Tutorial-7: The Stack

AbdulWahab Kabani

Outline

- The Stack – Introduction
- Push Instruction
  - Push Instruction (Efficient)
- Pull Instruction
  - Pull Instruction (Efficient)
- Subroutine
  - Subroutine – Problems
  - Subroutine – Efficient push/pull registers

Outline

- **The Stack – Introduction**
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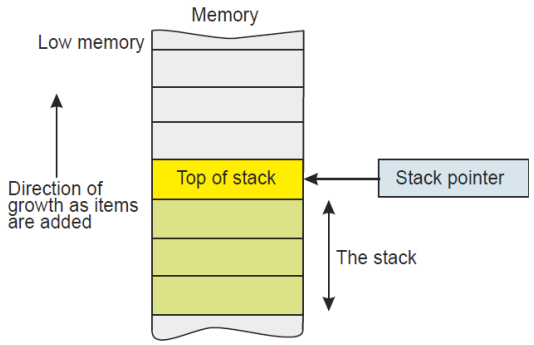
The Stack - Introduction

- Last-in-First-out
- Many applications:
  - Storing subroutine return address
  - Passing parameters from a program to a subroutine
  - Providing temporary storage (local workspace) in a subroutine.

The Stack - Introduction



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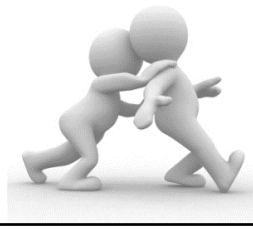
Push Instruction

- What is the register that is used as a stack pointer?
  - R13 or (SP)
- How can we **push** an item in register r0 to the stack?
  - Hint: update r13 and store the item in r0 in memory
    - SUB **r13**,r13,#4
    - STR r0,**[r13]**



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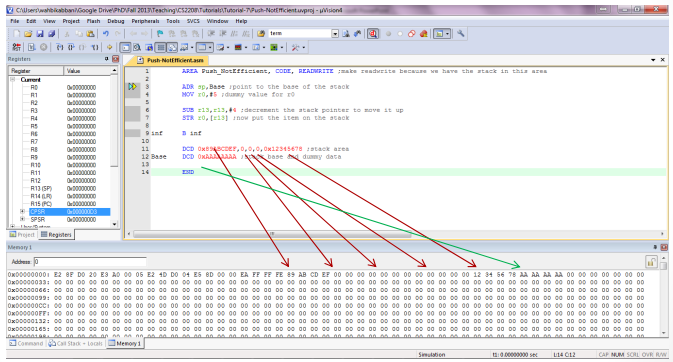
Push Instruction



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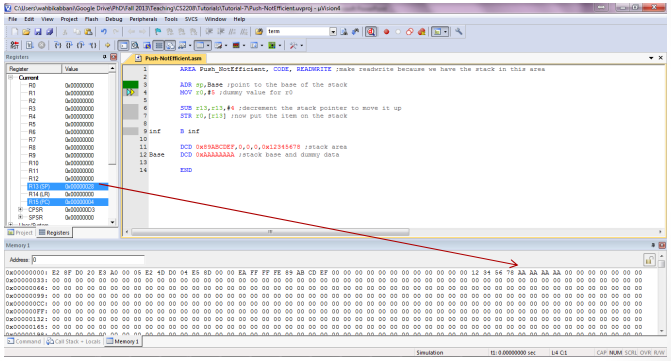
Push Instruction



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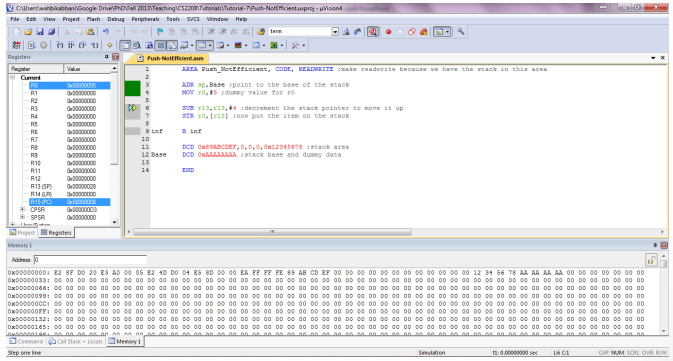
Push Instruction



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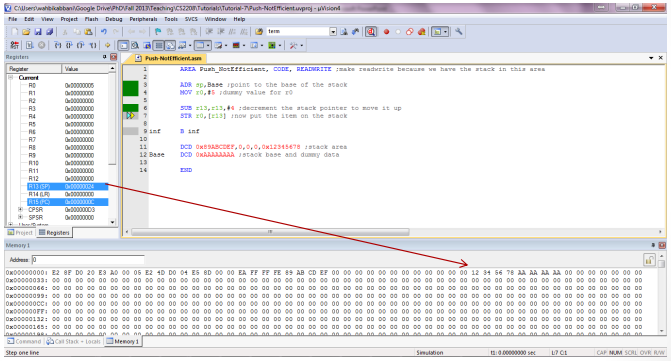
Push Instruction



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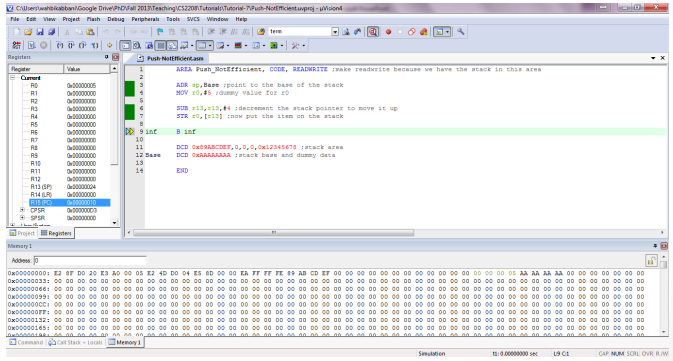
Push Instruction



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Push Instruction (Efficient)

- Efficient way:
  - STR **r0**,[r13,#-4]!
  - Pre-update Instruction
  - stores the contents of r0 at an address -4 bytes from r13 (4 bytes above it)
  - Decrement the contents of r13 by 4
- Be efficient in your assignments!

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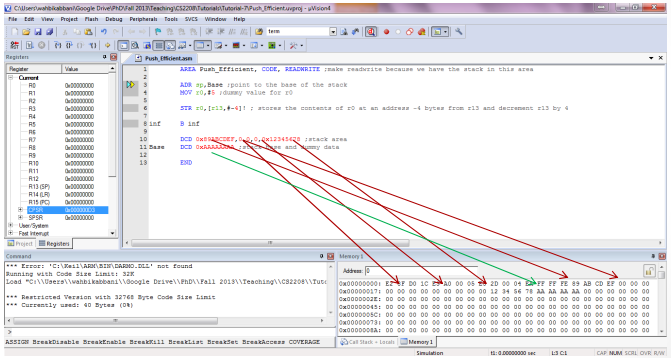
Push Instruction (Efficient)



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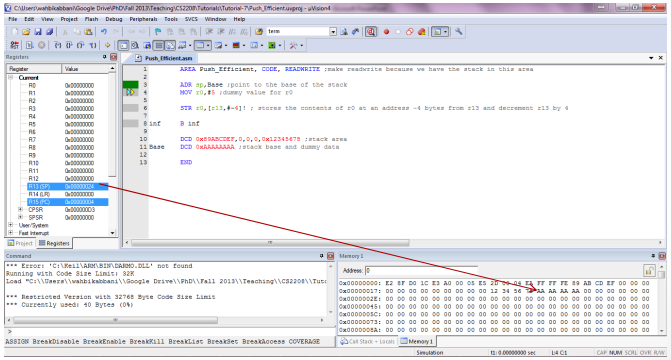
Push Instruction (Efficient)



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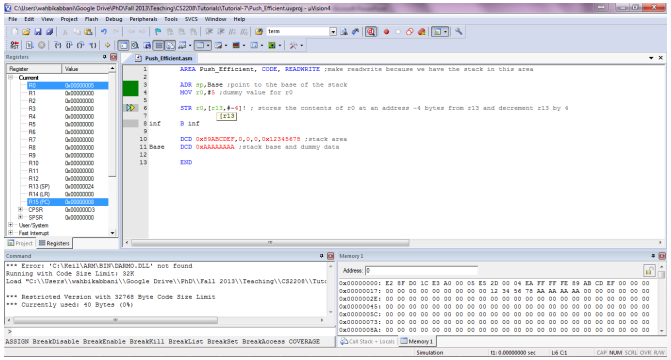
Push Instruction (Efficient)



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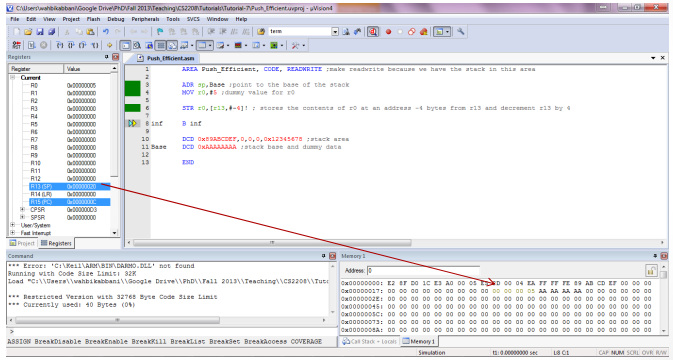
Push Instruction (Efficient)



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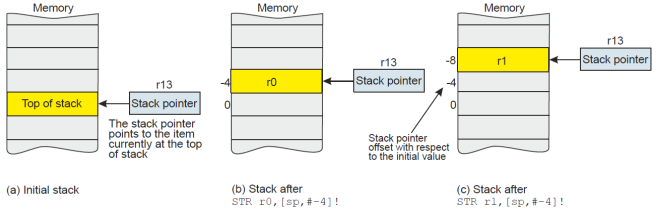
Push Instruction (Efficient)



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Pull Instruction

- How can we pull (pop) a word off the stack?
  - **Hint**: read the item currently at the top and increment stack pointer
  - Answer:
    - LDR **r0**,[r13]
    - ADD **r13**,r13,#4

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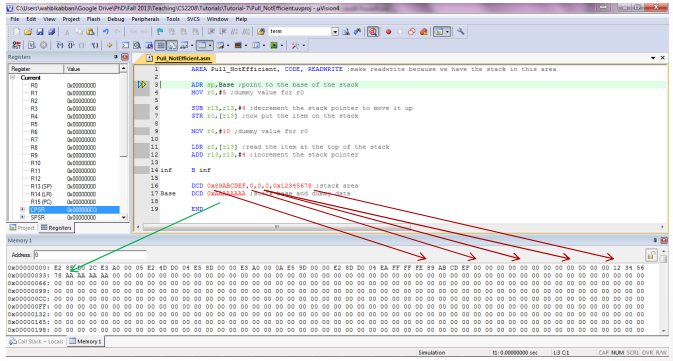
Pull Instruction



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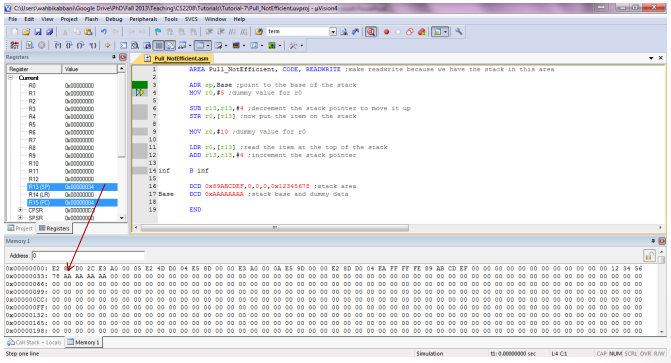
Pull Instruction



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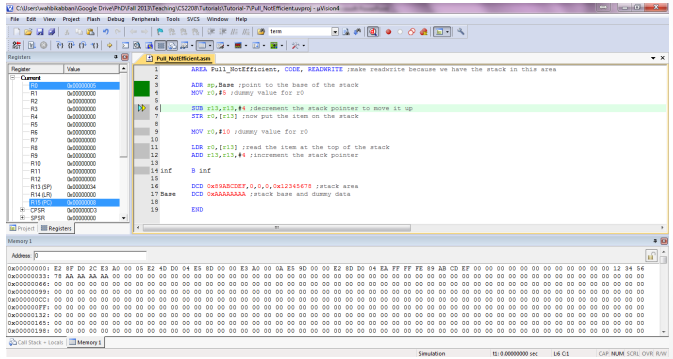
Pull Instruction



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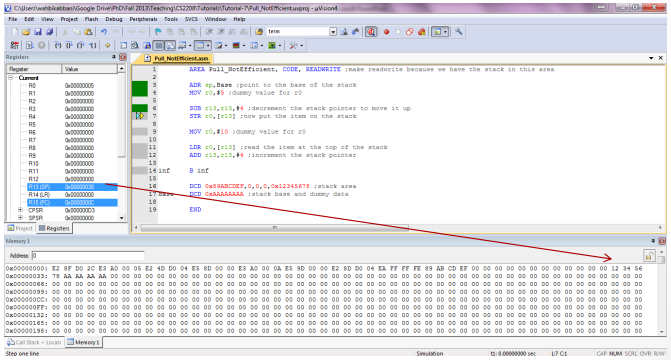
Pull Instruction



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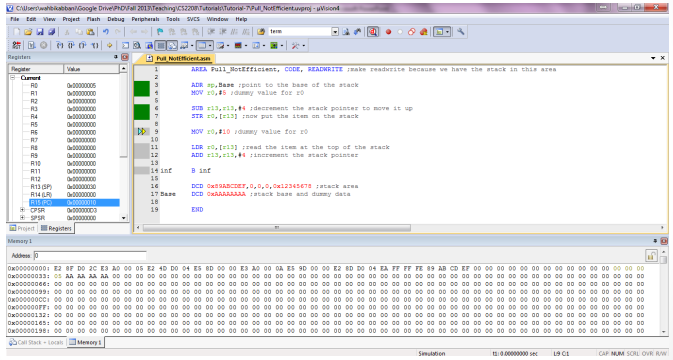
Pull Instruction



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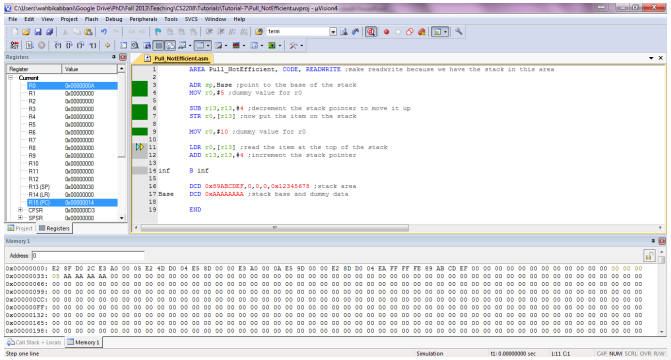
Pull Instruction



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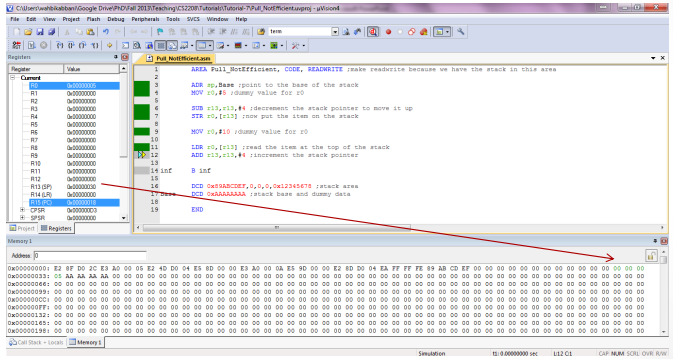
Pull Instruction



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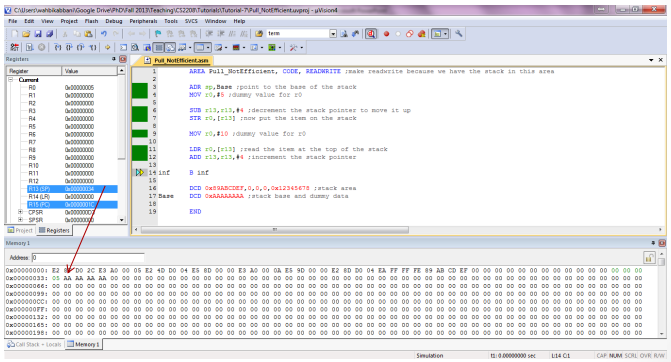
Pull Instruction



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Pull Instruction (Efficient)

- Efficient way:
  - LDR **r0**,[r13],#4
- Post-update Instruction
- Again, make sure to use the efficient way in your assignments

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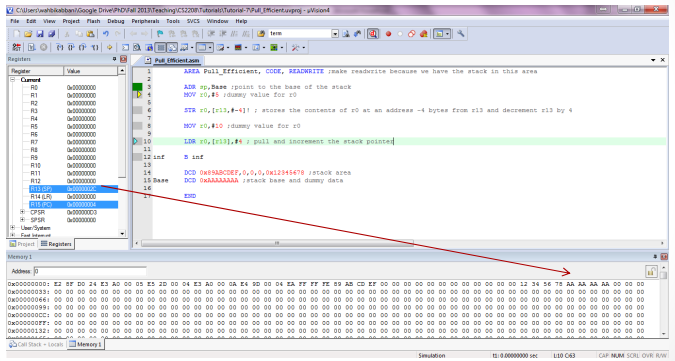
Pull Instruction (Efficient)



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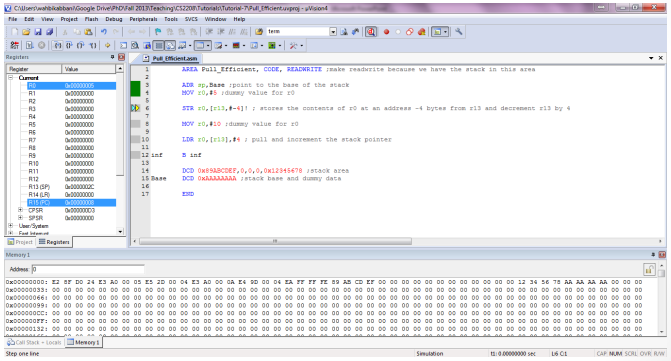

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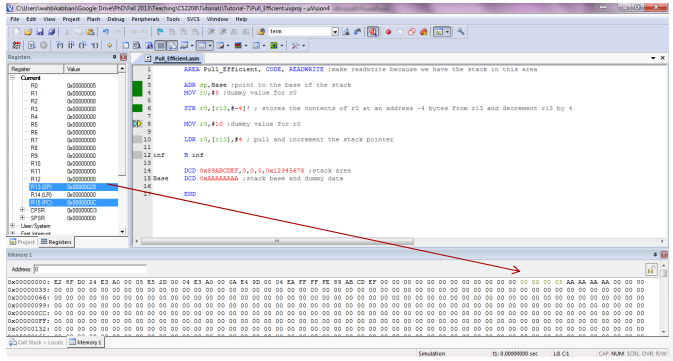

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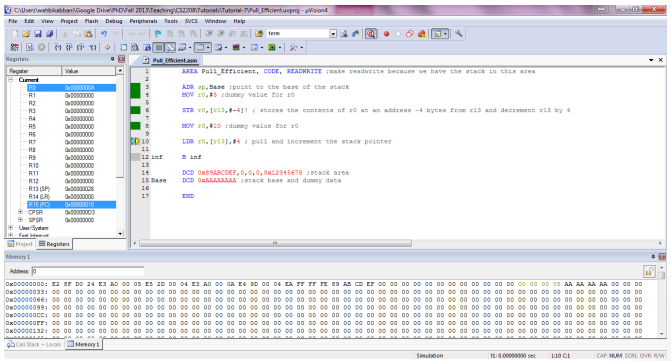

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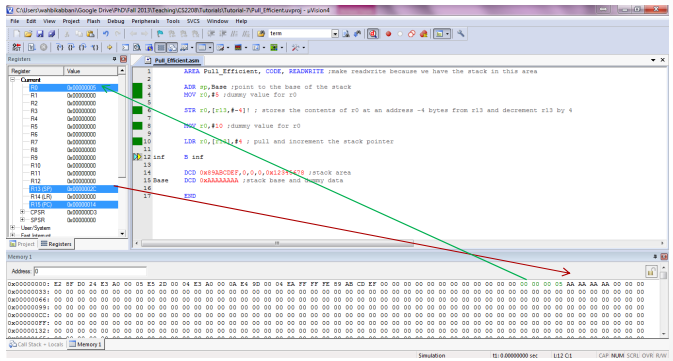
Pull Instruction (Efficient)



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Push/Pull Comparison

Push	Pull (Pop)
STR **r0**,[r13,#-4]!	LDR **r0**,[r13],#4
stores the contents of r0 at an address -4	read the item currently at top
Decrement the contents of r13 by 4	increment stack pointer

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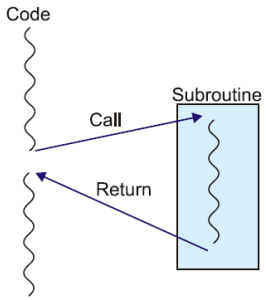
Subroutine

- A subroutine is a piece of code that is called, executed and a return is made to the calling point.
- Implement a *"function" in high level languages*
- Instruction: BL (branch to subroutine)



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Subroutine

- BL ABC (branch to subroutine)
  - saves a copy of the return address in the link register (r14)
  - A return back to the calling point is made by copying the return address from the link register to the program counter, r15.

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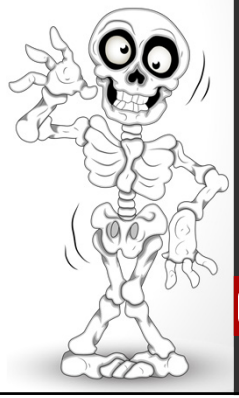
Subroutine

- The skeleton of a typical processor call and return routine:
  - Main Code
    - BL XYZ → call XYZ
    - … ← Return here
  - XYZ ← Subroutine
    - …
    - MOV **pc**,lr

copy saved address to PC to return



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Subroutine

- a simple subroutine called SQR1
- SQR1 calculates $x^2 + 1$
  - x is in register r0
  - Result will be returned in r0
- **Question**: How can we call this subroutine?
  - BL SQR1

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Subroutine

- Help me write the code. We will do it step by step:
  - Initialize register r0 with the value: 4
    - MOV **r0**,#4
  - Call subroutine SQR1:
    - BL **SQR1**
  - First line of subroutine SQR1, multiply x by x
    - SQR1 MUL **r1**,r0,r0
  - Add 1 to get $x^2 + 1$. Put the result in r0
    - ADD **r0**,r1,#1
  - Return
    - MOV **pc**,lr

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Subroutine

- Thank you for helping me write the code.
- Now, let's run the program

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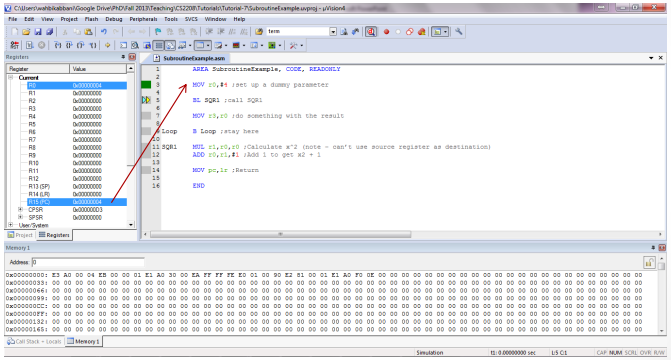
Subroutine



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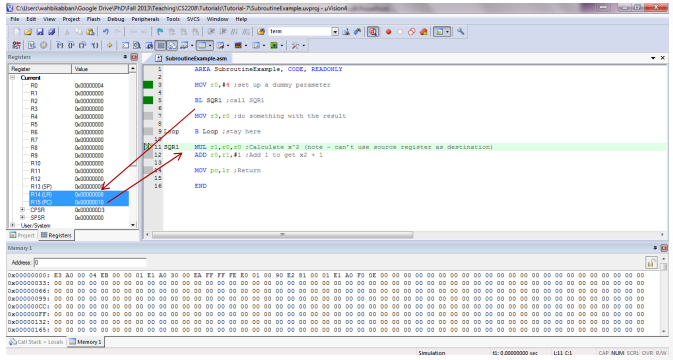
Subroutine



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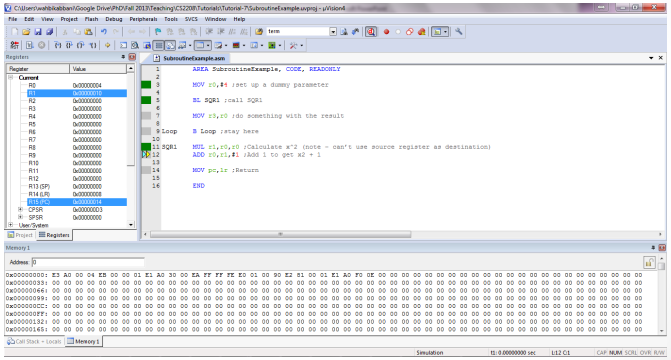
Subroutine



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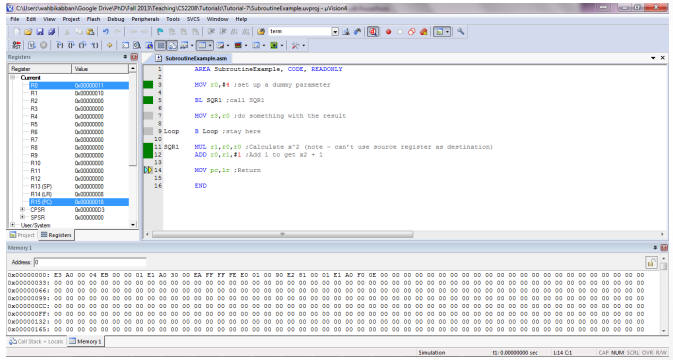
Subroutine



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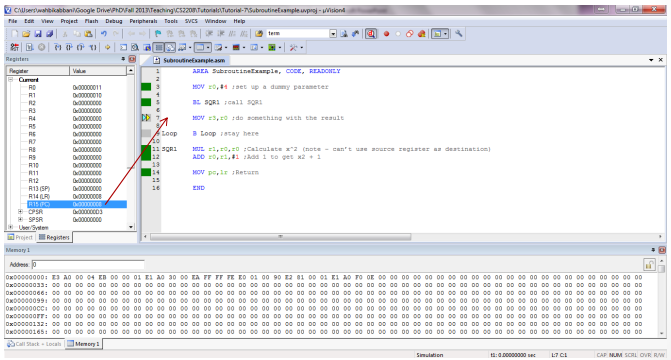
Subroutine



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Subroutine – Problems

- Our code is NOT perfect
- We will modify the code to explore a possible problem

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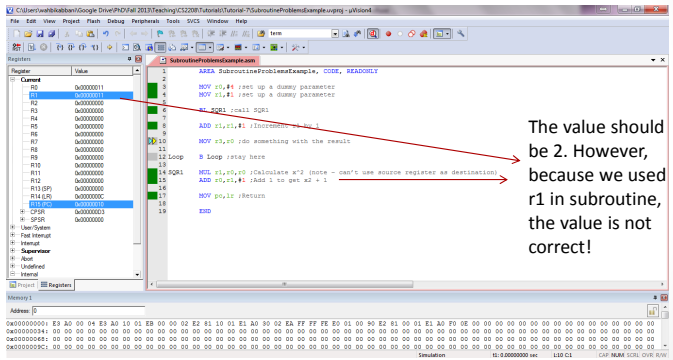
Subroutine – Problems



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Subroutine – Problems

- Two problems:
  - Problem-1:
    - We used r1 to return the result of x^2
    - What happens to the original value stored in this register?
  - Problem-2:
    - subroutine can't call another subroutine
    - the return address is in lr will be overwritten

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Subroutine – Problems

- Two Steps to solve both problems:
  - Save the content of the link register and other needed registers in stack
  - Why is the stack the best place to save these values?
    - Values won't be overwritten

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Subroutine – Problems

- Remember our push/pull instructions:
  - Push: STR **r0**,[r13,#-4]!
  - Pull : LDR **r0**,[r13],#4
- Using these instructions, help me modify the code of the subroutine.
  - Save link register on the stack
    - SQR1 STR lr **,[sp,#-4]!**
  - We will be overwritting r1. What is the instruction to save it in the stack?
    - STR r1 **,[sp,#-4]!**

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Subroutine – Problems

- Remember our push/pull instructions:
  - Push: STR **r0**,[r13,#-4]!
  - Pull : LDR **r0**,[r13],#4
- Using these instructions, help me modify the code of the subroutine.
  - At the end of the subroutine, we want to restore the original value of r1:
    - LDR **r1** ,[sp] ,#4
  - At the end of the subroutine, restore the value of the link register:
    - LDR **lr** ,[sp] ,#4

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Subroutine – Problems

- Let's put everything together:

SQR1 STR lr ,[sp,#-4]! ;Save link register on the stack

STR r1 ,[sp,#-4]! ;Save register r1 on the stack

MUL r1,r0,r0 ;Calculate x^2

ADD r0,r1,#1 ;Add 1 to get $x^2 + 1$

LDR r1 ,[sp] ,#4 ;Restore register r1 from the stack

LDR lr ,[sp] ,#4 ;Restore link register from the stack

MOV pc,lr ;Return

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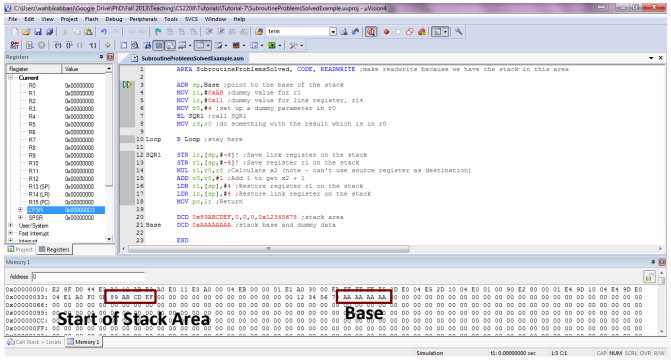
Subroutine – Problems



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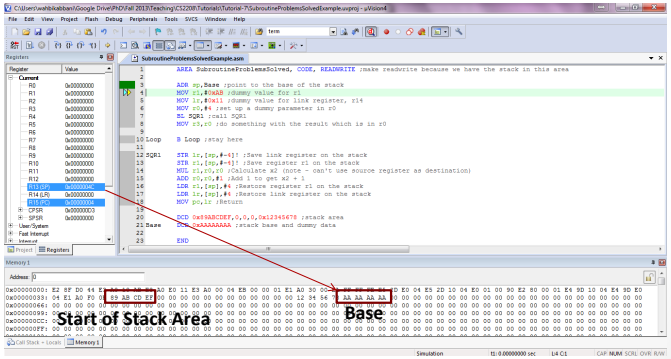
Subroutine – Problems



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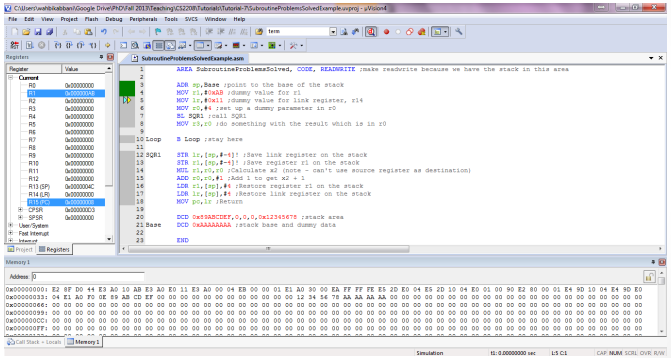

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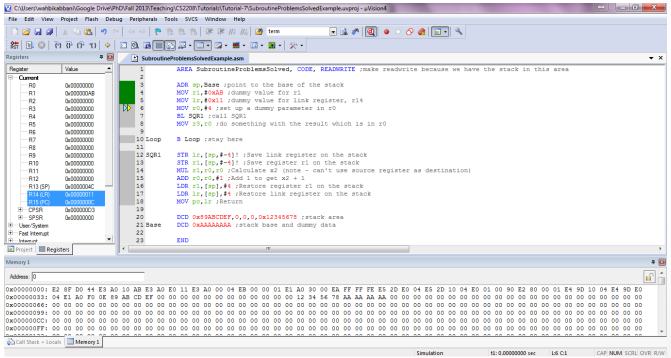

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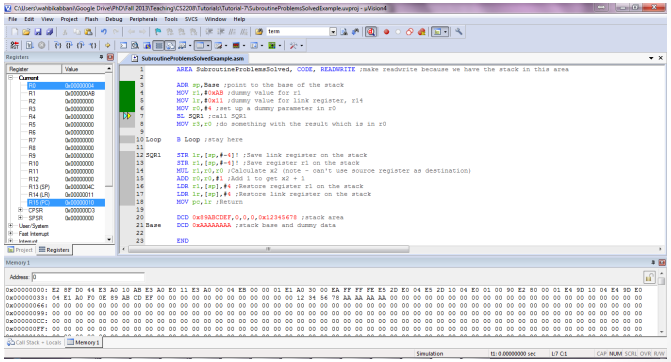
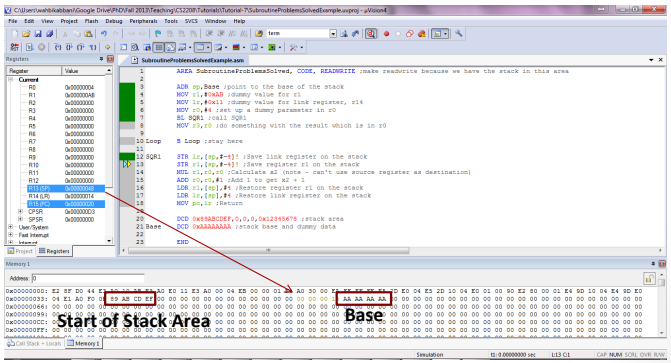
Subroutine – Problems



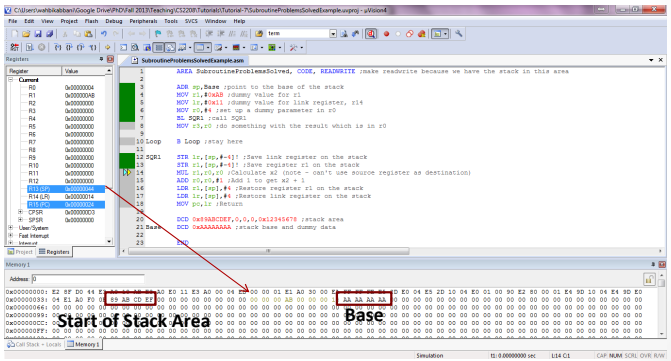
62

Subroutine – Problems



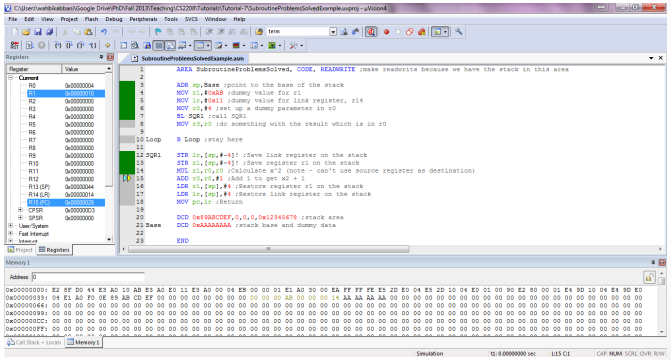
63

Subroutine – Problems



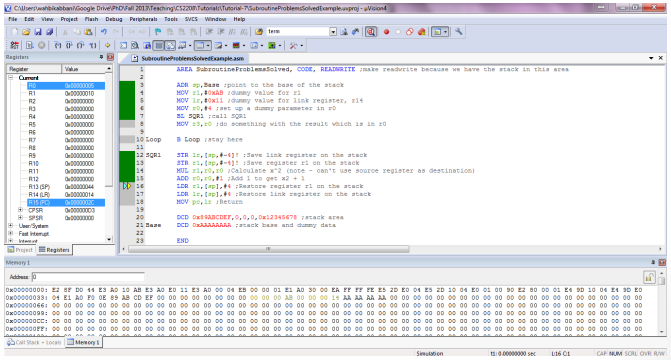
64

Subroutine – Problems



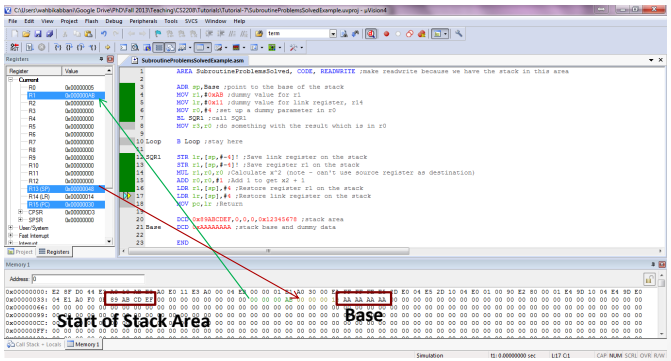
65

Subroutine – Problems



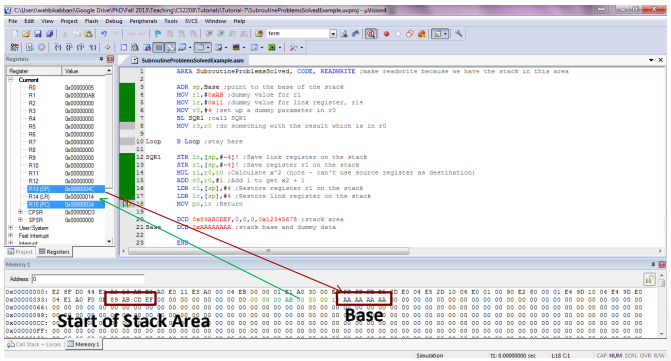
66

Subroutine – Problems



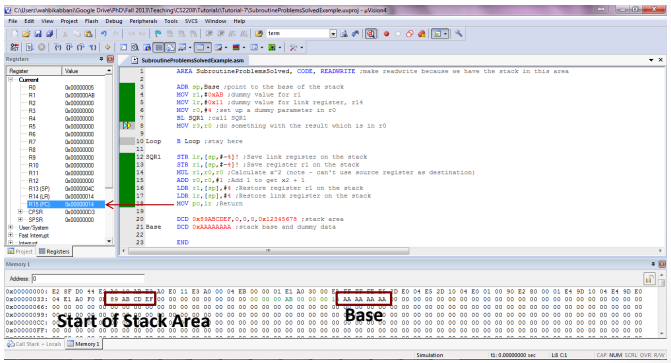
67

Subroutine – Problems



68

Subroutine – Problems



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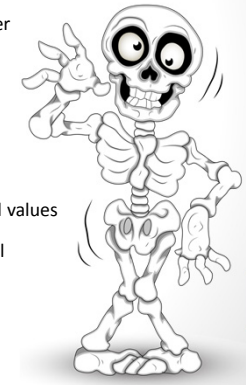
Subroutine – Problems

- The skeleton of a typical pushing/pulling to a stack in a subroutine:
  - STR lr **,[sp,#-4]!** → Save the link register
  - STR r1 **,[sp,#-4]!** → Save the registers
  - ….
  - LDR **r1** ,[sp] ,#4 → Restore the original values
  - LDR **lr** ,[sp] ,#4 → Restore the original Link register value
  - MOV **pc**,lr → Return



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Outline

- The Stack – Introduction
- Push Instruction
  - Push Instruction (Efficient)
- Pull Instruction
  - Pull Instruction (Efficient)
- Subroutine
  - Subroutine – Problems
  - Subroutine – Efficient push/pull registers

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Subroutine – Efficient push/pull registers

- The previous code solved the 2 problems we had
- However, there's a more efficient way to save/restore multiple registers in/from memory
  - STMFD ;Push a group of registers on the stack
  - LDMFD ;Pull a group of registers off the stack

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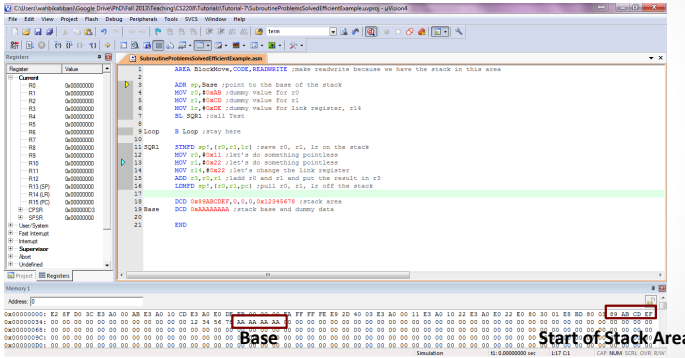
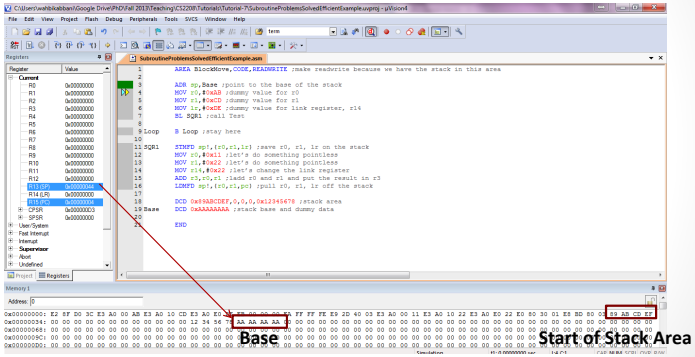
Subroutine – Efficient push/pull registers



73

Subroutine – Efficient push/pull registers



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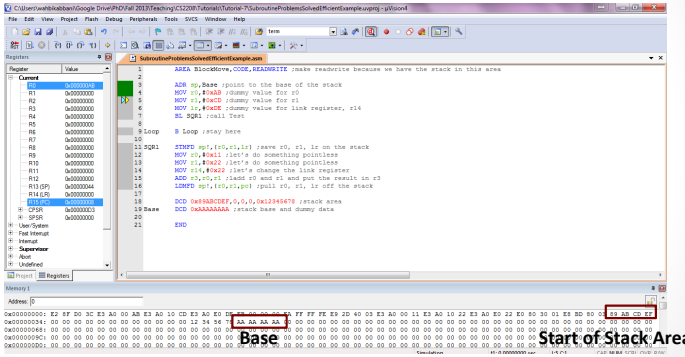
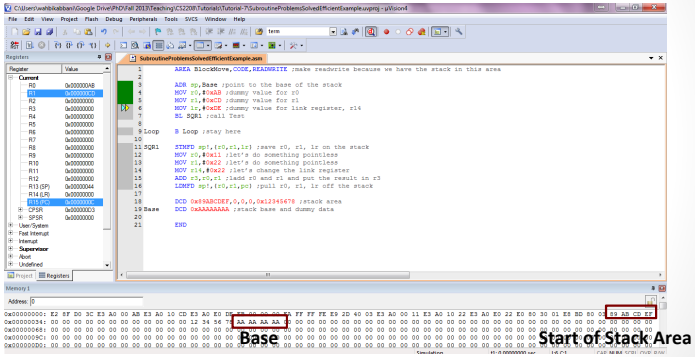
Subroutine – Efficient push/pull registers



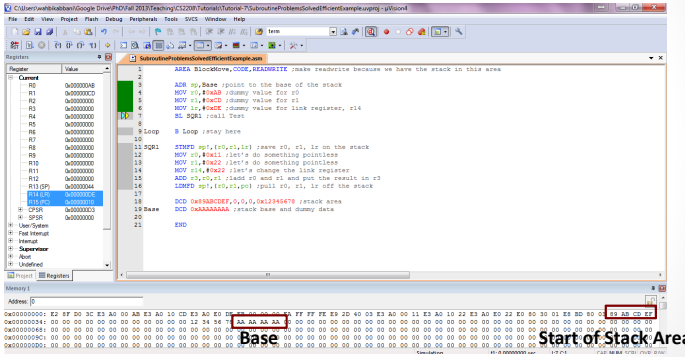
75

Subroutine – Efficient push/pull registers



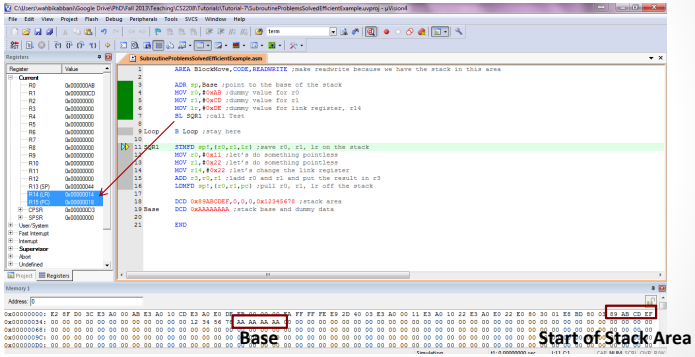
76

Subroutine – Efficient push/pull registers



77

Subroutine – Efficient push/pull registers



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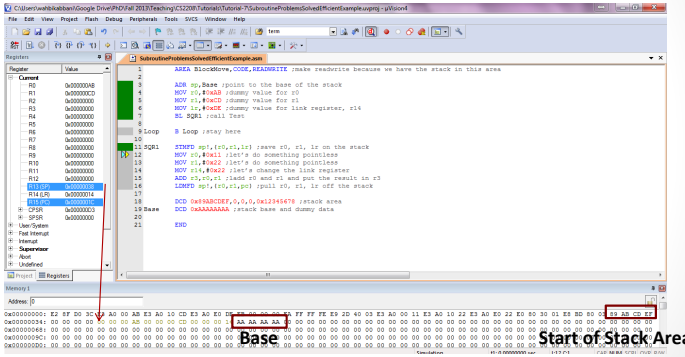
Subroutine – Efficient push/pull registers



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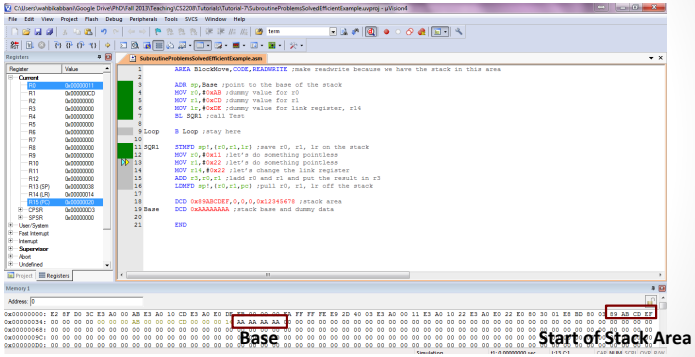
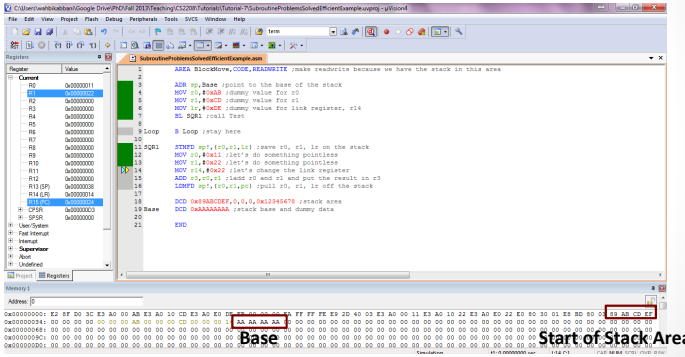
Subroutine – Efficient push/pull registers



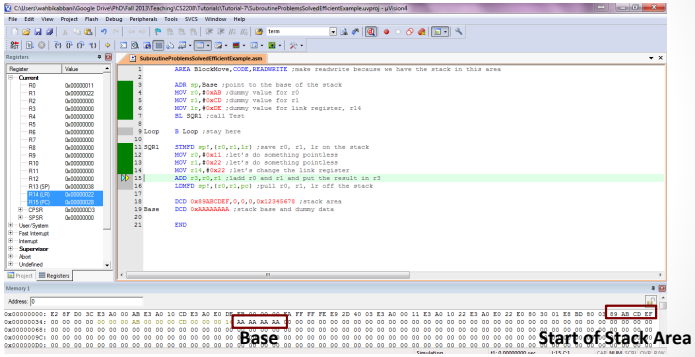
80

Subroutine – Efficient push/pull registers



81

Subroutine – Efficient push/pull registers



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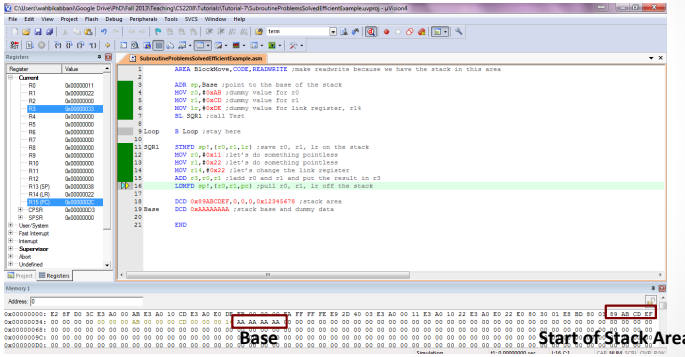
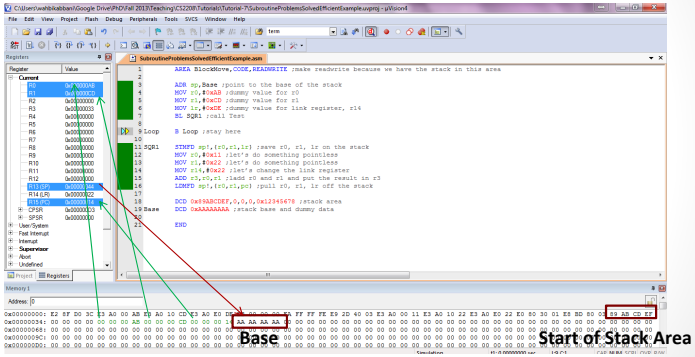
Subroutine – Efficient push/pull registers



83

Subroutine – Efficient push/pull registers



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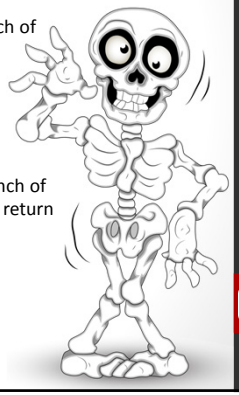
Subroutine – Efficient push/pull registers

- The skeleton of a typical **Efficient** pushing/pulling to a stack in a subroutine (call/return):
  - STMFD sp!,{r0,r1,lr} → Save a bunch of registers in memory
  - ….
  - LDMFD sp!,{r0,r1,pc} → Restore a bunch of registers and return



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Outline

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Summary

Push	Pull (Pop)
STR **r0**,[r13,#-4]!	LDR **r0**,[r13],#4
stores the contents of r0 at an address -4	read the item currently at top
Decrement the contents of r13 by 4	increment stack pointer

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Summary

- The skeleton of a typical processor call and return routine:
  - Main Code
    - BL XYZ → call XYZ
    - … ← Return here
  - XYZ ← Subroutine
    - …
    - MOV **pc**,lr → copy saved address to PC to return

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Summary

- The skeleton of a typical pushing/pulling to a stack in a subroutine:
  - STR lr **,[sp,#-4]!** → Save the link register
  - STR r1 **,[sp,#-4]!** → Save the registers
  - **….**
  - LDR **r1** ,[sp] ,#4 → Restore the original values
  - LDR **lr** ,[sp] ,#4 → Restore the original Link register value
  - MOV **pc,**lr → Return

Summary

- The skeleton of a typical **Efficient** pushing/pulling to a stack in a subroutine (call/return):
  - STMFD sp!,{r0,r1,lr} → Save a bunch of registers in memory
  - **….**
  - LDMFD sp!,{r0,r1,pc} → Restore a bunch of registers and return