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03 – ARM Assembly Language

CS1021 – Introduction to Computing I

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Registers

```
start
        MOV   total, a              ; Make the first number the subtotal
        ADD   total, total, b       ; Add the second number to the subtotal
        ADD   total, total, c       ; Add the third number to the subtotal
        ADD   total, total, d       ; Add the fourth number to the subtotal
```

Demo program from Lecture #1

Add four numbers together

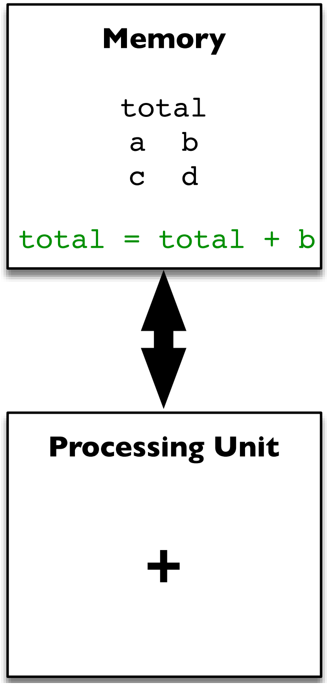
total = a + b + c + d

total, a, b, c, and d are stored in memory

operations (move and add) are performed in CPU

how many memory ↔ CPU transfers?

remember our
simple model of a
microprocessor system



Registers

total = total + b

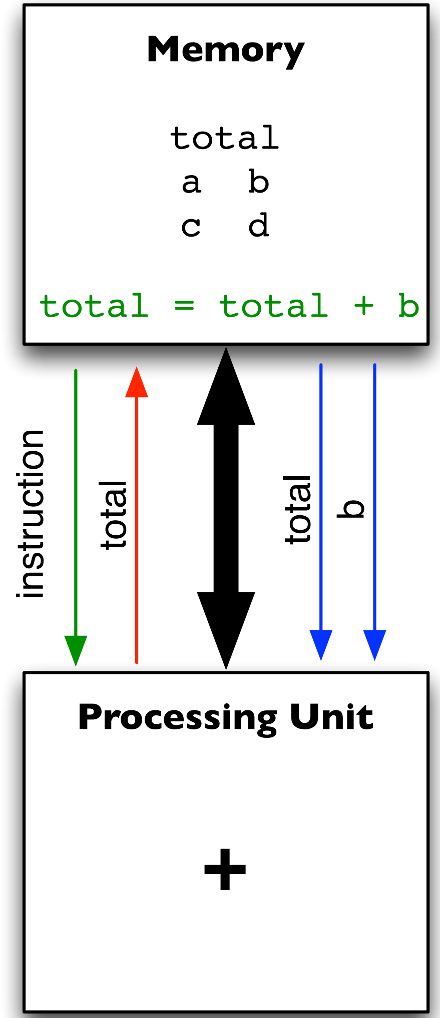
Load instruction from Memory to CPU

Load total from Memory to CPU

Load b from Memory to CPU

Compute total + b

Store total from CPU to Memory



Accessing memory is slow relative to the speed at which the processor can execute instructions

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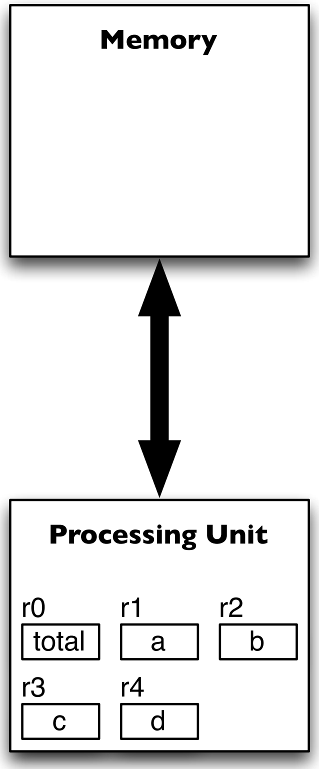
Processors use small fast internal storage to temporarily store values – called <u>registers</u>



ARM has 16 **word-size (32 bit)** registers

Labelled r0, r1, …, r15

r15 is special – the Program Counter

r13 and r14 are also special
(you should avoid using them for now)

Machine Code

A program (any program, originally written using any language) is composed of a sequence of machine code instructions that are stored in memory

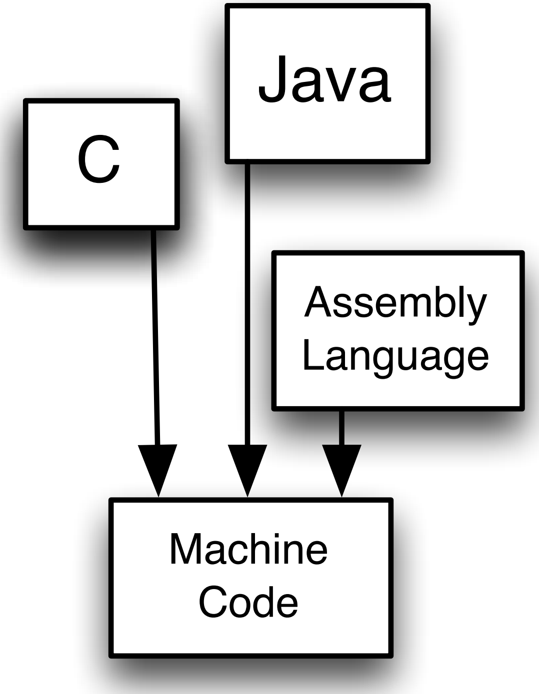
Instructions determine the operations performed by the processor (e.g. add, move, multiply, subtract, compare, ...)

A single instruction is composed of

- an operator (instruction)
- zero, one or more operands

Each instruction and its operands are encoded using a 32-bit value

- e.g. 0xE0810002 is the machine that causes the processor to add the values in r1 and r2 and store the result in r3



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Writing programs using machine code is possible …
… but not practical

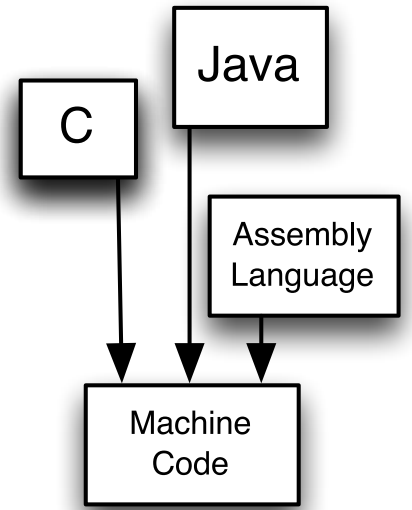
Instead, we write programs using assembly language

- Instructions are expressed using mnemonics
- e.g. the word "ADD" instead of the machine code 0xE08
- e.g. the expression "r2" to refer to register number two

Assembly language must still be translated into machine code

- Done using a program called an assembler
- Machine code produced by the assembler is stored in memory and executed by the processor

You writing a machine code program!!



Demo Program – ARM Assembly Language


```
start
        MOV   r0, r1                ; Make the first number the subtotal
        ADD   r0, r0, r2            ; Add the second number to the subtotal
        ADD   r0, r0, r3            ; Add the third number to the subtotal
        ADD   r0, r0, r4            ; Add the fourth number to the subtotal

stop    B     stop
```

Demo Program – Machine Code

We can observe generated machine code by examining the **`.lst`** file:

```
 1 00000000                   AREA            Demo, CODE, READONLY
 2 00000000                   IMPORT          main
 3 00000000                   EXPORT          start
 4 00000000
 5 00000000          start
 6 00000000 E1A00001          MOV             r0, r1
 7 00000004 E0800002          ADD             r0, r0, r2
 8 00000008 E0800003          ADD             r0, r0, r3
 9 0000000C E0800004          ADD             r0, r0, r4
10 00000010
11 00000010 EAFFFFFE
                     stop     B               stop
12 00000014
13 00000014                   END
```

line #

instruction address

machine code instructions

original assembly language

Machine Code and Assembly Language

Every ARM machine code instruction is 32-bits long

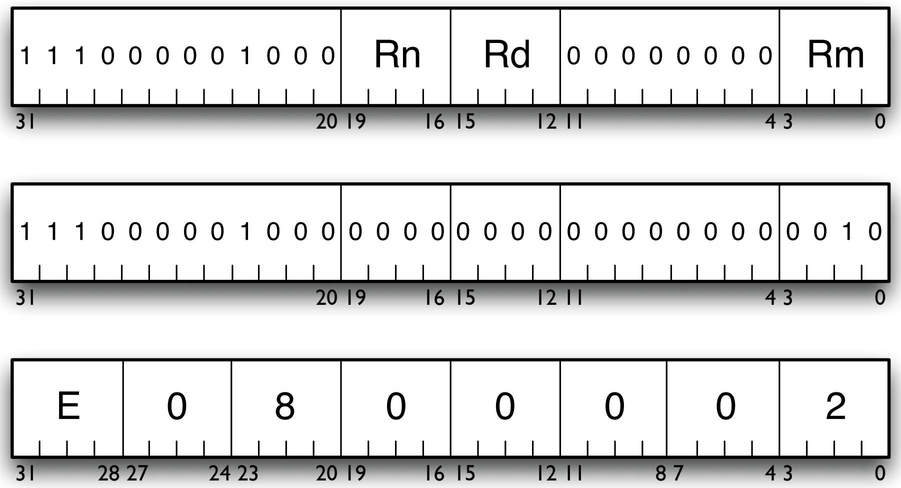
32-bit instruction word must encode

- operation (instruction)
- all the required instruction operands

Destination
Operand
Rd

Source
Operands
Rn, Rm

Example – `add r0, r0, r2`

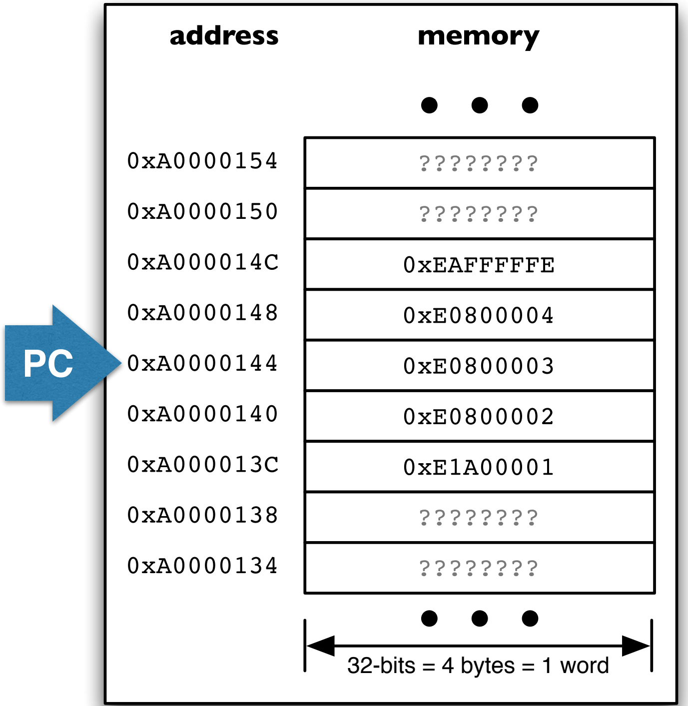


add instruction template

machine code binary

machine code hexadecimal

Instruction Execution

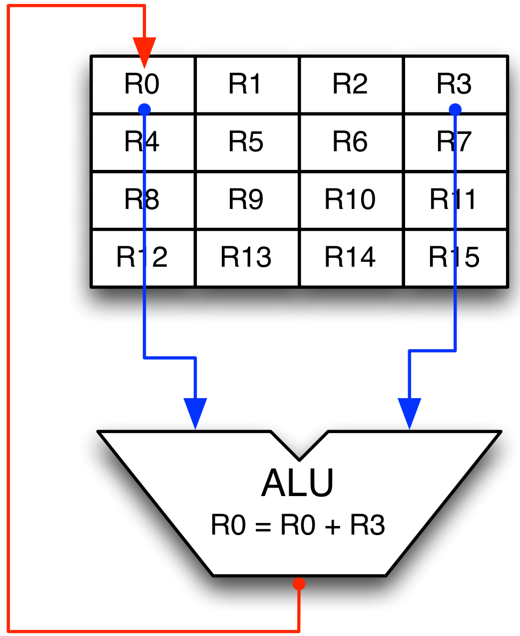


Fetch next instruction from memory at the address contained in the Program Counter (PC ≡ R15)

PC is advanced to next instruction (PC ⟵ PC + 4)

<u>**0xE0800003**</u>
operation: add
source R*n*: R0
source R*m*: R3
destination R*d*: R0

Machine Code instruction is decoded to determine operation and source / destination operands



Instruction is executed. (In this example the ALU adds the values in R0 and R3, storing the result back in R0.)

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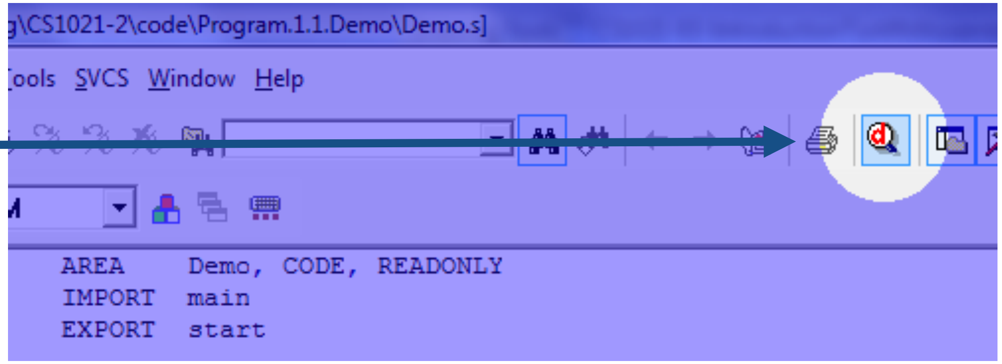
Program Execution (using uVision)

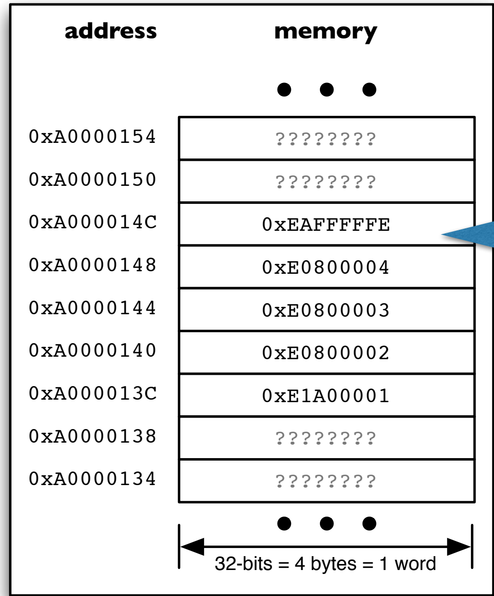
Start Debug session

Assembled program (Machine Code) loaded into memory as pre-defined address

Program Counter (PC ≡ R15) set to same pre-defined address

Fetch-Decode-Cycle resumes





What happens when we reach the end of our program?

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Program: Swap Registers

In-class exercise: Write a ARM Assembly Language program to swap the contents of registers R0 and R1

Bonus exercise: swap the contents of registers R0 and R1 without using an additional register – post your solution on blackboard!

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Immediate Operands

Register Operands

```
ADD   R0, R1, R2
MOV   R5, R2
```

Register Operand

Often want to use constant values, instead of registers

e.g. move the value 0 (zero) into register R3

```
MOV   R0, #0
```

Immediate Operands

e.g. set R1 = R2 + 1

```
ADD   R1, R2, #1
```


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Simple Arithmetic

Write an ARM Assembly Language program to compute $4x^2+3x$ if x is stored in register R1. Store the result in register R0.

```
start
        MUL   r0, r1, r1           ; result = x * x
        LDR   r2, =4               ; tmp = 4
        MUL   r0, r2, r0           ; result = 4 * x * x

        LDR   r2, =3               ; tmp = 3
        MUL   r2, r1, r2           ; tmp = x * tmp

        ADD   r0, r0, r1           ; result = result + tmp


stop    B     stop
```

cannot use MUL to multiply by a constant value *(a.k.a. immediate operand)*

MUL Rx, Rx, Ry produces unpredictable results

R1 is unmodified by our solution … which may be something we want … or maybe we don't care …

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LoaD Register (LDR)


```
...
LDR   r2, =3                ; tmp = 3
MUL   r2, r1, r2            ; tmp = x * tmp
...
```

Move constant value 3 into register R2

Loa**D** **R**egister instruction can be used to load any 32-bit signed constant value into a register

```
...
LDR   r4, =0xA000013C       ; r4 = 0xA000013C
...
```

Note use of **=x** syntax instead of **#x** with LDR instruction

MOV, LDR and Constant Values

Cannot fit large constant values in a 32-bit MOV instruction (Remember: all ARM instructions are 32-bit words)

```
        MOV   r0, #0x4FE8
```

```
error: A1510E: Immediate 0x00004FE8 cannot be represented by 0-255 and a rotation
```

LDR is a “pseudo-instruction” that simplifies the implementation of a work-around for this limitation

For small constant values, the Assembler quietly replaces the LDR instruction with a simple MOV instruction

```
        LDR   r0, =7
```

```
6 00000000 E3A00007         LDR                 r0, =7
```

```
        MOV   r0, #7
```

```
6 00000000 E3A00007         MOV                 r0, #7
```

Assembler transparently implements the work-around for us for large constant values

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Assembly Language Programming Guidelines

Provide meaningful comments and assume someone else will be reading your code

```
MUL   r2, r1, r2            ; r2 = r1 * r2
```

✗

```
MUL   r2, r1, r2            ; tmp = x * tmp
```

✓

Break your programs into small pieces separated by white space

While starting out, keep programs simple

Pay attention to initial values in registers (and memory)

don't assume everything is set to zero when you start / switch on!!