COMSM1302
Overview of Computer Architecture

Lecture 15

Performance Considerations in Assembly Programming

In the previous lecture

- Load and store instructions
  - Single register data transfer (LDR / STR).
  - Block data transfer (LDM/STM).
- Pre- and post- addressing modes
- Direct and sequential access of array elements
- Copy data blocks with Block data transfer instructions
- Stack

In this lecture

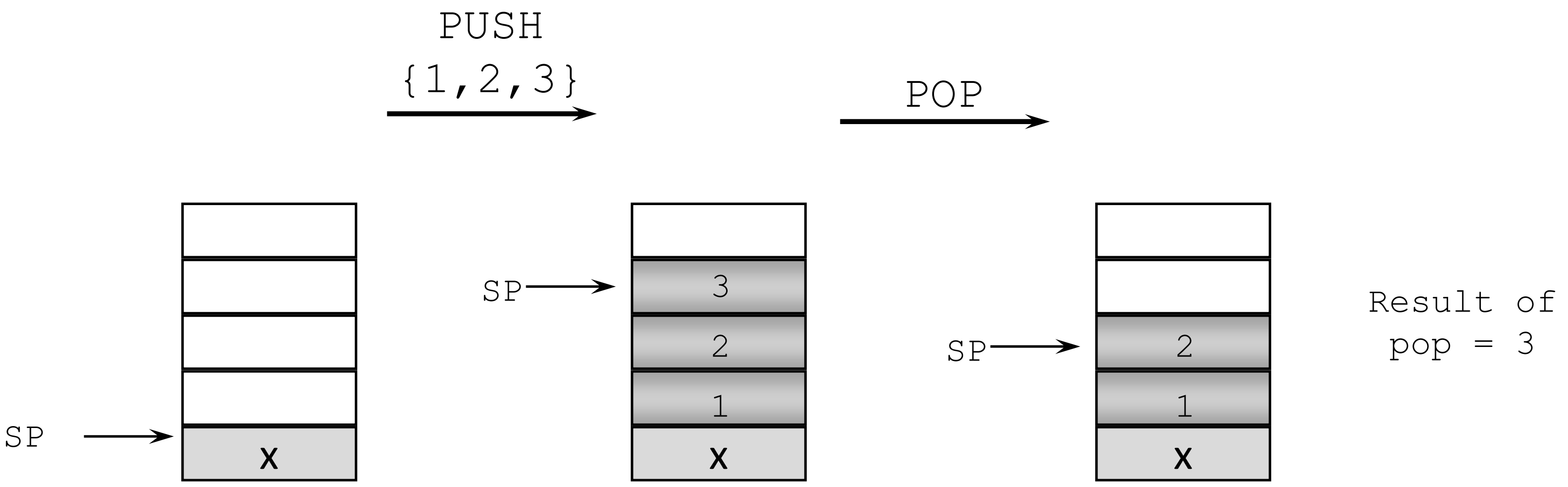
Example of using stack → Program performance measures → Performance considerations in ARM assembly programming

- At the end of this lecture:
  - Understand how the stack help us in tracking function calls.
  - Learn about programs performance measures.
  - Learn how to write efficient assembly programs.

Assembly programming performance

Example of using stack → Program performance measures → Performance considerations in ARM assembly programming

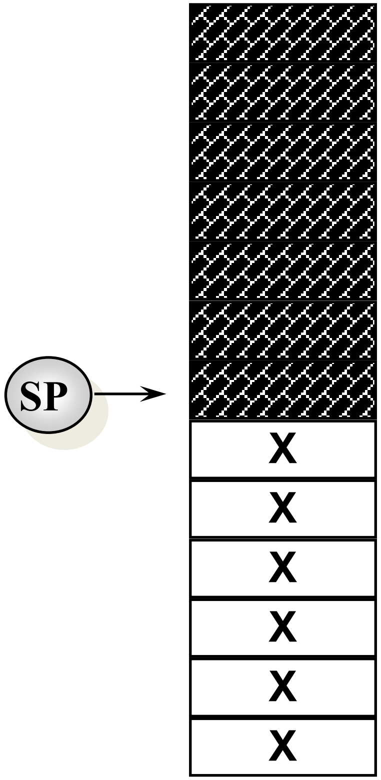
Stack



Stacks in ARM

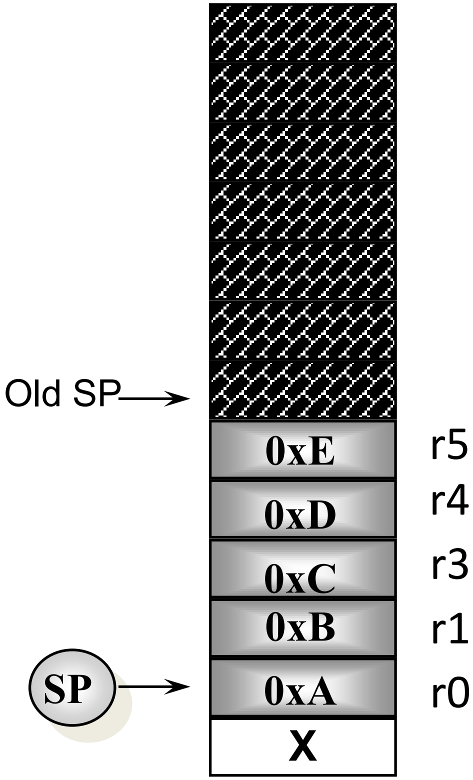
- The stack type to be used is given by the postfix to the instruction:
  - STMFD / LDMFD : Full Descending stack
  - STMFA / LDMFA : Full Ascending stack.
  - STMED / LDMED : Empty Descending stack
  - STMEA / LDMEA : Empty Ascending stack

Full Descending stack – 1/3



Register	Value
r0	0xA
r1	0xB
r3	0xC
r4	0xD
r5	0xE

```
STMFD sp!,
{r0,r1,r3-r5}
```

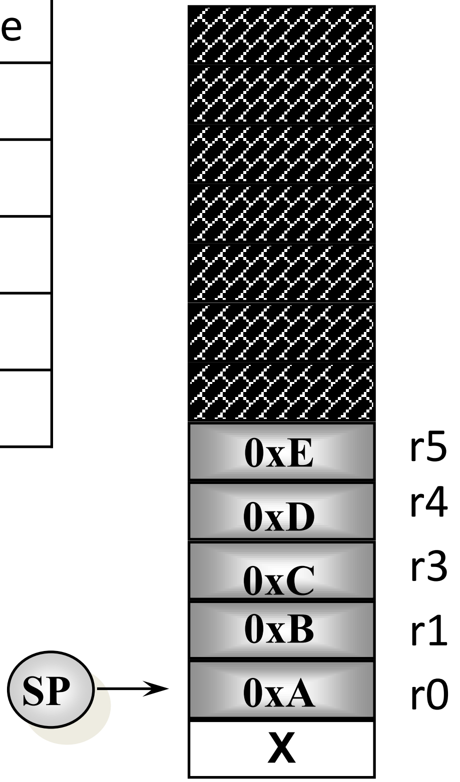


Full Descending stack – 2/3

Register	Value
r0	0xA
r1	0xB
r3	0xC
r4	0xD
r5	0xE

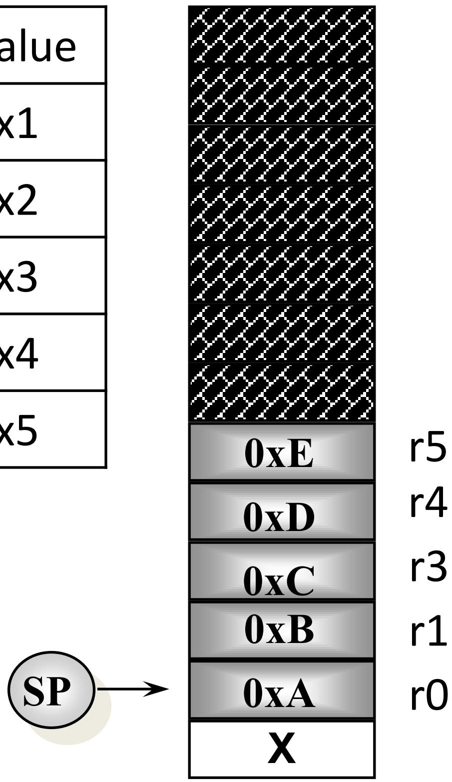
Some assembly code →

Register	Value
r0	0x1
r1	0x2
r3	0x3
r4	0x4
r5	0x5

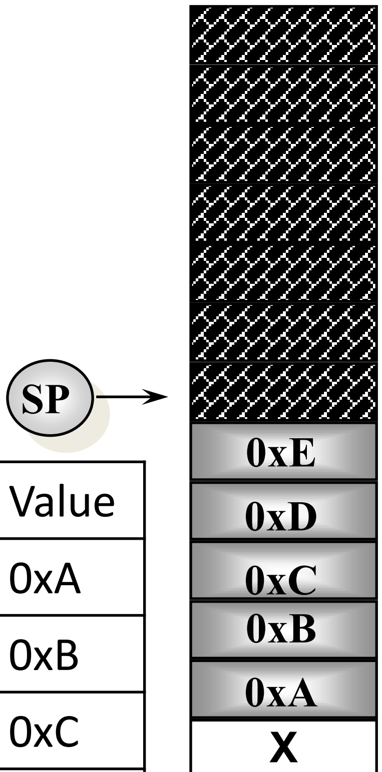


Full Descending stack – 3/3

Register	Value
r0	0x1
r1	0x2
r3	0x3
r4	0x4
r5	0x5

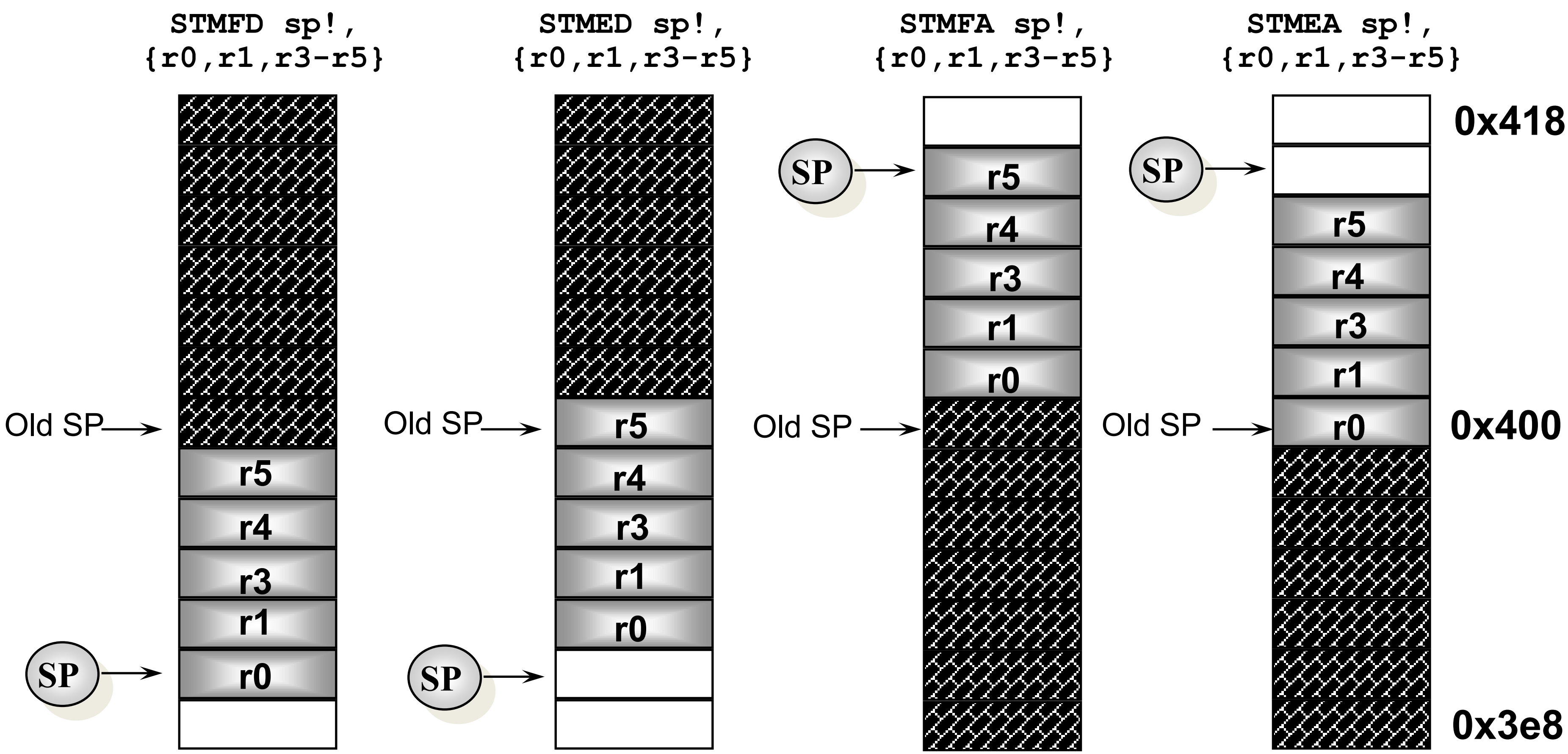



```
LDMFD sp!,
{r0,r1,r3-r5}
```



Register	Value
r0	0xA
r1	0xB
r3	0xC
r4	0xD
r5	0xE

ARM Stack Implementations



Example : factorial

- Factorial of a non-negative integer, is multiplication of all integers smaller than or equal to n. For example factorial of 4 is 4*3*2*1 which is 24.

- n! = n*(n-1)*(n-2)*(n-3)*…*1
- 4! = 4*(4-1)*(4-2)*(4-3) = 24

4 × 3 × 2 × 1 = 24

Factorial – recursive solution

- n! = n*(n-1)*(n-2)*(n-3)*…*1
- (n-1)! = (n-1)*((n-1)-1)*((n-1) -2)*…*1
- (n-1)! = (n-1)*(n-2)*(n-3)*…*1
- n! = n * (n-1)!
- n! = 1 if n = 0 or n = 1

Factorial – recursive solution – C code

```
// function to find factorial of given number
unsigned int factorial(unsigned int n)
{
   if (n == 0)
      return 1;
   return n * factorial(n - 1);
}
```

$n=0 \Rightarrow n! = 1$

$n=1 \Rightarrow 1 \times f(1-1) = 1 \times f(0) = 1$

$n! = 1$

1

Factorial – recursive solution – assembly code – 1/6

```
Ldr r0, =#3          0x0
bl _factorial        0x1   => Lr = 0x2
b _end               0x2

_factorial:
        cmp r0,#0
        moveq r0,#1
        moveq pc ,lr        0x2
```

```
if (n == 0)
    return 1;
```

$r_0 = 1$

```
_end: B _end
```

Factorial – recursive solution – assembly code – 2/6

```
Ldr r0, =#3
bl _factorial
b _end

_factorial:
        cmp r0,#0
        moveq r0,#1
        moveq pc ,lr
        mov r1,r0
        sub r0,r0,#1
        stmfd sp!,{r1,lr}
        bl _factorial
```

if (n == 0)
    return 1;

Save n and calculate n-1 then call factorial for n-1

$n \cdot f(n-1)$

n

$n-1$

$n-2$

n

$r_1 = 3$

$r_0 = 2$

$n-1$

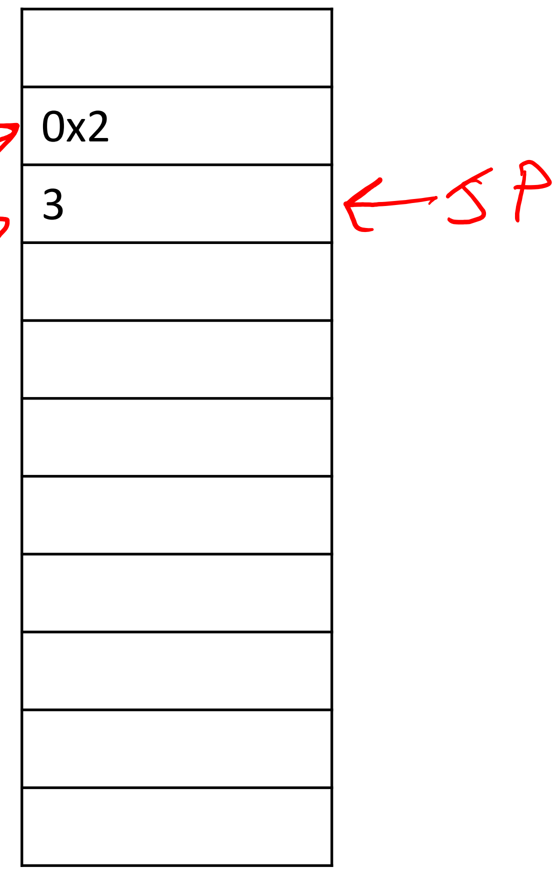
$r_0 = n-2$

$n-3$

Factorial – recursive solution – assembly code – 3/6

```
Ldr r0, =#3
bl _factorial          Lr = 0x2
b _end                         <- 0x2

_factorial:
        cmp r0,#0
        moveq r0,#1
        moveq pc ,lr
        mov r1,r0       3
        sub r0,r0,#1          0x2
        stmfd sp!,{r1,lr}
        bl _factorial
                                   <- 0xA
```



Factorial – recursive solution – assembly code – 4/6

```
Ldr r0, =#3
bl _factorial
b _end                <- 0x2

_factorial:   2
      cmp r0,#0
      moveq r0,#1
      moveq pc ,lr
      mov r1,r0        r1 = 2
      sub r0,r0,#1     r0 = 1
      stmfd sp!,{r1,lr}
      bl _factorial    Lr = 0xA
                       <- 0xA
```

0x2	
3	← SP
0xA	
2	← SP

Factorial – recursive solution – assembly code – 5/6

```
Ldr r0, =#3
bl _factorial
b _end                  <- 0x2

_factorial:
        cmp r0,#0
        moveq r0,#1
        moveq pc ,lr
        mov r1,r0          r1 = 1
        sub r0,r0,#1       r0 = 0
        stmfd sp!,{r1,lr}
        bl _factorial      lr = 0xA
                           <- 0xA
```

0x2	
3	
0xA	
2	← SP
0xA	
1	← SP

Factorial – recursive solution – assembly code – 6/6

```
Ldr r0, =#3
bl _factorial
b _end                         <- 0x2

_factorial:
        cmp r0,#0
        moveq r0,#1
        moveq pc ,lr
        mov r1,r0
        sub r0,r0,#1
        stmfd sp!,{r1,lr}
        bl _factorial
        lmdfd sp!, {r1,lr}   <- 0xA
        mul r0,r1,r0
        mov pc, lr
```

0x2
3
0xA
2
0xA
1

3! = 6

r0 = 0

r0 = 1

Lr = 0xA

r1 = 3

Lr = 0x2

r0 = 2 x 3 = 6 $\boxed{r_0 = 6}$

0x2

SP

SP

SP

Assembly programming performance

Example of using stack → Program performance measures → Performance considerations in ARM assembly programming

Program performance measures

- Program Execution Time
  - Worst-case execution time (WCET):
  - Best-case execution time (BCET)
  - Average-case execution time (ACET)
- Program Size: number of instructions in ARM
- Program Energy Consumption

Assembly programming performance

Example of using stack → Program performance measures → Performance considerations in ARM assembly programming

ARM assembly programming performance issues

- LDM /STM
- Conditional execution
- Using the barrel shifter
- Optimising register usage
- Loop unrolling
- Initiate a register with zero
- Addressing modes
- Multiplication / Division

LDM / STM

- Use LDM and STM instead of a sequence of LDR or STR instructions wherever possible.
  - The code is smaller.
  - An instruction fetch cycle can be saved for each eliminated LDR or STR.
  - Can turn non-sequential memory cycles into faster memory sequential cycles.

LDM / STDM - example

9 inst

```
MOV r1,#4
MOV r3,#0
LDR r0,=_data
_loop:
LDR r2, [r0], #4
ADD r3, r3, r2
SUBS r1,r1,#1
BNE _loop
STR r3, [r0]
_end: B _end
```

3

4x4 = 16

2

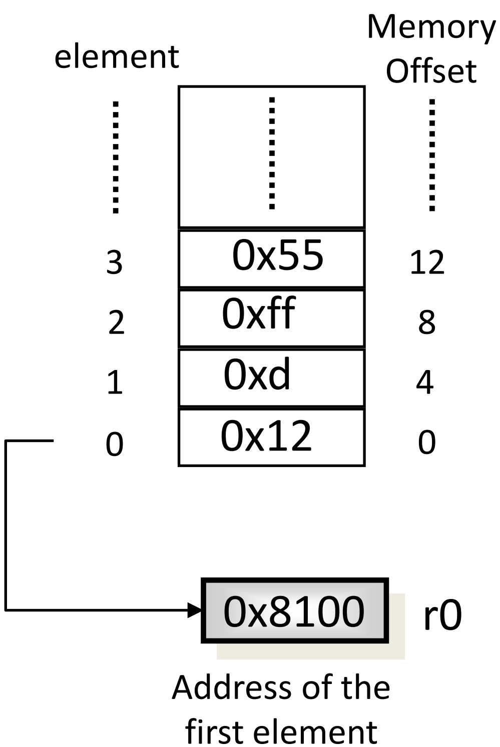
if = 3 + 16 + 2 = 21

8 inst.

```
MOV r3,#0
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```

8 if

$r_3 = r_3 + r_4 + r_5 + r_6$



Conditional execution

- Using conditionally executed instructions can avoid branches around short pieces of code.
  - This reduces the size of code

```
TST r0,#1
BLEQ _even:
_end: B _end

_even:
LSL r0,r0,#1
MOV r1,r0
MOV pc, lr
```

```
TST r0,#1
LSLEQ r0,r0,#1
MOVEQ r1,r0
_end: B _end
```

000 0
001 1
010 2
011 3
100 4
101 5
110 6
111 7
1000 8

101
001
001

100
001
000

Using the barrel shifter

- Combining shift operations with other operations can significantly increase the code density and thus performance.

```
TST r0,#1
LSLEQ r0,r0,#1
MOVEQ r1,r0
_end: B _end
```

```
TST r0,#1
MOVEQ r1,r0,LSL #1
_end: B _end
```

$r_1 = r_0 \times 2$

Conditional execution and barrel shifter example

```
TST r0,#1
BLEQ _even:
_end: B _end

_even:
LSL r0,r0,#1
MOV r1,r0
MOV pc, lr
```

```
TST r0,#1
LSLEQ r0,r0,#1
MOVEQ r1,r0
_end: B _end
```

```
TST r0,#1
MOVEQ r1,r0,LSL #1
_end: B _end
```

Optimising register usage

- Register spillage happens when we have more variables than the number of available registers.
  - a value has to be reloaded.
  - an intermediate value saved and then reloaded.

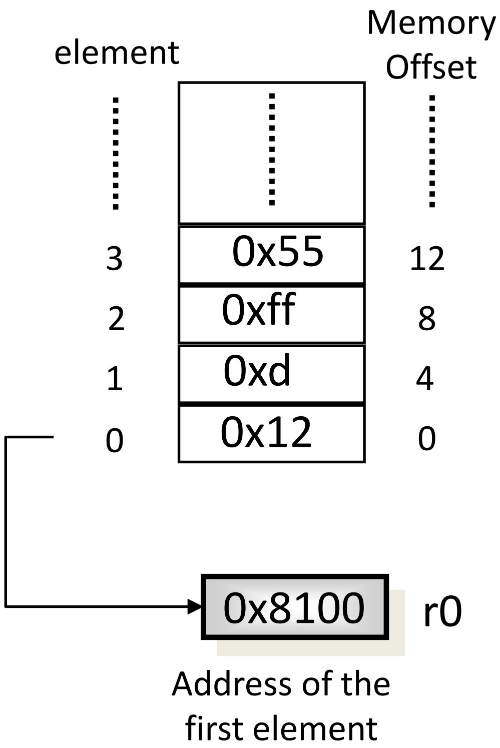
Loop unrolling

- Loop unrolling involves using more than one copy of the inner loop of an algorithm
  - The branch back to the beginning of the loop is executed less frequently.
  - it may be possible to combine some of one iteration with some of the next iteration, and thereby significantly reduce the cost of each iteration.

Loop unrolling - example

```
MOV r1,#4
MOV r3,#0
LDR r0,=_data
_loop:
LDR r2, [r0], #4
ADD r3, r3, r2
SUBS r1,r1,#1
BNE _loop
STR r3, [r0]
_end: B _end
```

```
MOV r3,#0
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```

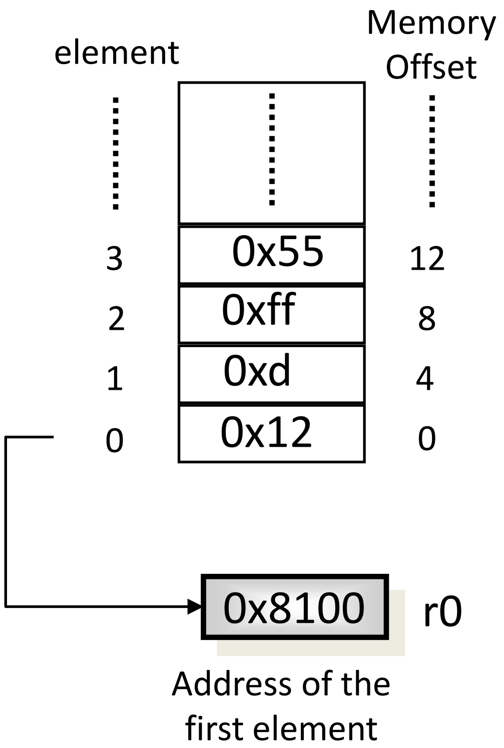


Initiate a register with zero

- What registers to reset and how?

```
MOV r3,#0
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```

```
EOR r3,r3,r3
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```

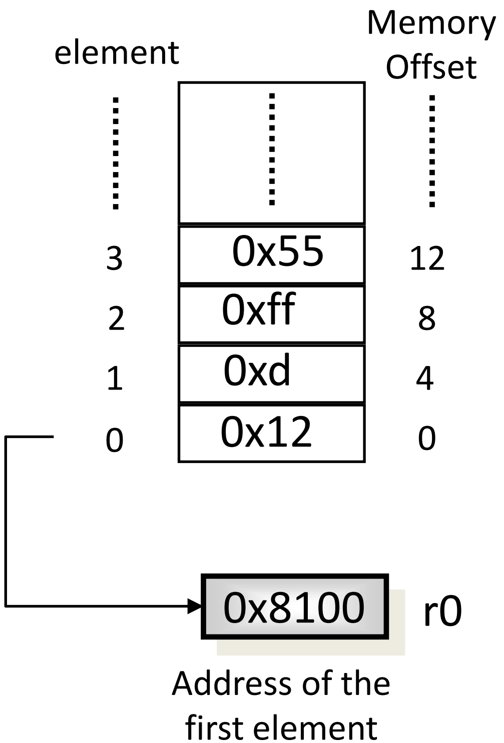


Initiate a register with zero

- What registers to reset and how?

```
MOV r3,#0
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```

```
EOR r3,r3,r3
LDR r0,=_data
LDMIA r0!, {r3-r6}
ADD r3, r3, r4
ADD r3, r3, r5
ADD r3, r3, r6
STR r3, [r0]
_end: B _end
```



Other performance issues

- **Addressing modes**
  - Using LDR or STR pre- or post-indexed with a non-zero offset increments the base register and performs the data transfer
- **Multiplication / Division**
  - Be aware of the time taken by the ARM multiply and division instructions

Summary

- Stack operation
- Recursive solution to compute the factorial of a given number.
- Programs performance measures
- How to write efficient assembly programs.