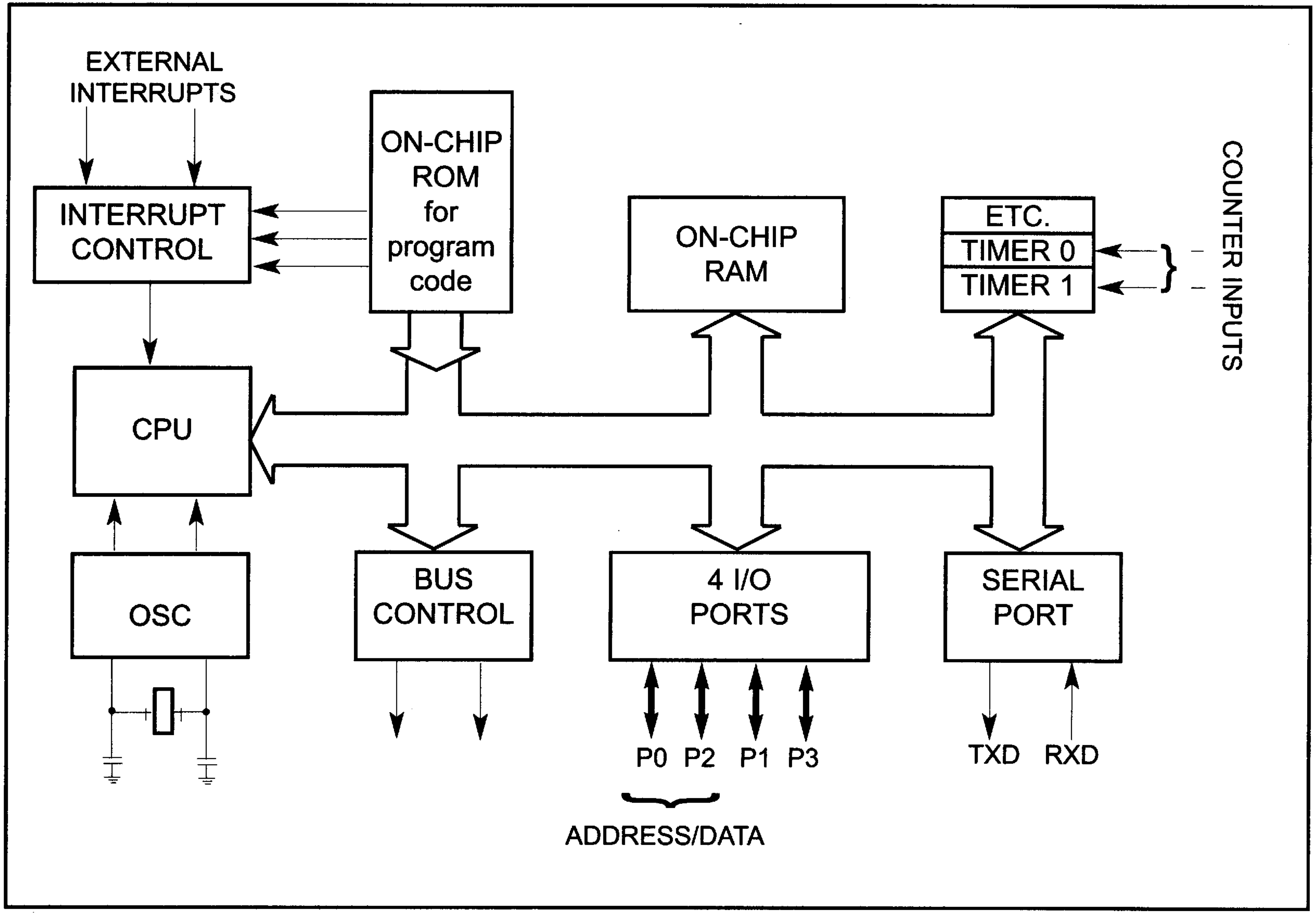
Microprocessor
Ch.2 Assembly Language Programming

OUTLINE

- Inside 8051
- Introduction to assembly programming
- Program counter and ROM space
- PSW register and flag bits
- Register bank and stack

INSIDE 8051: BLOCK DIAGRAM

- **Block diagram**

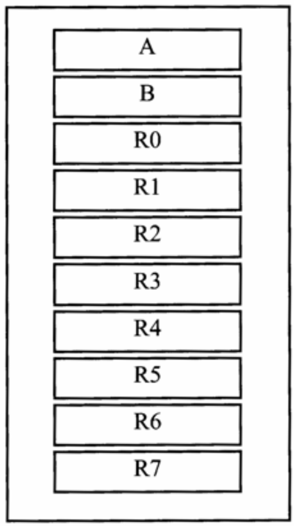


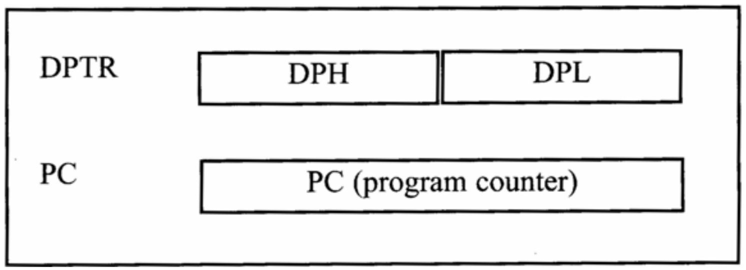
INSIDE 8051: REGISTERS

- **Registers (inside CPU)**
  - Most widely used registers:
    - 8-bit registers: A (accumulator), B, R0 ~ R7, PSW (program status word)
    - 16-bit registers: DPTR (data pointer), PC (Program counter)
  - Most registers are 8-bit
    - The bits inside one register are designated as 7, 6, 5, 4, 3, 2, 1, 0
    - MSB (most significant bit): bit 7
    - LSB (least significant bit): bit 0

an 8-bit register:

7	6	5	4	3	2	1	0





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ASSEMBLY: MOV

- **MOV**
  - MOV *destination, source*
    - Copies data from source to destination
  - Example:

    Comments

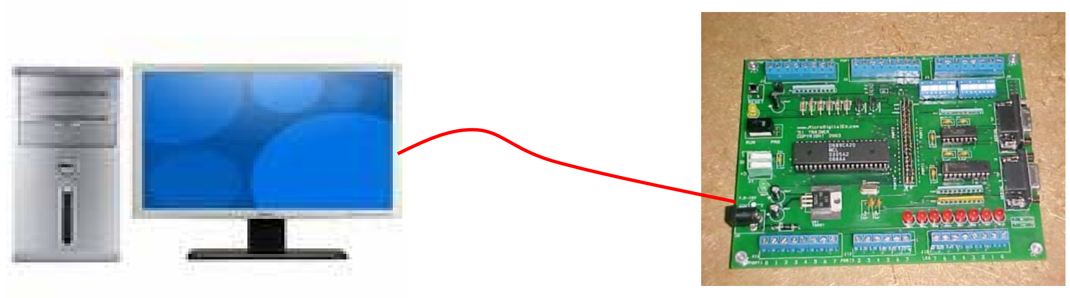
    - MOV A, #55H ; load 55H into reg. A
    - MOV R0, A ; copy contents of A into R0
    - MOV R3, #16 ; load 16 into R3
    - MOV A, R3 ; copy contents of R3 into A
  - Notes:
    - Immediate number: a regular constant number, always prefixed by a pound sign #.
    - A post-fix of 'H' means this is a hex number
  - Opcode v.s. Mnemonics
    - The Opcode for "MOV A, #55H" is: 01110100 01010101 (74H 55H)
    - CPU will only understand Opcode (machine code)
    - MOV is called the mnemonic for Opcode → easy to remember, easy to read.
    - Mnemonics will be translated to Opcode by an assembler.

ASSEMBLY: RUN PROGRAM

- **Assembling and running an 8051 program (Demo)**
  - 1. Use an editor to type in your assembly program (source file)
    - Usually has an extension of *.asm, *.a51
  - 2. Assembler
    - An assembler program converts the mnemonics into binary machine code that can be understood by the MCU.
    - Assembler will generate two files
      - 1) list file (*.lst)
        - » Optional. List all the instructions and addresses.
        - » Helpful for program development
      - 2) object file (*.obj)
        - » Binary file contains the binary machine code
  - 3. Linker
    - Combine one or more obj files into an absolute object file (no extension)
  - 4. Object to hex converter
    - Convert absolute obj file to a file with extension “hex”, which can be burned into the ROM of the MCU.
  - 5. Burn the HEX file to 8051.

ASSEMBLY: DEVELOPMENT ENVIRONMENT

- **Host**
  - The PC used to develop the program, it usually has
    - Editor (edit source file)
    - Compiler (convert high level language to machine code *.obj)
    - Assembler (convert assembly language to machine code *.obj)
    - Linker (link several obj files into an absolute obj file)
    - Obj to Hex converter (convert obj file to Hex file)
    - Loader (load the hex file to target)
- **Target**
  - The development hardware with embedded microcontroller.
  - It can be connected to Host through various interfaces
    - E.g. RS232, USB, JTAG, IEEE1394, ……



Host Target

ASSEMBLY: MOV

- **Some additional notes about MOV (Cont'd)**
  - MOV #0F3H
    - If the number starts with a letter, put '0' in front of it.
  - MOV A, #7F2H ; possible error
    - Why?
  - MOV A, #257 ; possible error
    - Why?
  - MOV A, #34H is different from MOV A, #34
  - MOV A, #34H is different from MOV A, 34H
    - We will discuss the meaning of MOV A, 34H later.

ASSEMBLY: ADD

- **ADD**
  - ADD *A, source*
    - Add the contents in Reg. A with source, and store the result in A
    - Review: Reg. A is also called accumulator
    - Destination must be A!!!
  - Examples
    - 1.
      ```
      MOV A, #25H      ;load 25H into A
      MOV R2, #34H     ;load 34H into R2
      ADD A, R2        ; A = A + R2
      ```
    - 2.
      ```
      MOV R1, #0F5H    ;load F5H into A (demo)
      MOV A, #0        ;load 0 into A
      ADD A, R1        ;
      ADD A, #34       ; what is the value of A after this operation?
      ```
  - Be careful of overflow (the result requires more than 8 bits)!
    - Only the lower 8 bits will be stored in register A
    - The carry flag in the PSW (program status word) register will be set if an overflow happens (we will talk about PSW later this chapter).

ASSEMBLY: STRUCTURE

- **Structures of assembly language**
  - 1. A series of lines of assembly language instructions and/or directives
  - 2. An assembly language instruction consists of up to 4 fields

    [label:] mnemonic [operands] [;comments]

    - Label: allows the program to refer to a line of code by name
      - E.g. HERE: SJMP HERE
    - Mnemonic and operands
      - The combination of mnemonic and operands will be translated to binary machine code
      - E.g. MOV A, #23H ;Opcode: 0111 0100 0010 0011 (7423H)

        MOV A 23H

```
      ORG   0H          ;start (origin) at location 0
      MOV   R5,#25H     ;load 25H into R5
      MOV   R7,#34H     ;load 34H into R7
      MOV   A,#0        ;load 0 into A
      ADD   A,R5        ;add contents of R5 to A
                        ;now A = A + R5
      ADD   A,R7        ;add contents of R7 to A
                        ;now A = A + R7
      ADD   A,#12H      ;add to A value 12H
                        ;now A = A + 12H
HERE:SJMP  HERE         ;stay in this loop
      END               ;end of asm source file
```

ASSEMBLY: DIRECTIVES

- **Directives**
  - A pseudo-code that cannot be translated into machine code
  - Used to notify assembler of certain operations
    - E.g. END: notify assembler the end of the source file.
- **Commonly used directives**
  - ORG: origin
    - Indicate the beginning of the address
    - The number after ORG can be either in hex or decimal
  - DB: define byte (demo directives)
    - Define an 8-bit data

```
        ORG  500H
DATA1:  DB   28                     ;DECIMAL(1C in hex)
DATA2:  DB   00110101B              ;BINARY (35 in hex)
DATA3:  DB   39H                    ;HEX
        ORG  510H
DATA4:  DB   "2591"                 ;ASCII NUMBERS
        ORG  518H
DATA6:  DB   "My name is Joe"       ;ASCII CHARACTERS
```

ASSEMBLY: DIRECTIVES

- **Commonly used directives**
  - EQU: equate
    - Define a constant without occupying a memory location
    - It DOES NOT use any memory space!
    - The constant value can be used later in the program
      - To improve the readability of the program
        - » Give a name to a constant
      - To improve code efficiency
        - » If the same constants are used twice in the program, with the EQU directive, we only need to change it in one location if its value is changed
        - » We should avoid using constant directly, and use the EQU directive as often as possible.
    - Example (Demo directives)

```
COUNT EQU 25H
MOV R3, #COUNT
MOV A, #COUNT
```

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ROM SPACE: PROGRAM COUNTER

- **Program counter (PC)**
  - A 16-bit register inside 8051 that points to the ROM address of the next instruction to be executed
  - Every time the CPU fetches the opcode from the program ROM, the PC will be automatically incremented to point to the next instruction
    - If the current opcode is one byte, PC will be incremented by 1 (Demo PC)
      - E.g. MOV A, R5, Opcode: $\underbrace{11101}_{\text{MOV R}n}\underbrace{101}_{n=5}$ (EDH)

        MOV R*n* n=5
    - If the current opcode is two bytes, PC will be incremented by 2 (Demo PC)
      - E.g. MOV A, #0H, Opcode $\underbrace{0111\ 0100}_{\text{MOV A}}\ \underbrace{0000\ 0000}_{00H}$ (7400H)

        MOV A 00H

```
0000              ORG  0H        ;start at location 0
0000 7D25         MOV  R5,#25H   ;load 25H into R5
0002 7F34         MOV  R7,#34H   ;load 34H into R7
0004 7400         MOV  A,#0      ;load 0 into A
0006 2D           ADD  A,R5      ;add contents of R5 to A
                                 ;now A = A + R5
0007 2F           ADD  A,R7      ;add contents of R7 to A
                                 ;now A = A + R7
0008 2412         ADD  A,#12H    ;add to A value 12H
                                 ;now A = A + 12H
000A 80FE HERE:   SJMP HERE      ;stay in this loop
000C              END            ;end of asm source file
```

Address	Code
0000	7D
0001	25
0002	7F
0003	34
0004	74
0005	00
0006	2D
0007	2F
0008	24
0009	12
000A	80
000B	FE

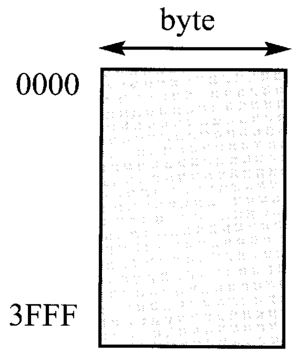
ROM SPACE: PROGRAM COUNTER

- **Program counter (Cont'd)**
  - When 8051 wakesup, the PC has an initial value of 0000H
    - We must put our initial program at location 0000H
    - What will happen if our program is not at 0000H? (Demo PC)
- **ROM space**
  - ROM is used to store program ➔ it's accessed by PC.
  - Address range that can be accessed by program counter
    - PC has 16-bits
      - Start address: 0000H (0000 0000 0000 0000)
      - Maximum end address: FFFFH (1111 1111 1111 1111)
      - Each address corresponds to 1 byte
    - The maximum ROM space that can be accessed by PC is: 64 KB
    - Most 8051 chips have a ROM size less than 64 KB

2^16

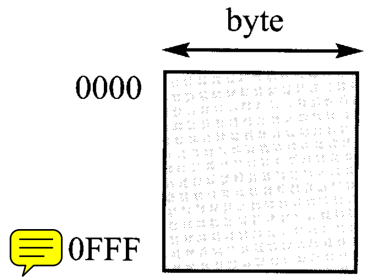
ROM SPACE: EXAMPLE

- **ROM space examples**
  - 1. Dallas Semiconductor DS89C430 has 16KB on chip ROM. Write down the ROM address range in hex format.



DS89C420/30

  - 2. The ROM address range of Atmel AT89C51 is 0000H to 0FFFFH. What is size of the ROM in AT89C51



8051
AT89C51

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PSW:

- **PSW: program status word register**
  - An 8-bit register used to indicate the status of the program and uC.
    - Only 6 bits are used by 8051
    - The 2 remaining bits can be used by users (programmers).
  - Also called flag register.
  - 4 conditional flags: indicate some conditions after an instruction is executed
    - CY (carry), AC (auxiliary carry), P (parity), OV (overflow)
  - 2 register bank selection bits: (will be discussed later

CY	AC	F0	RS1	RS0	OV	--	P

CY	PSW.7	Carry flag.
AC	PSW.6	Auxiliary carry flag.
F0	PSW.5	Available to the user for general purpose.
RS1	PSW.4	Register Bank selector bit 1.
RS0	PSW.3	Register Bank selector bit 0.
OV	PSW.2	Overflow flag.
--	PSW.1	User-definable bit.
P	PSW.0	Parity flag. Set/cleared by hardware each instuction cycle to indicate an odd/even number of 1 bits in the accumulator.

PSW: CONDITIONAL FLAGS

- **PSW conditional flags**
  - CY (carry flag, PSW.7)
    - The flag is set (value changed to 1) whenever there is a carryout from the D7 bit of RA. (demo add)
      - E.g. MOV A, #9CH

        ADD A, #64H

        What is the value in A and PSW.7?
    - The CY bit can be set or cleared (value changed to 0) by the following instructions (demo add)
      - SETB C ; set the CY bit to 1
      - CLR C ; clear the CY bit to 0
  - AC (auxiliary carry flag, PSW.6)
    - If there is a carry from the bits D3 to D4 during an ADD or SUB operation, this bit is set; otherwise it's cleared
    - E.g. What is the value of CY and AC after the following instructions?

      MOV A, #38H

      ADD A, #2FH

PSW: CONDITIONAL FLAGS

- **PSW conditional flags (Cont'd)**
  - P (the parity flag, PSW.0)
    - If the number of 1s in register A is odd, then P = 1
    - If the number of 1s in register A is even, then P = 0
    - E.g. find the values of CY, AC, and P after the following instructions

      MOV A, #88H

      ADD A, #93H

  - OV (the overflow flag, PSW.2)
    - The bit is set whenever the result of a signed number operation is too large (we will discuss signed number operation in Ch. 6)
    - OV is used for signed arithmetic (to detect whether there is an overflow)
    - CY is used for unsigned arithmetic (to detect whether there is a carry)

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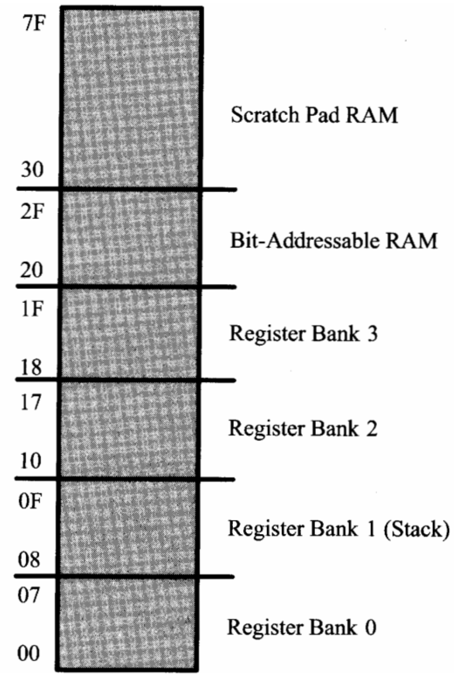
REGISTER BANKS: RAM SPACE

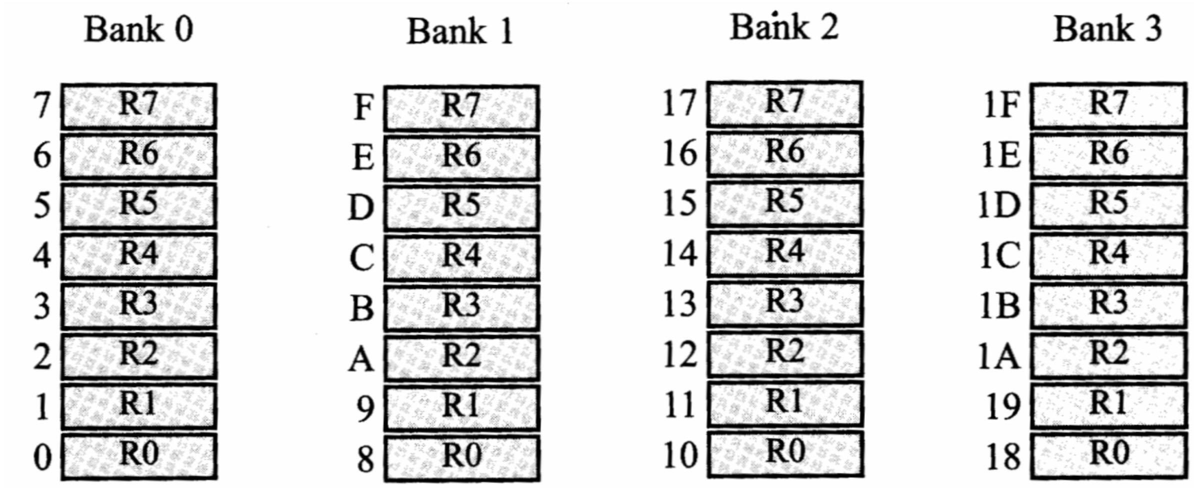
- **RAM space**
  - There are total 128 bytes of RAM in 8051 (recall: the max ROM size that can be supported by 8051 is 64 KB corresponding to 16-bit PC)
    - Address range: 00H ~
    - DO NOT confuse with ROM address range (ROM can only be accessed with the PC register)
  - The 128 bytes are divided into three groups
    - 00H – 1FH (bytes):
      - register bank and stacks
    - 20H – 2FH (bytes):
      - bit-addressable memory
    - 30H – 7FH (bytes):
      - "scratch pad"
      - Storing data and parameters



REGISTER BANKS

- **Register banks (total 32 bytes)**
  - The 32 bytes are divided into 4 banks with 8 bytes in each bank
    - Each bank has 8 8-byte registers: R0 – R7
  - When programming, e.g. “MOV A, R0”, which R0 are actually used?
    - Depends on the values of the RS1 (PSW.4) and RS0 (PSW.3) bits in PSW.
    - When 8051 powered on, RS1 = RS0 = 0 → bank 0 is used by default

	RS1 (PSW.4)	RS0 (PSW.3)
Bank 0	0	0
Bank 1	0	1
Bank 2	1	0
Bank 3	1	1



REGISTER BANKS: EXAMPLES

- **Examples (demo)**
  - Fill out the contents of the memory between 00H – 1FH after the following operations
  - 1.

```
MOV R0, #99H
MOV R7, #63H
```

  - 2.

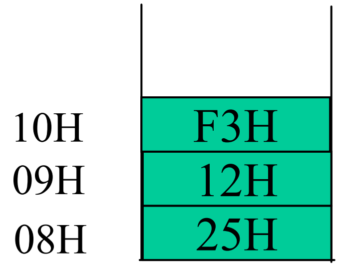
```
SETB PSW.4        ; set PSW.4 to 1
MOV R0, #76H
CLR PSW.4
SETB PSW.3
MOV R5, #12H
```

  - 3.

```
; the register banks can be directly accessed through its address
MOV 06H, 18H      ; RAM address 06H = bank 0, R6
MOV 10H, 25H      ; RAM address 10H = bank 2, R0
```

REGISTER BANKS: STACK

- **Stack**
  - A section of RAM used by CPU to temporarily store information
    - First in last out (FILO)
  - There are two 8051 instructions for stack
    - PUSH *reg*: put the byte stored in the register into the top of the stack
      - E.g.
```
MOV R6, #25H
MOV R1, #12H
MOV R4, #0F3H
PUSH 6          ; push R6 into stack
PUSH 1          ; push R1 into stack
PUSH 4          ; push R4 into stack
```
    - POP *reg*: pop out one byte from the top of the stack and save it in reg.
      - E.g.
```
POP 3
POP 5
POP 2
```



REGISTER BANKS: STACK

- **SP register**
  - How does the CPU know where is the top of the stack?
    - The CPU has a special register, SP (statck pointer), to always point at the top of the stack
  - When 8051 is powered on, SP contains a value of 07H
    - The first byte pushed into stack will be at 08H (register bank 1)
  - Every time a PUSH is executed, SP will automatically increase by 1
  - Every time a POP is executed, SP will automatically decrease by 1
  - Demo

```
MOV R0, #25H
MOV R1, #12H
MOV R2, #0F3H
PUSH 0   ; push R6 into stack
PUSH 1   ; push R1 into stack
PUSH 2   ; push R4 into stack
POP 3
POP 4
POP 5
```

REGISTER BANKS: STACK

- **SP register**
  - We can change the value of the SP register manually
    - MOV SP, 30H
  - Conflicts between register bank 1 and stack
    - Register bank 1 and the default stack are using the same address (08H – 0FH)
    - If in a program we need to use register bank 1, we need to reallocate the stack to somewhere else (e.g. scratch pad, 30H)
  - What if the stack is empty and we try to do POP (there are more POP than PUSH)? (Demo stack)
    - The SP will keep decreasing
    - We should avoid unequal number of PUSH and POP in our program
  - What if we keep PUSHing?
    - The SP will keep increasing until we run out of memory.
  - We should be very careful with stack during programing
    - Plan a section of memory space for stack before programming
    - Do not exceed the upper limit or lower limit of in program.

REGISTER: STACK

- **Call instruction**
  - Whenever the "CALL" instruction is executed, CPU will use stack to temporarily store information
    - SP and stack contents will change
    - We will discuss more details later