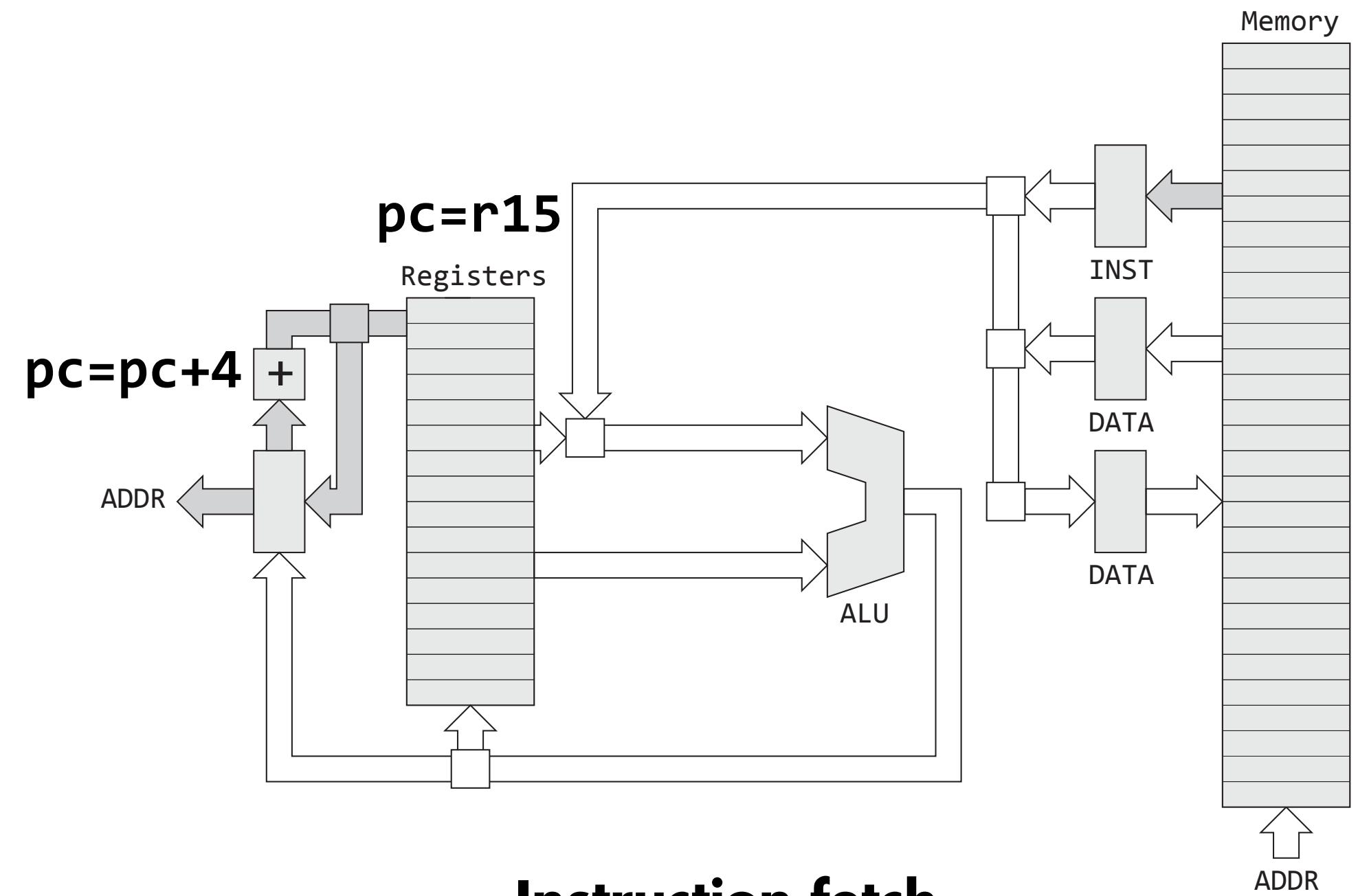
**Addresses are 32-bits**

**Instructions are fixed size - 32-bits**

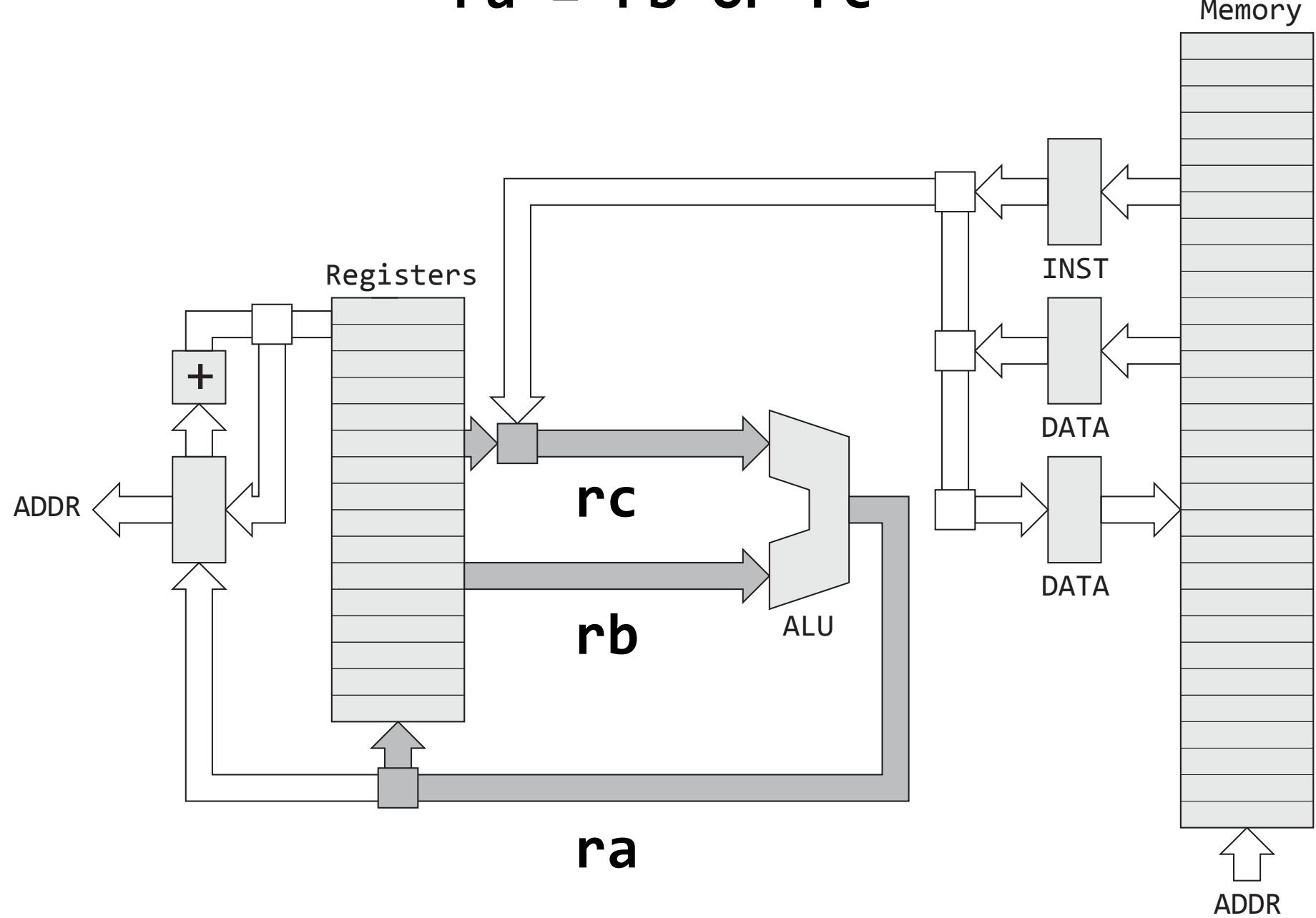
***The fact that everything is 32-bits simplifies things quite a bit!***

# ARM Architecture





$$ra = rb \text{ OP } rc$$



# Instructions

**Meaning (C)**

$r0 = r1 + 1$

**Assembly language**

`add r0, r1, #1`

**Machine language**

`E2 81 00 01`

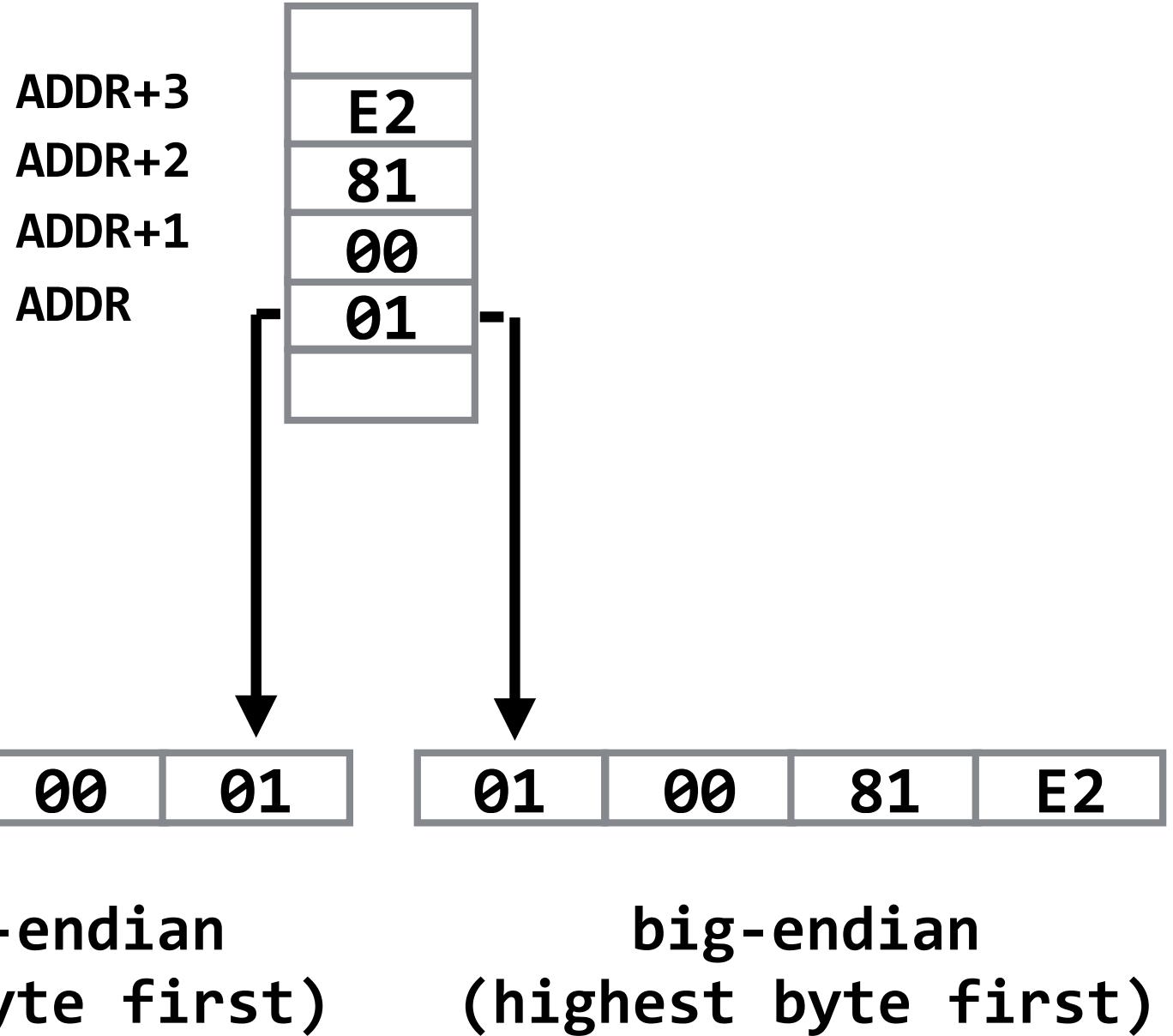
```
// Single instruction program  
  
add r0, r1, #1 // #n is an immediate
```

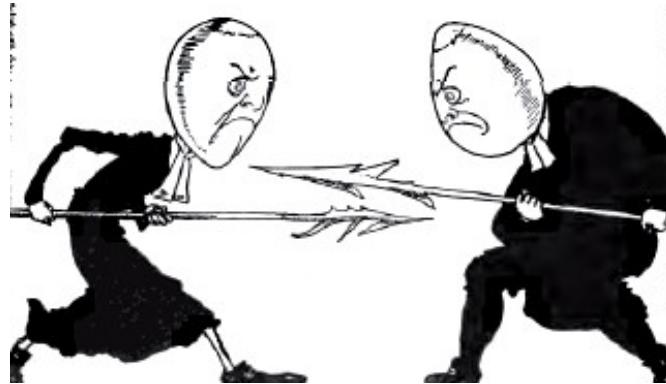
```
# Assemble and generate listing
% arm-none-eabi-as add.s -o add.o -a

# Create binary
% arm-none-eabi-objdump add.o -O binary add.bin

# Size
% ls -l add.bin
-rw-r--r--+ 1 hanrahan  staff  4 add.bin

# Dump binary
% xxd -g 1 add.bin
0000000: 01 00 81 e2 // little-endian
```





**The 'little-endian' and 'big-endian' terminology which is used to denote the two approaches [to addressing memory] is derived from Swift's Gulliver's Travels. The inhabitants of Lilliput, who are well known for being rather small are, in addition, constrained by law to break their eggs only at the little end. When this law is imposed, those of their fellow citizens who prefer to break their eggs at the big end take exception to the new rule and civil war breaks out. The big-endians eventually take refuge on a nearby island, which is the kingdom of Blefuscu. The civil war results in many casualties.**

**Read: Holy Wars and a Plea For Peace, D. Cohen**

# **Cross-Development**

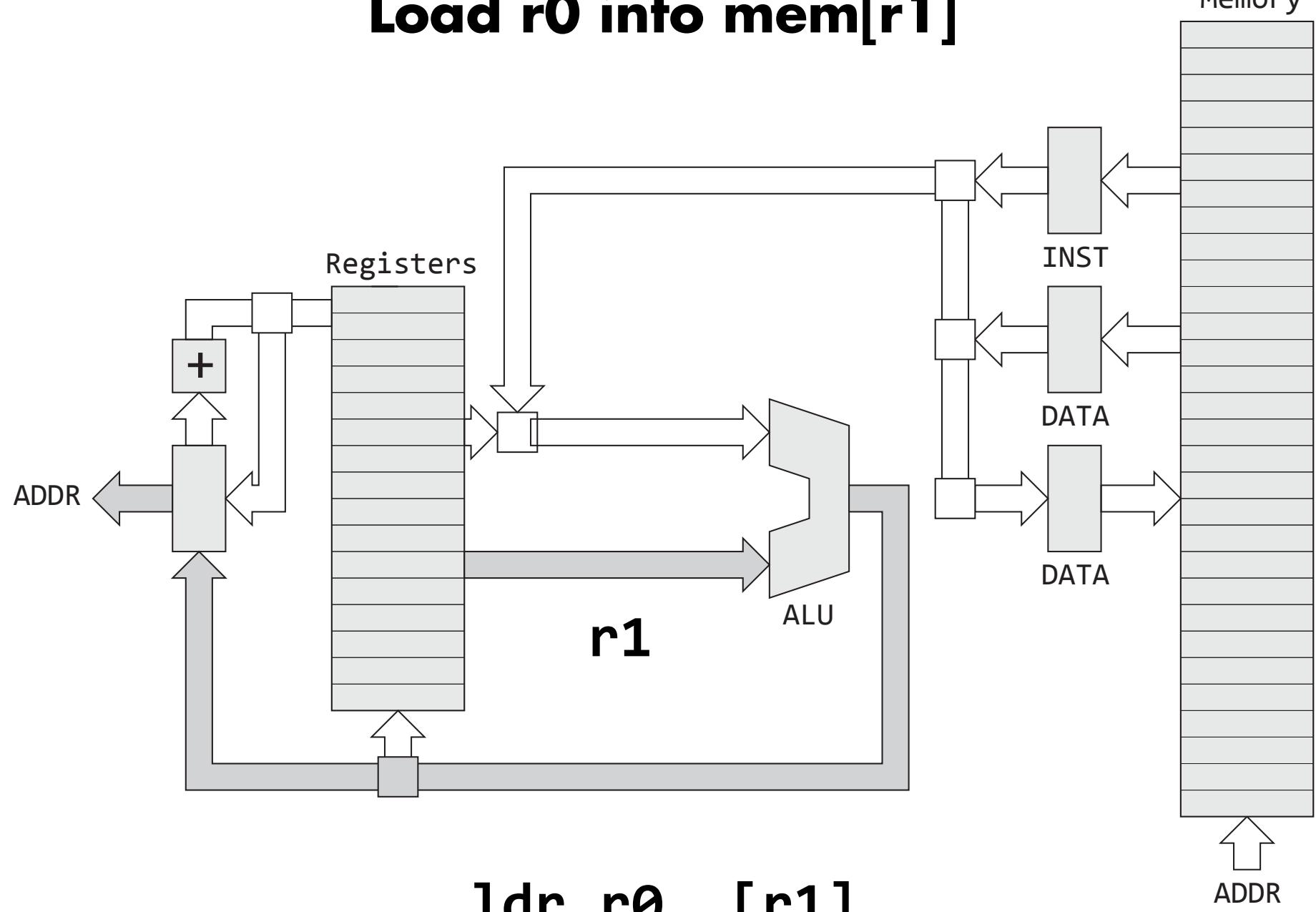
**Run tools on your personal computer**

**Tools prefixed with arm-none-eabi-**

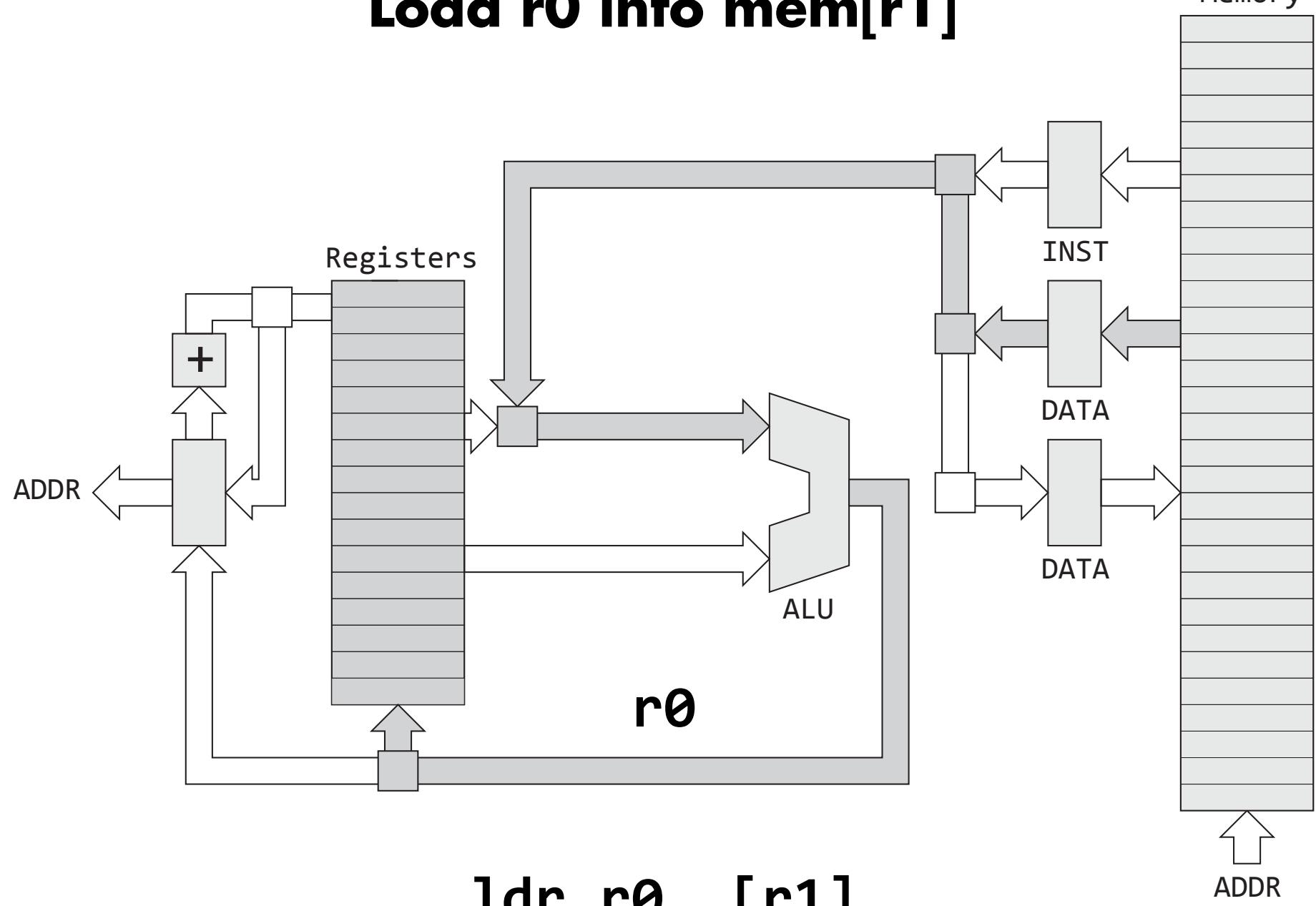
**Tools generate binary for raspberry pi**

# **Loads and Stores**

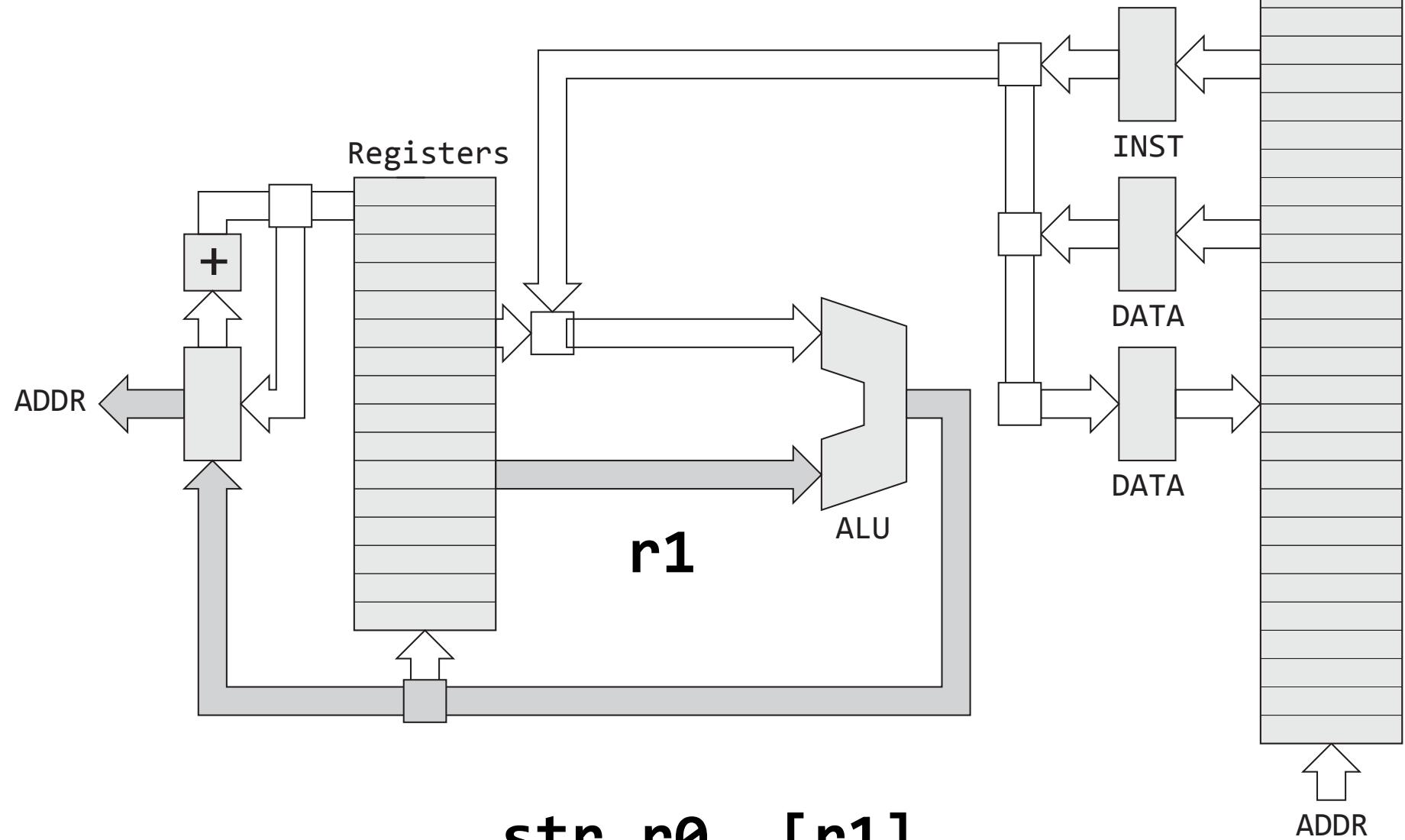
# Load r0 into mem[r1]



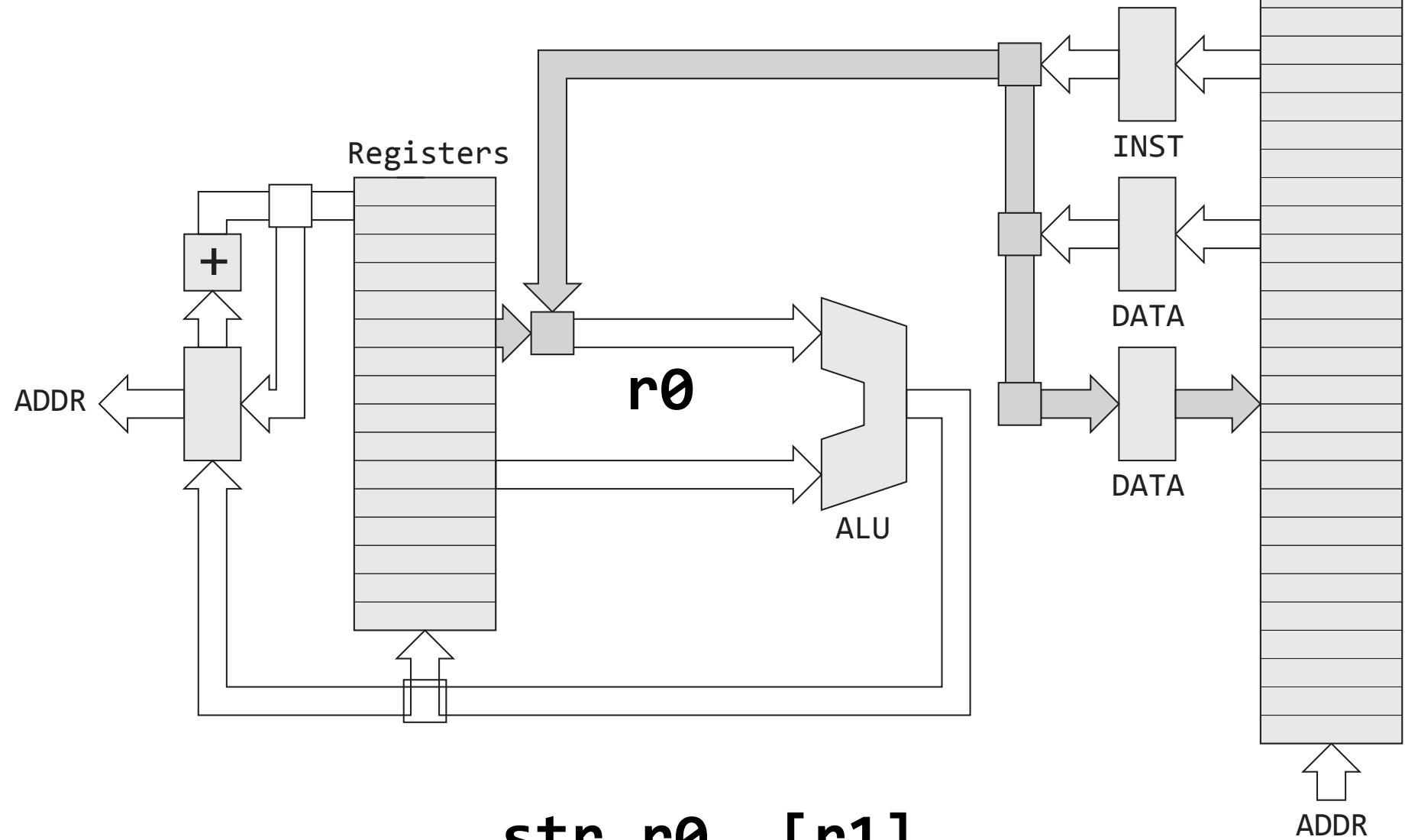
# Load r0 into mem[r1]



# Store r0 to mem[r1]



# Store r0 to mem[r1]



# **Conceptual Exercises**

- 1. Suppose you have 0x8000 stored in r0, how could you jump and start executing instructions at that location?**
- 2. All instructions are 32-bits. Can you add any 32-bit immediate constant to a register using the add instruction?**
- 3. What instruction do you think takes longer to execute, str or add?**

# **Turning on an LED**

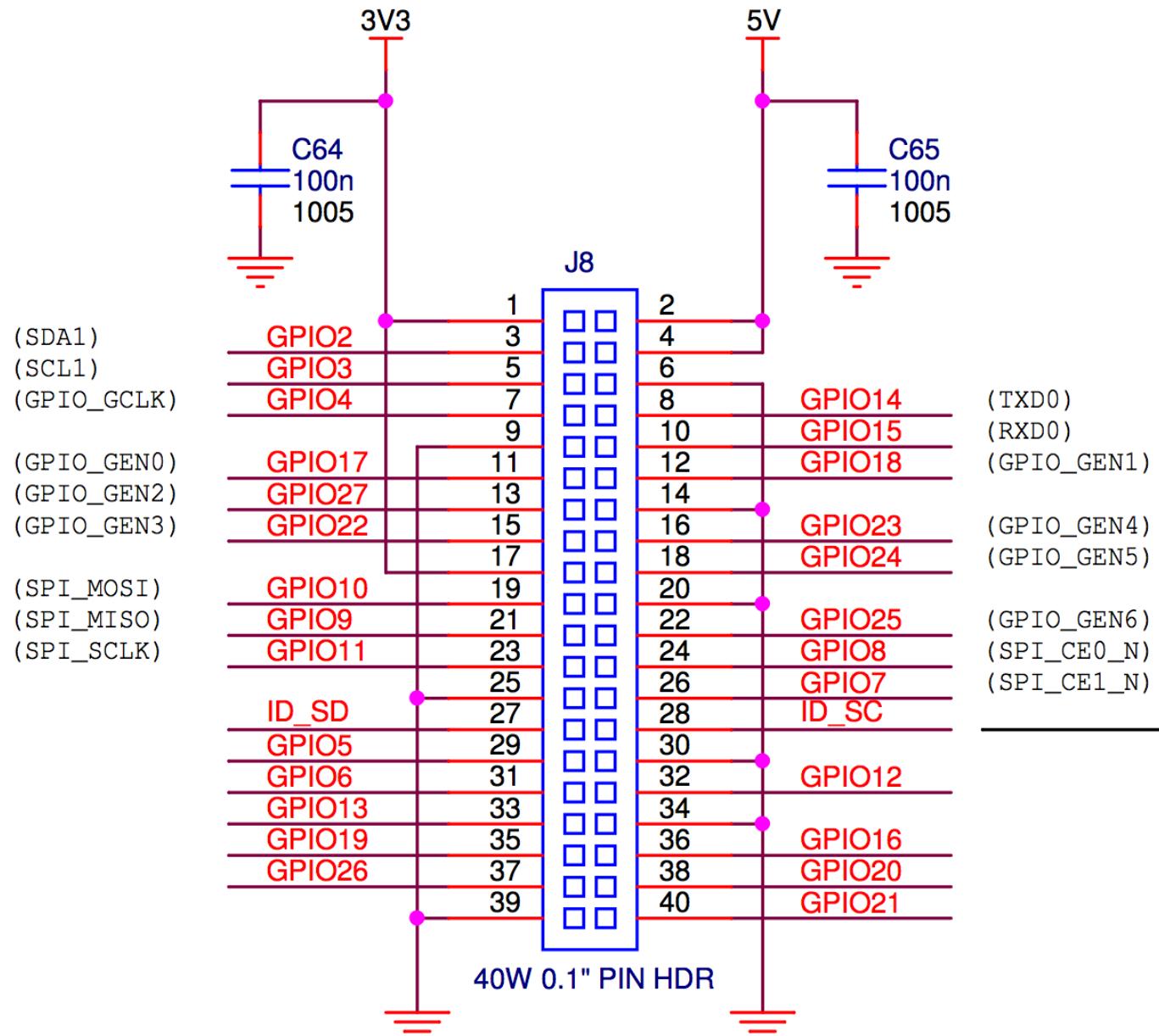
# **Powering**

**The USB port on my Macbook Pro provides 500 mA @ 5V**

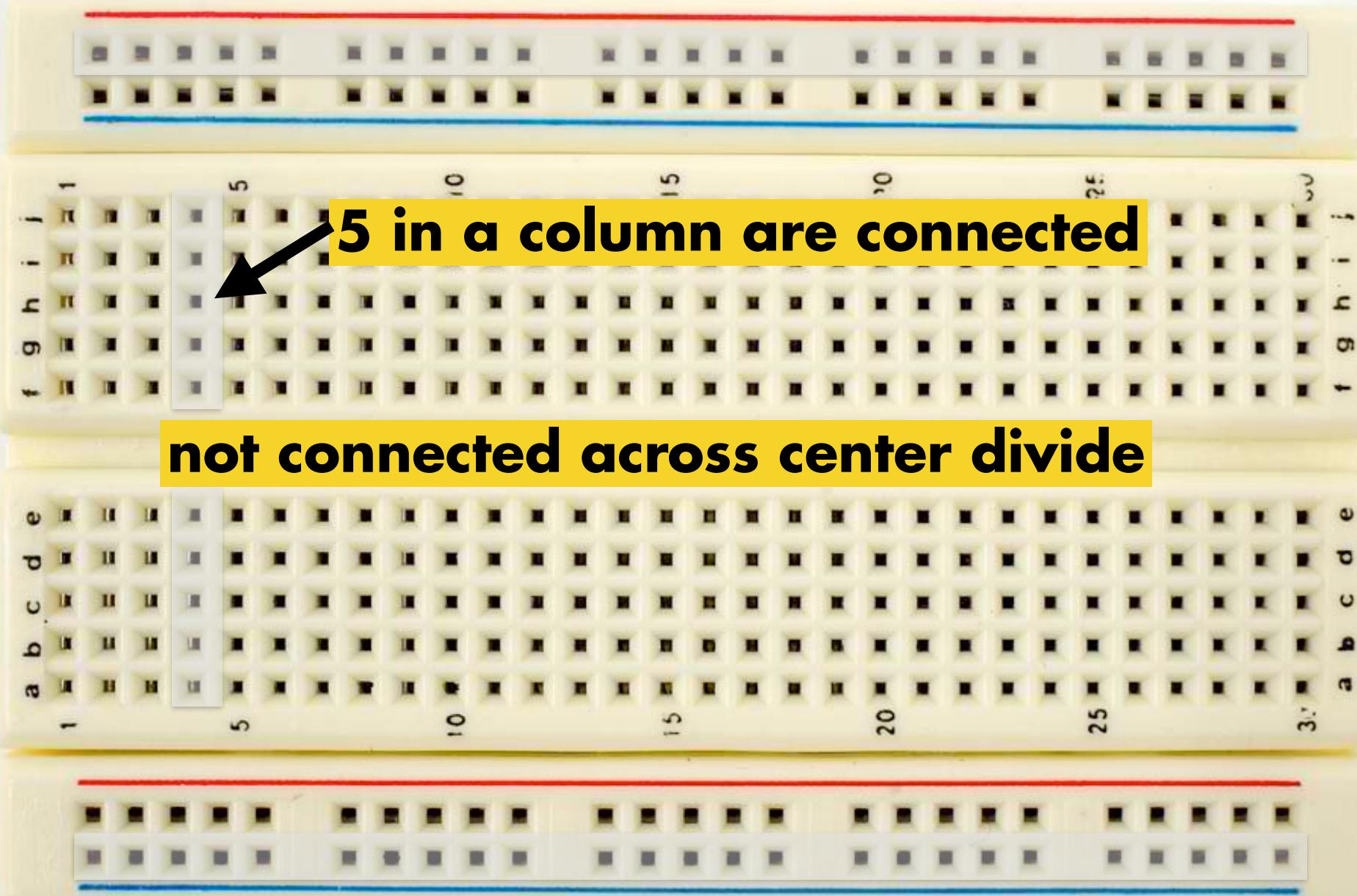
**Power can be provided through the GPIO header**

**How much power does the Pi need?**

# General-Purpose Input/Output (GPIO)

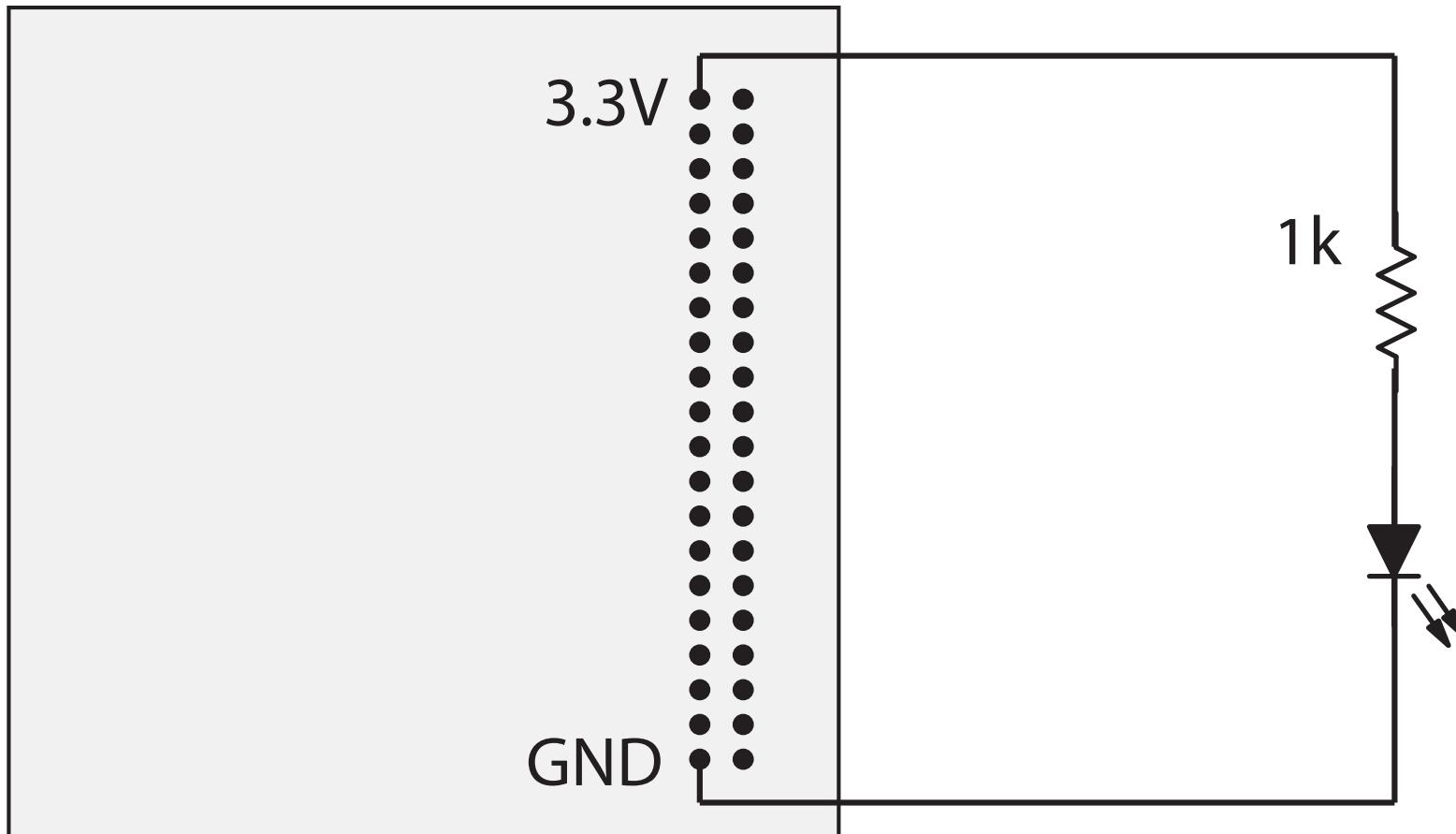


# Power

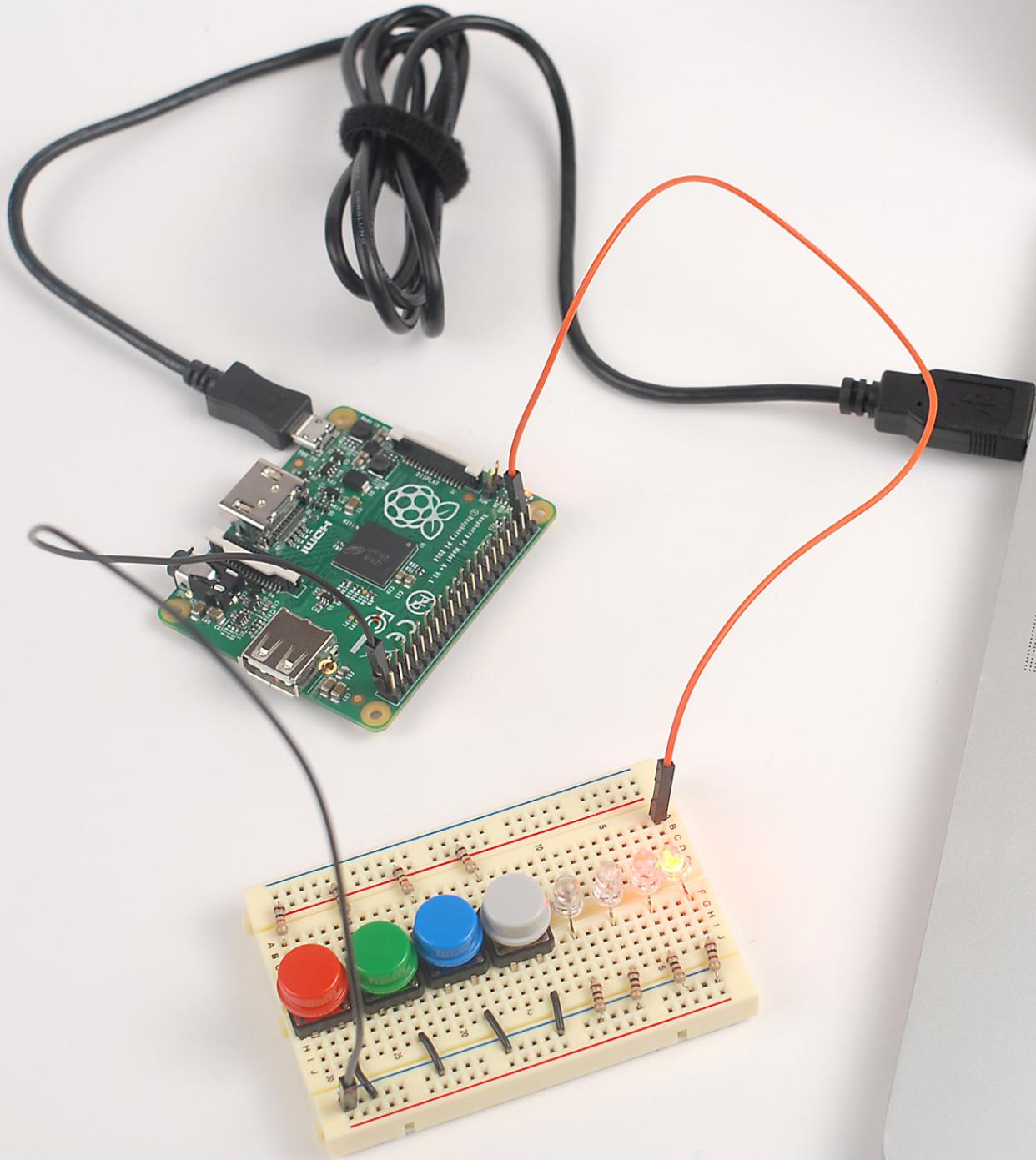


# Ground

**Logic 1 -> 3.3V (V<sub>cc</sub>)**  
**Logic 0 -> 0.0V (GND)**

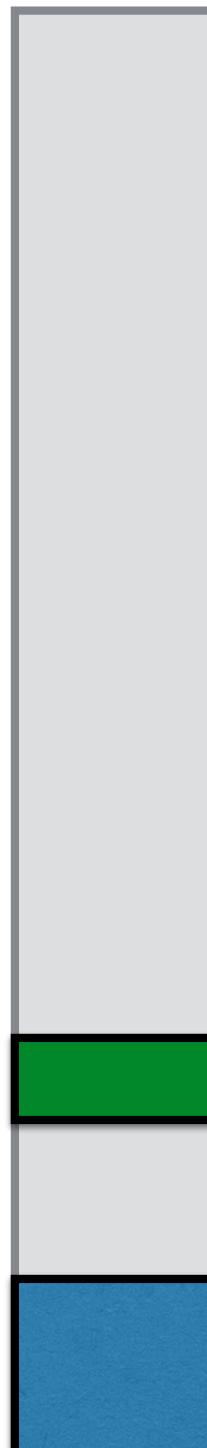


**From the datasheet: A maximum of 16mA per pin with the total current from all pins not exceeding 51mA.**



# **Controlling GPIO Pins**

# Memory Map



$100000000_{16}$   
**4 GB**

## Peripheral Registers

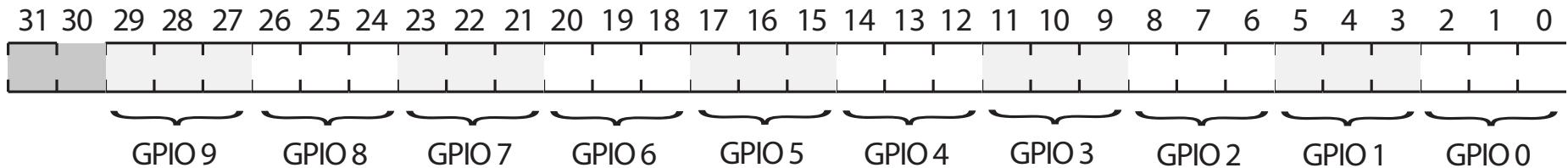
$020000000_{16}$   
 $010000000_{16}$

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	-	-

## Notes

1. 0x 7E00 0000 -> 0x 2000 0000
2. 54 GPIO pins
3. 3-bits per GPIO pin
4. => 6 GPIO function select registers

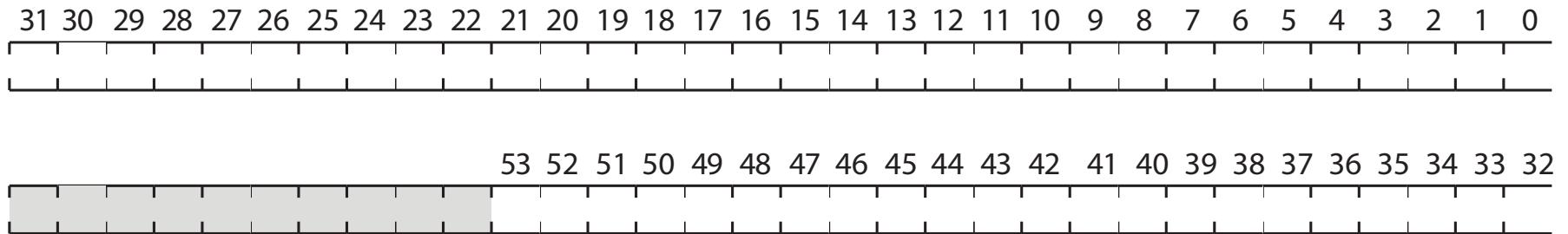
# GPIO Function Select Register



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

```
// Turn on an LED via GPIO 20  
  
// FSEL2 controls pins 20-29  
  
// load r0 with GPIO FSEL2 address  
ldr r0, =0x20200008  
  
// GPIO 20 function select is bits 0-2  
// load r1 with 1 (OUTPUT)  
mov r1, #1  
  
// store the value in r1  
// to the address in r0  
str r1, [r0]
```

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



...

```
// 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, #(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, #(1<<20)
```

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

```
// loop forever using a branch  
b .
```

```
# What to do on your laptop
```

```
# Assemble
```

```
% arm-none-eabi-as on.s -o on.o
```

```
# Create binary
```

```
% arm-none-eabi-objcopy on.o -O binary  
on.bin
```

```
# Copy to SD card
```

```
% cp on.bin /Volumes/BARE/kernel.img
```

```
# What to do on your laptop
```

```
# Insert SD card - Volume mounts
```

```
% ls /Volumes/
```

```
BARE Macintosh HD MobileBackups
```

```
# 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  
# PWR LED - 3.3V present  
# ACT LED - SD card access  
#  
# Raspberry pi boots  
#  
# LED connected to GPIO20 turns on!!  
#
```



# **Booting on Power On**

**1. Run hardware boot sequence**

**1. Initializes the processor and memory**

**2. Reads files from SDHC card**

**2. GPU runs bootcode.bin**

**3. GPU runs start.elf**

**4. GPU loads kernel.img at 0x8000**

**5. ARM processor jumps to 0x8000**

# **Memory-Mapped IO (MMIO)**

**Peripherals which control input and output devices are controlled by special peripheral registers.**

**These registers are mapped into the address space of the processor.**

**These registers may not behave as memory.**

- Memory stores values. If you write a value, then read it, you get the value you wrote.**
- Writing a 1 into a SET register sets the output; writing a 0 into a SET register does not effect the output value. Reading the SET register always returns 0**



**Details Omitted**

# **Definitive References**

**ARMv6 architecture reference manual**

**BCM2865 peripherals document + errata**

**Raspberry pi schematic**