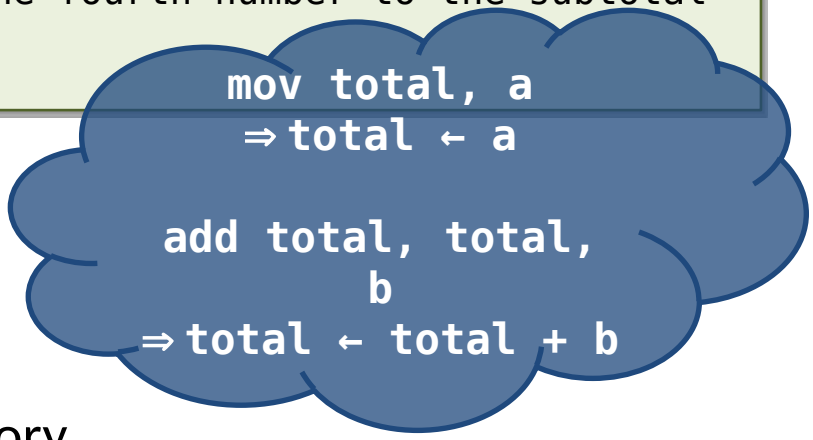
Registers

```
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

stop:       B       stop
```



- 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?**
- **Accessing memory is slow relative to the speed at which the processor can execute instructions**
- **Processors use small fast internal storage to temporarily store values – called registers**

ARMv5te Registers

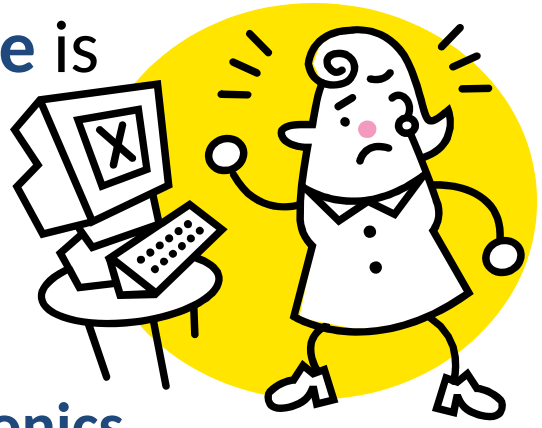
- **armv5te Registers**
  - **15 word-size registers, labelled r0, r1, …, r14**
  - **Program Counter Register, PC, also labelled r15**
  - **Current Program Status Register (CPSR)**

- Program Counter always contains the address in memory of the next instruction to be fetched
- CPSR contains information about the result of the last instruction executed (e.g. Was the result zero? Was the result negative?) and the status of the processor
- r13 and r14 are normally reserved for special purposes and you should avoid using them

Machine Code and Assembly Language

- A program is composed of a sequence of instructions stored in memory as **machine code**
  - 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**
- e.g. ADD the values in r1 and r2 and store the result in r0
  - Operator is ADD
  - Want to store the result in r0 (first operand)
  - We want to add the values in r1 and r2 (second and third operands)
- Each instruction and its operands are encoded using a unique 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

Machine Code and Assembly Language

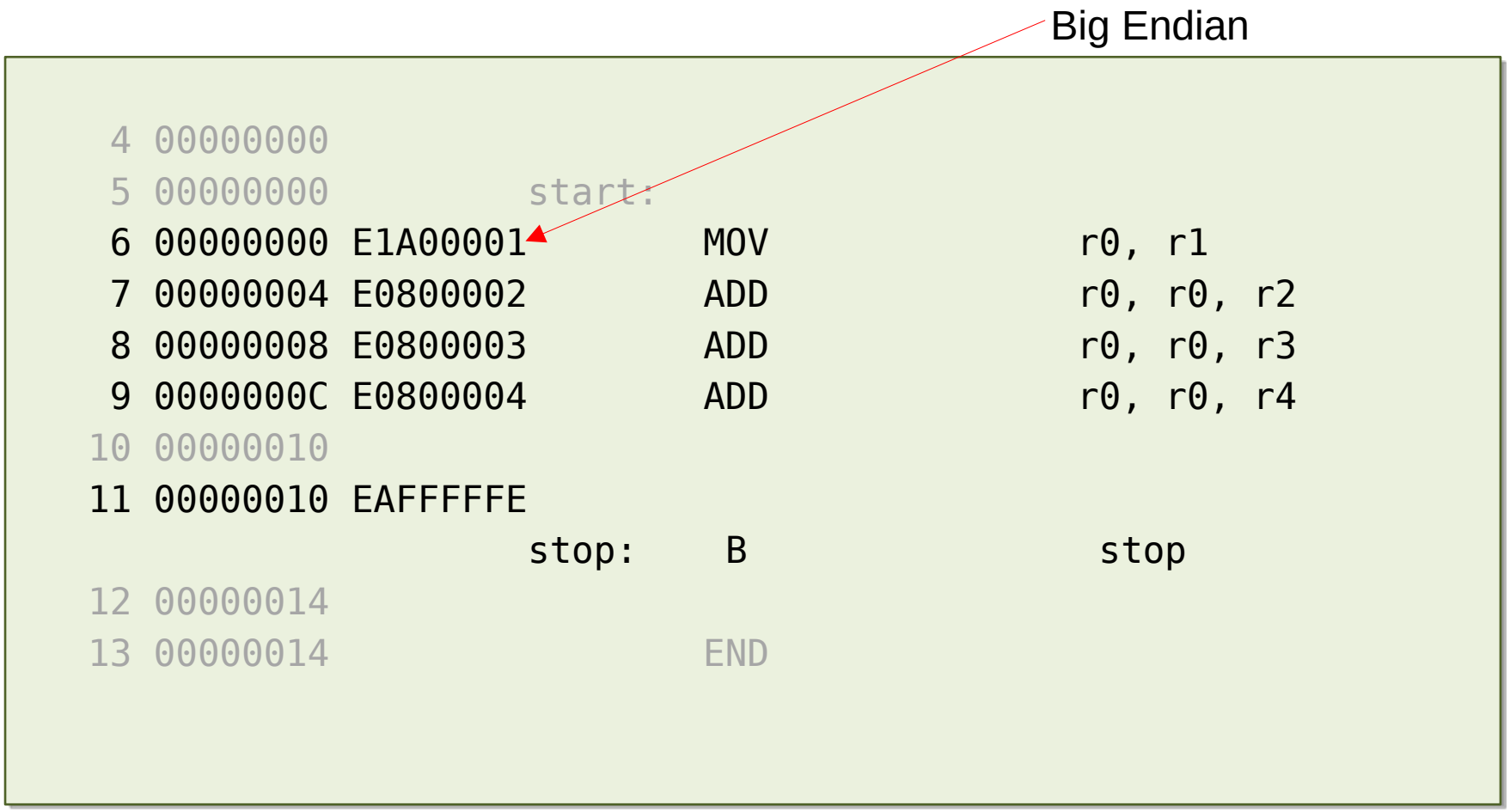


- Writing programs using **machine code** is possible but not practical
- Instead, we write programs using **assembly language**
  - Instructions are expressed using **mnemonics**
  - e.g. the word "`ADD`" instead of the machine code `0xE08`
  - e.g. the expression "r2" to refer to register number two, instead of the machine code value `0x2`
- 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

Program 1.1

```
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
```

Program 1.1 – Demonstration (Demo.lst)



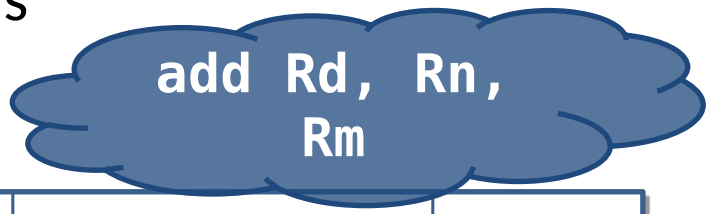
Little Endian

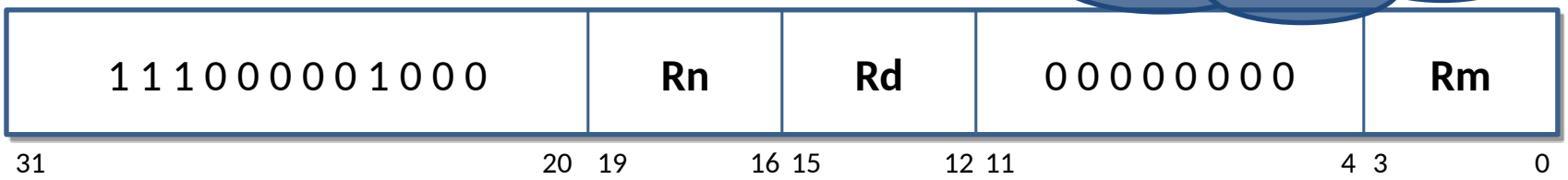
new step continue restart R0 set reg breakpoint

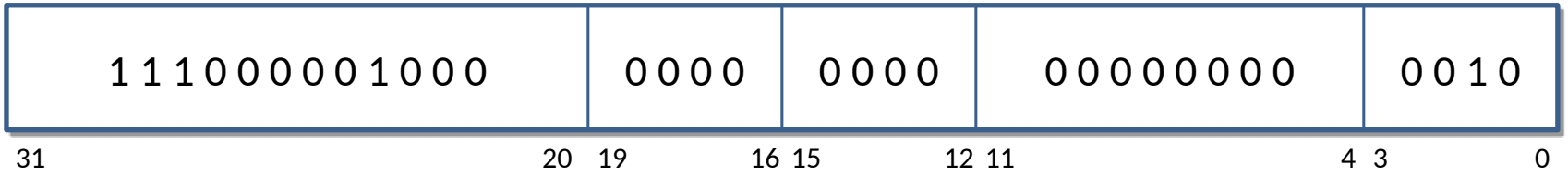
```
R00=00000000 R01=00000000 R02=00000000 R03=00000000  > 3 0000 0100A0E1                MOV     r0, r1
R04=00000000 R05=00000000 R06=00000000 R07=00000000    4 0004 020080E0                ADD     r0, r0, r2
R08=00000000 R09=00000000 R10=00000000 R11=00000000    5 0008 030080E0                ADD     r0, r0, r3
R12=00000000 R13=00000000 R14=00000000 R15=00000000    6 000c 040080E0                ADD     r0, r0, r4
PSR=400001d3 -Z--                                      8 0010 FEFFFFEA        stop:   B       stop

0xA1000400: 00 00 00 00 00 00 00 00
0xA1000408: 00 00 00 00 00 00 00 00
0xA1000410: 00 00 00 00 00 00 00 00
0xA1000418: 00 00 00 00 00 00 00 00
0xA1000420: 00 00 00 00 00 00 00 00
0xA1000428: 00 00 00 00 00 00 00 00
0xA1000430: 00 00 00 00 00 00 00 00
0xA1000438: 00 00 00 00 00 00 00 00
```

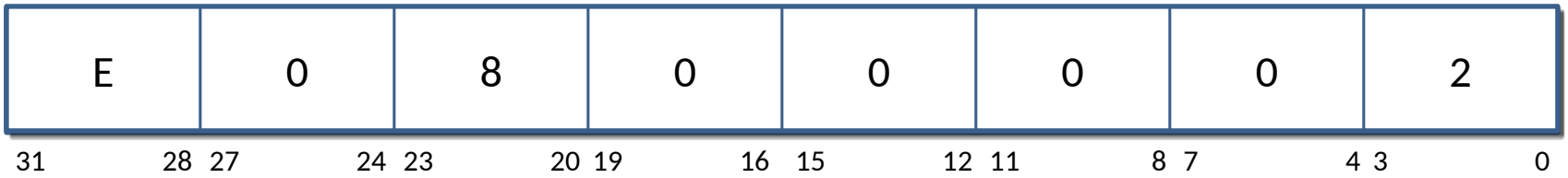
Machine Code and Assembly Language

- Every ARM machine code instruction is 32-bits long
- 32-bit instruction word must encode
  - operation (instruction)
  - all the required instruction operands
- Example – `add r0, r0, r2`

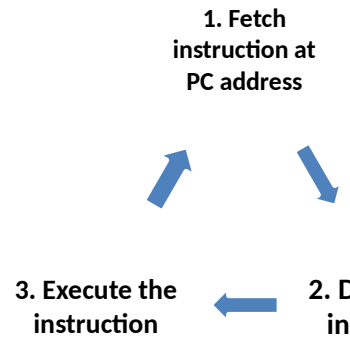


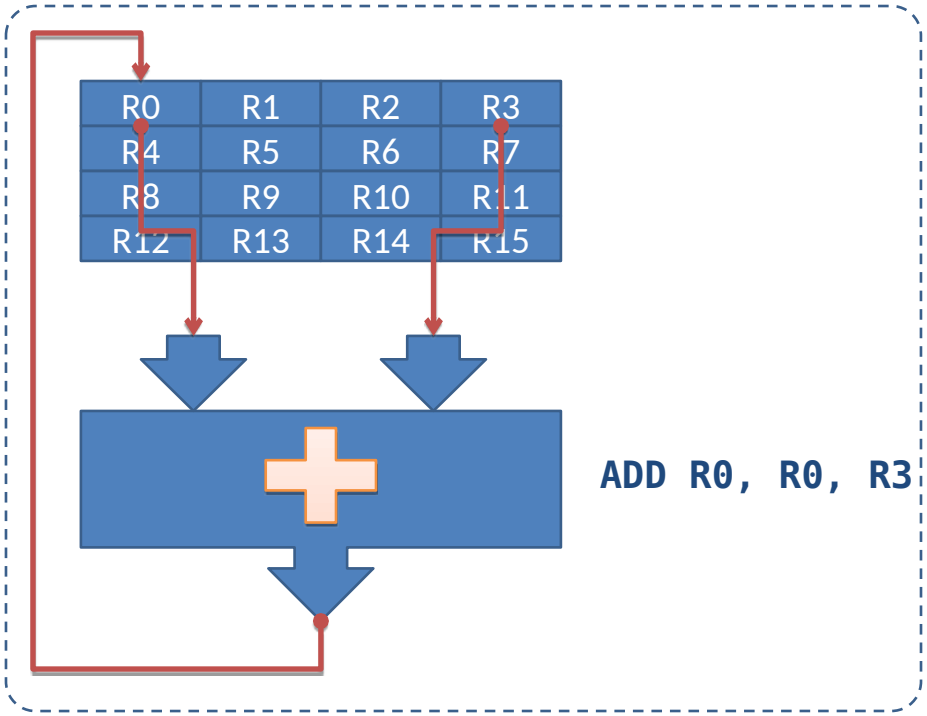


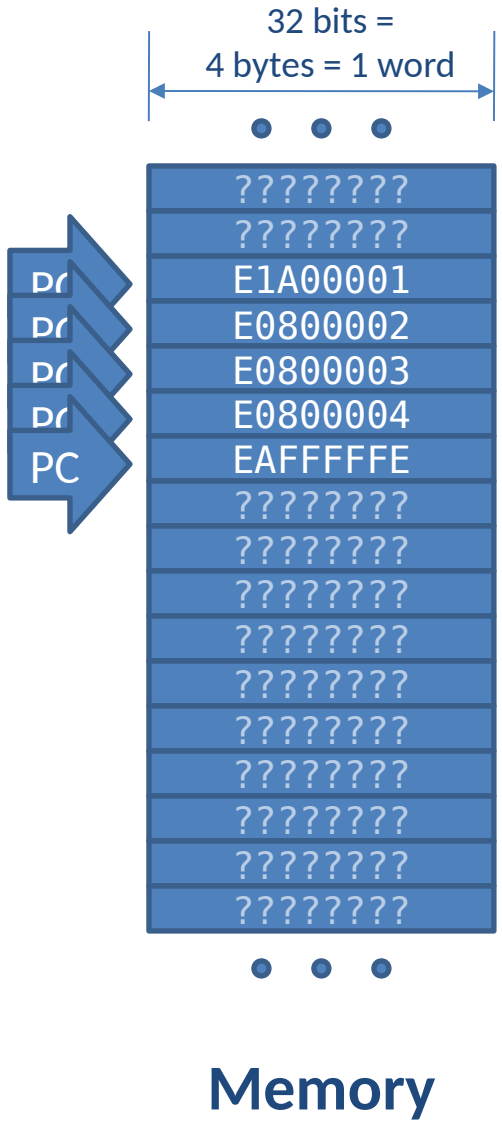




Machine Code and Assembly Language







Memory

Program 3.1 – Swap Registers

- Write an assembly language program to swap the contents of register `r0` and `r1`

```
start:
            MOV     r2, r0          @ temp <-- r0
            MOV     r0, r1          @ r0 <-- r1
            MOV     r1, r2          @ r1 <-- temp

stop:       B       stop
```

Compare both programs with respect to instructions executed and registers used …

```
start:
            EOR     r0, r0, r1      @ r0 <-- r0 xor r1
            EOR     r1, r0, r1      @ r1 <-- (r0 xor r1) xor r1 = r0
            EOR     r0, r0, r1      @ r0 <-- (r0 xor r1) xor r0 = r1

stop:       B       stop
```

Immediate Operands

- Register operands

ADD Rd, Rn, Rm

MOV Rd, Rm

- Often want to use constant values as operands, instead of registers

ADD Rd, Rn, #x

MOV Rd, #x

  - e.g. Move the value 0 (zero) into register r0

```
        MOV     r0, #0          @ r0 <-- 0
```

  - e.g. Set r1 = r2 + 1

```
        ADD     r1, r2, #1      @ r1 <-- r2 + 1
```

- Called an **immediate operand**, syntax **#x**

Program 3.2 – Simple Arithmetic

- Write an assembly language program to compute …

$$4x^2 + 3x$$

… if *x* is stored in `r1`. Store the result in `r0`

- Cannot use `MUL` to multiply by a constant value
- `MUL Rx, Rx, Ry` produces unpredictable results

LoaD Register

```
        ...     ...             ...

        LDR     r2, =3          @ tmp <-- 3
        MUL     r2, r1, r2      @ tmp <-- x * tmp

        ...     ...             ...
```

- Note use of operand **=3**
  - Move constant value **3** into register r2
- **LoaD Register** 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


```
            MOV     r0, #7
```

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

```
            LDR     r0, =7
```

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

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

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

```
            LDR     r0, =0x4FE8
```

```
6 00000000 E59F0000        LDR             r0, =0x4FE8
```

- Cannot fit large constant values in a 32-bit instruction
- LDR is a “pseudo-instruction” that simplifies the implementation of a work-around for this limitation
- For small constants, LDR is replaced with MOV

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
- While starting out, keep programs simple
- Pay attention to initial values in registers (and memory)