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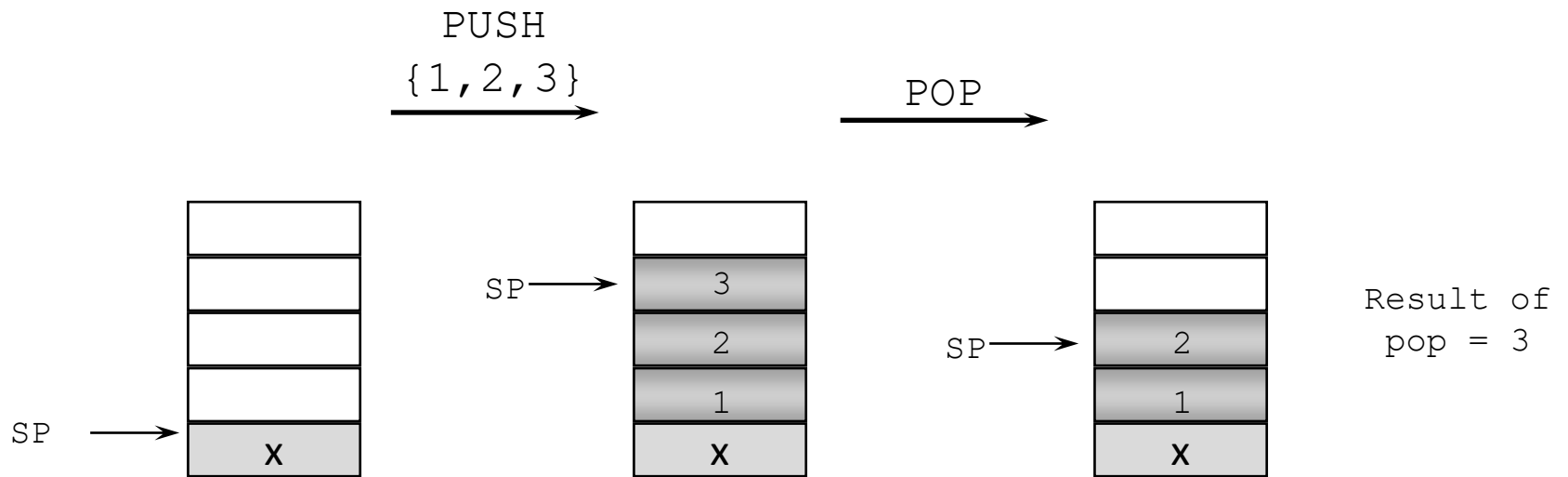
- At the end of this lecture:
  - Understand how the stack help us in tracking function calls.
  - Learn about programs performance measures.
  - Learn how to write efficient assembly programs.
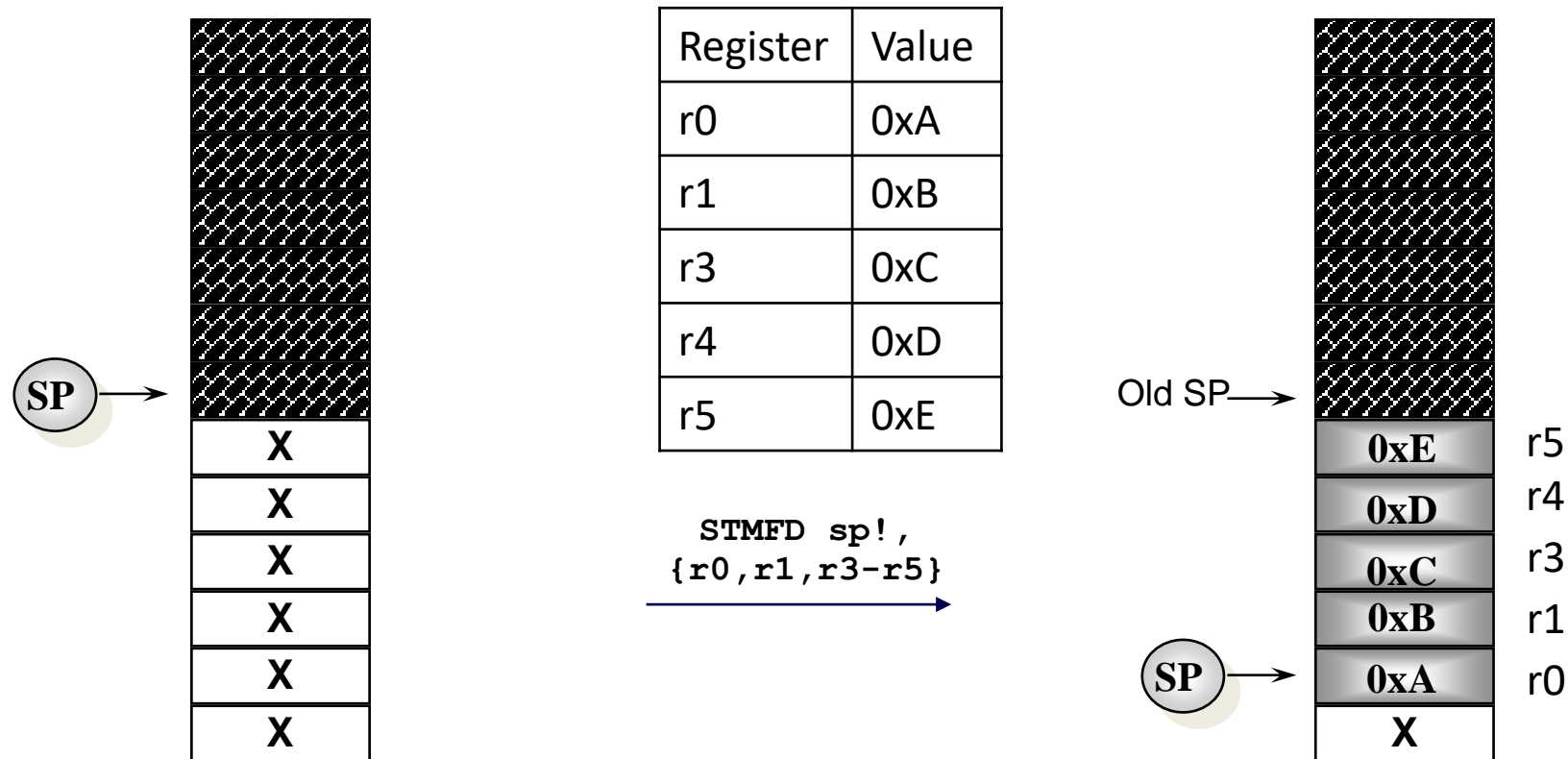
🔥 Assembly programming performance

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

🔥 Stack

PUSH
{1,2,3}

POP

SP →

3
2
1
X

SP →

SP →

2
1
X

SP →

Result of
pop = 3

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
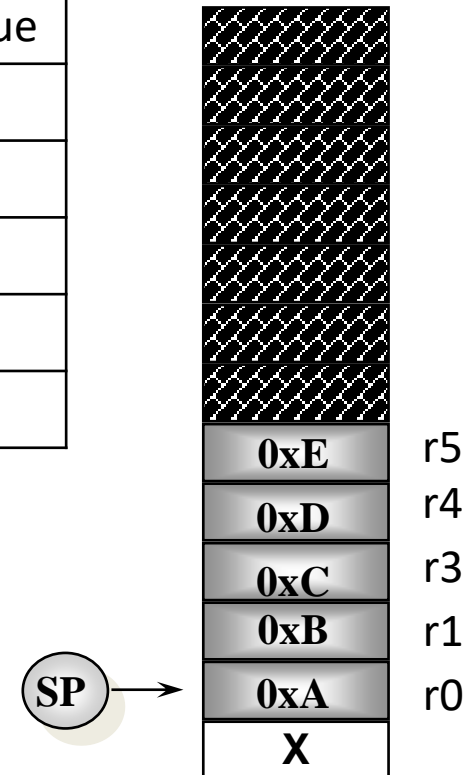
🎇 Full Descending stack – 1/3

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

SP →

X
X
X
X
X
X

```
STMFD sp!,
{r0,r1,r3-r5}
```
→

Old SP →

0xE	r5
0xD	r4
0xC	r3
0xB	r1
0xA	r0
X	

SP →

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🔥 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

0xE	r5
0xD	r4
0xC	r3
0xB	r1
0xA	r0
X	

SP →

🔥 Full Descending stack – 3/3

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

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

	0xE	r5
	0xD	r4
	0xC	r3
	0xB	r1
SP →	0xA	r0
	X	

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

SP →

0xE
0xD
0xC
0xB
0xA
X
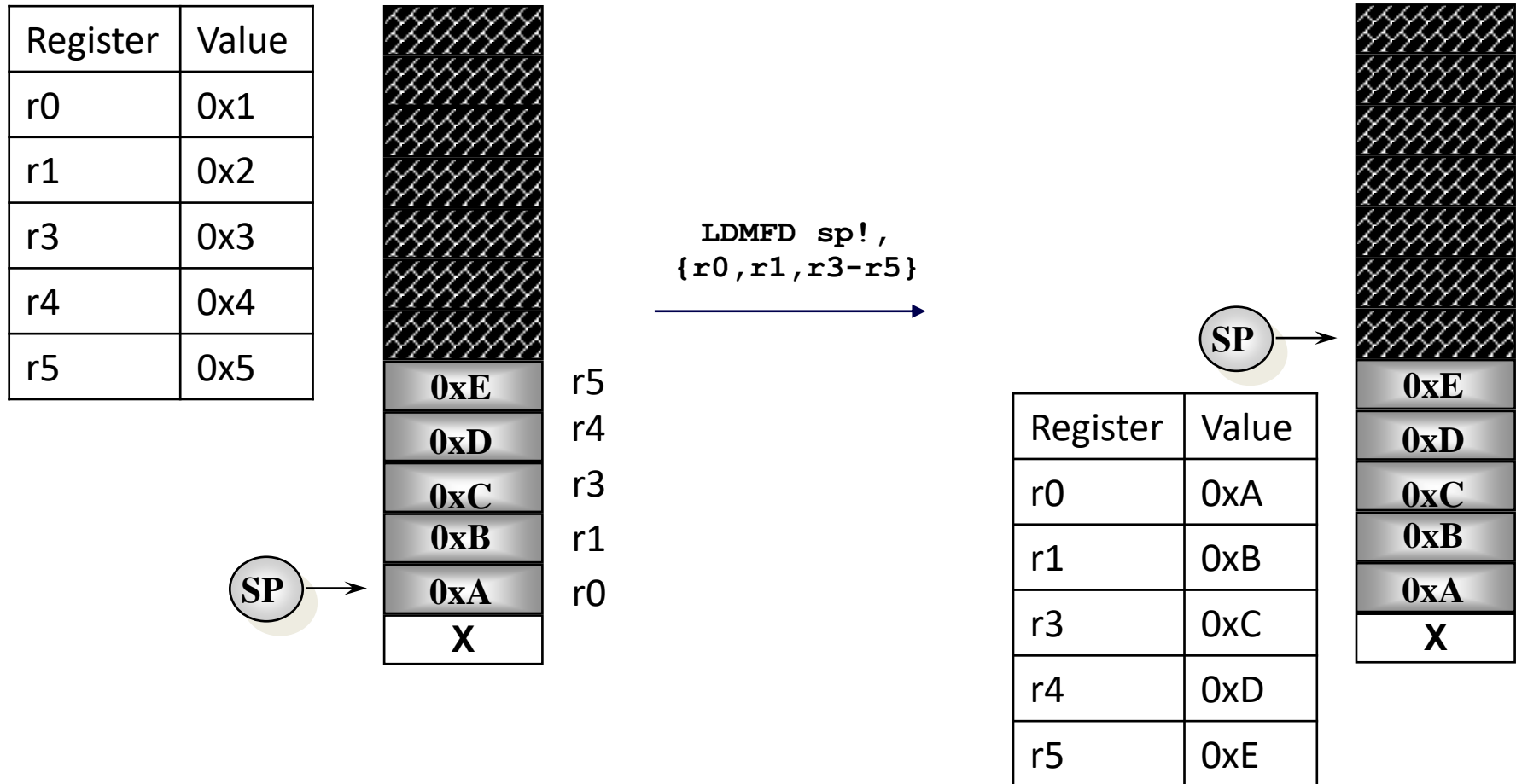
ARM Stack Implementations
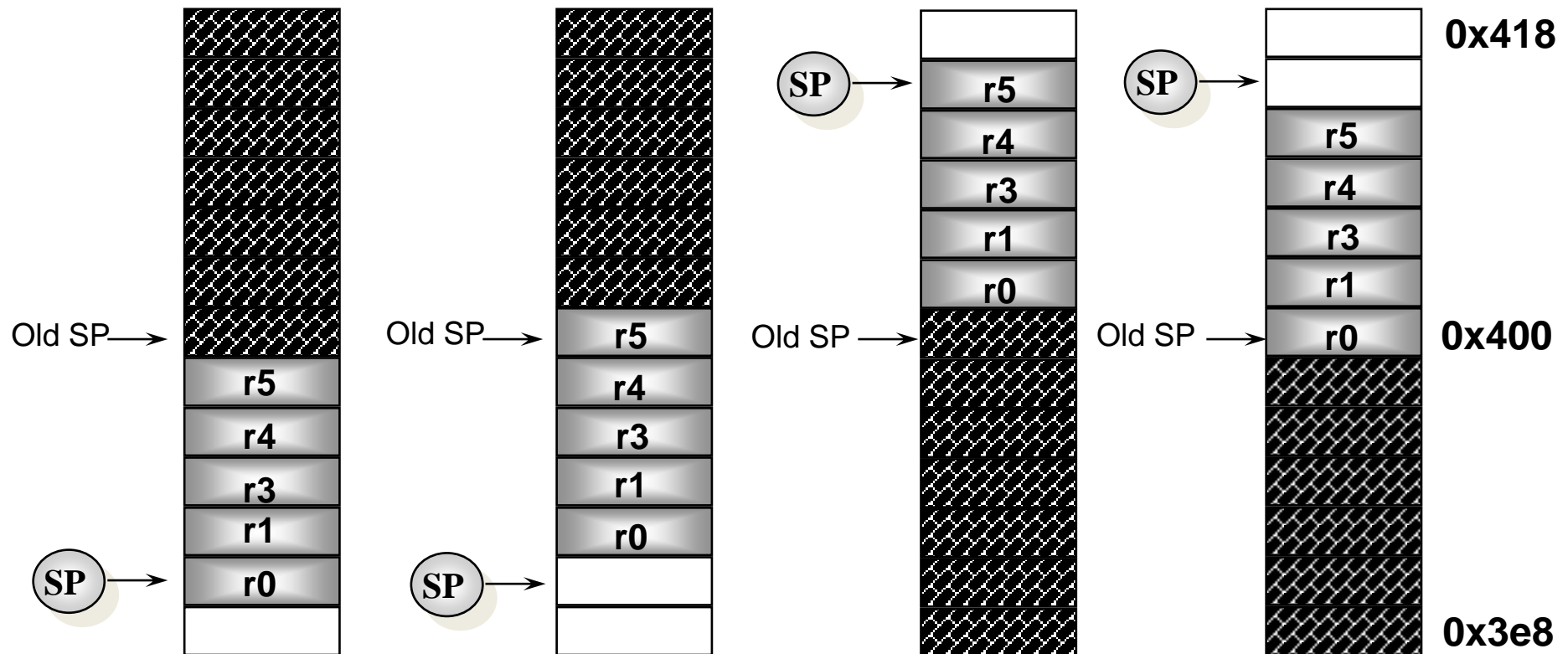
Example : factorial

- 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

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

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🎇 Factorial – recursive solution – C code

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

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

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

if (n == 0)
    return 1;

```
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

```
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
                          <- 0xA
```

0x2
3

```
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

                          <- 0xA
```

0x2
3
0xA
2

```
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
                          <- 0xA
```

0x2
3
0xA
2
0xA
1

```
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

🔥 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

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🔥 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
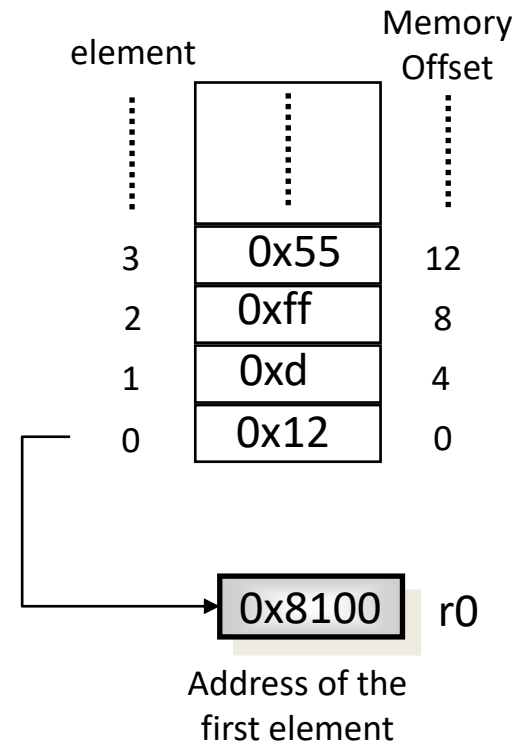
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LDM / STM

- 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

```
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
```

element		Memory Offset
	⋮	
3	0x55	12
2	0xff	8
1	0xd	4
0	0x12	0

0x8100 r0

Address of the
first element

🔥 Conditional execution

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

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

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

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🔥 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
```

🔥 Conditional execution and barrel shifter example

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

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

🔥 Optimising register usage

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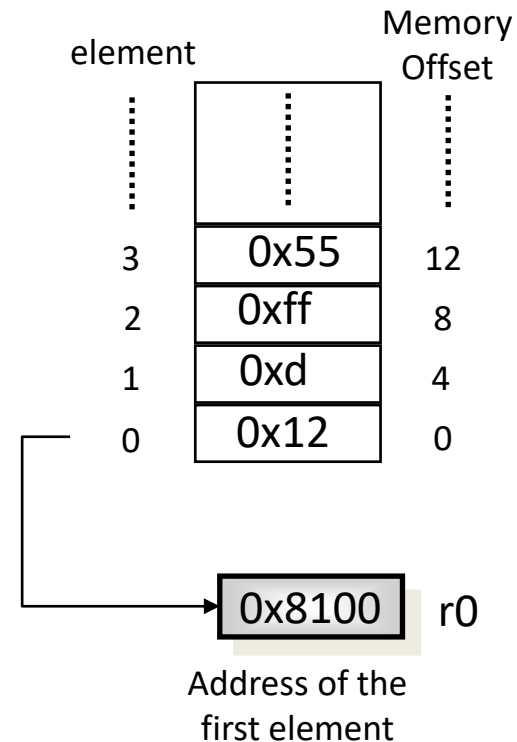 - an intermediate value saved and then reloaded.

🔥 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
```

element		Memory Offset
	⋮	
3	0x55	12
2	0xff	8
1	0xd	4
0	0x12	0

0x8100   r0

Address of the first element
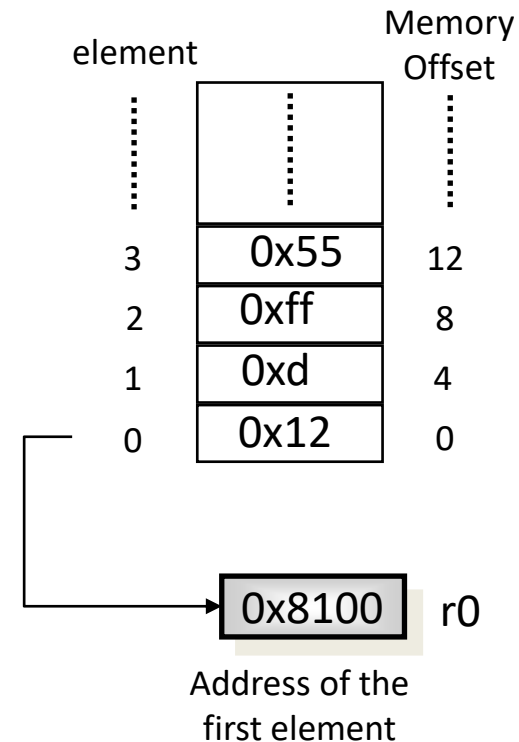
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🔥 Initiate a register with zero

- ## 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
```

element		Memory Offset
	⋮	⋮
3	0x55	12
2	0xff	8
1	0xd	4
0	0x12	0

0x8100 r0

Address of the first element

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🔥 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
```
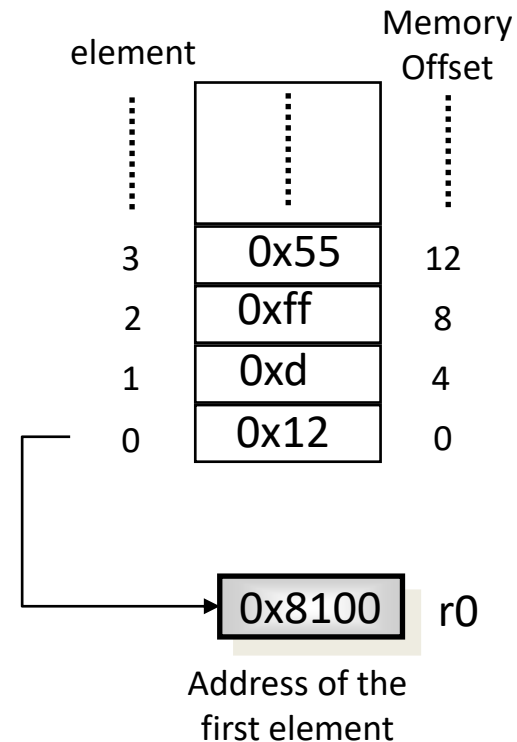
element		Memory Offset
⋮	⋮	⋮
3	0x55	12
2	0xff	8
1	0xd	4
0	0x12	0

0x8100   r0

Address of the first element

🔥 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

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🔥 Summary

- Stack operation

- Recursive solution to compute the factorial of a given number.

- Programs performance measures

- How to write efficient assembly programs.