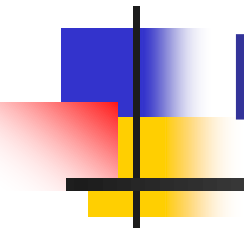
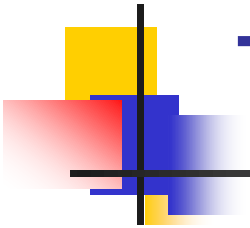


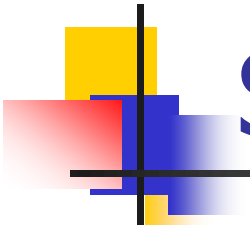
Microprocessor Systems

Dr. Gökhan İnce



Topics

- Stack
- Subroutine
- Interrupt

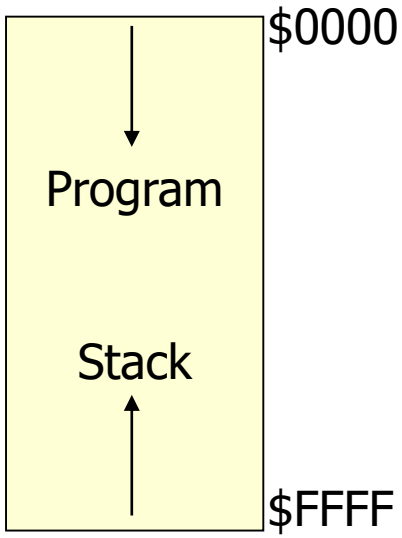


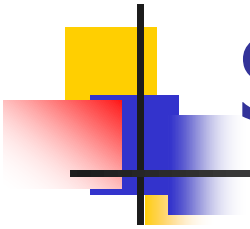
Stack

- Stack is a **temporary storage area** in memory identified by the programmer
  - Variables are stored temporarily
  - Program addresses are stored temporarily
  - Connection to subroutine
- Last In First Out (LIFO) structure
- The stack normally grows **backwards** into memory.
  - Programmer defines the bottom address of the stack and the stack grows up into reducing address range.

Stack

- The stack grows **from higher addresses to lower** so that the top of the stack grows upwards.
- Because of this, the bottom of the stack is often located at the **highest** available memory address.
- It is used in two ways
  - Data is stored in the program
    - By `PUSH(PSH)` and `POP` instructions
  - While branching to the subroutine or branching to interrupt service routine the **return addresses (PC)** and **parameters** are pushed onto stack





Stack in Educational CPU

- There is a 16-bit Stack Pointer (SP) in the Educational CPU
- Stack pointer points the next available address in the stack
- The accumulator contents can be pushed to stack
- The stack contents can be pulled to the accumulators
- The stack grows from higher addresses to lower

Saving Information on the Stack

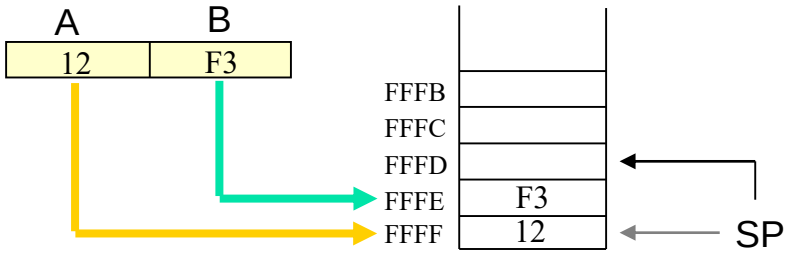
- Stack pointer is set to a suitable address

```
LDA SP, $FFFF
```

- To store data to the stack: `PSH A`
  - Data of ACC A is stored at the address pointed with SP

    `<SP>` ⟵ `A`
  - SP is decremented by one to point the next available address in the stack

    `SP` ⟵ `SP-1`



The POP Instruction

- In order to retrieve data from stack:

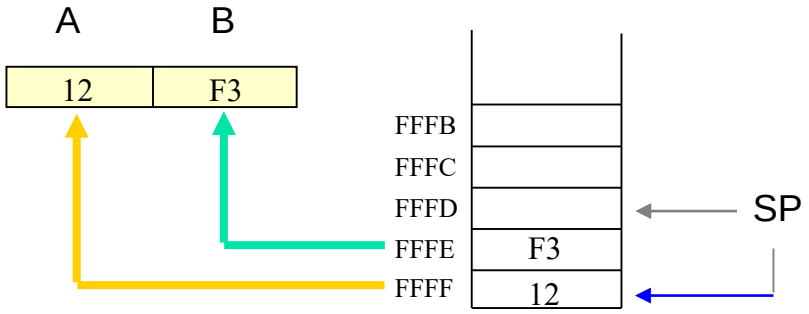
  `POP B`

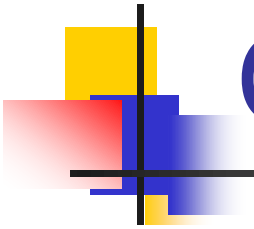
  - Increment SP

    `SP ← SP + 1`

  - Copy the content of the memory location pointed by the SP to accumulator B

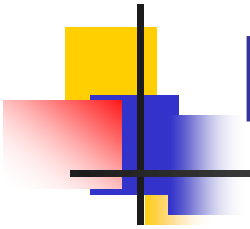
    `B ← <SP>`





Operation of the Stack

- During pushing, the stack operates in a “store then decrement” style.
  - The information is placed on the stack first, then the stack pointer is decremented.
- During popping, the stack operates in an “increment then use” style.
  - The pointer is incremented and then the information is retrieved from the top of the stack
- The SP always points to “the top of the stack”.



LIFO

- Push and pop operations must be done **in reverse order** in order **to retrieve information** back into its original location.

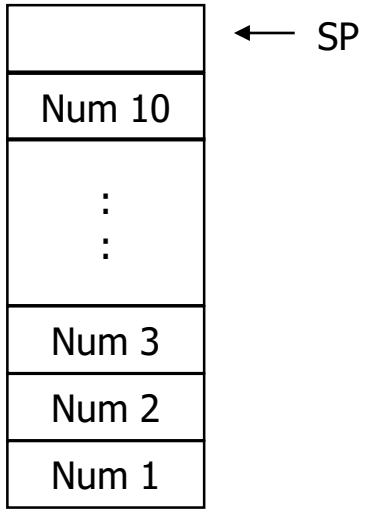
```
PUSH A
PUSH B
:
:
POP B
POP A
```

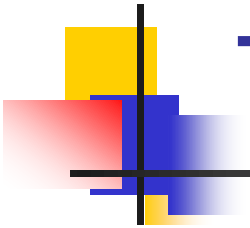
- Push too much without popping and you can overwrite your program! It's your responsibility not to do this.

Example-1

There is an array of ten elements starting from address $1000 in memory.
They will be stored in reverse order starting at the same address.

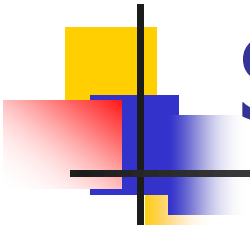
```
START   LDA   SP,$2000
        LDA   IX,$1000
        LDA   B,$0A
BACK    BEQ   NEXT
        LDA   A,<IX+0>
        INC   IX
        PSH   A
        DEC   B
        BR    BACK
NEXT    LDA   IX,$1000
        LDA   B,$0A
LOOP    BEQ   END
        POP   A
        STA   A,<IX+0>
        INC   IX
        DEC   B
        BR   LOOP
END     SWI
```





Topics

- Stack
- Subroutine
- Interrupt



Subroutine

- A subroutine is a group of instructions that will be used repeatedly in different locations of the program.

- In Assembly language, a subroutine can exist anywhere in the code.
  - However, it is customary to place subroutines separately from the main program.

Subroutine Instructions

- The instructions that are used for calling subroutine and returning from subroutine in educational CPU:
  - **BSR ADDRESS:** Calling the subroutine in the ADDRESS.

    <SP> ← PC(low), SP ← SP-1

    <SP> ← PC(high), SP ← SP-1

    PC ← ADDRESS
  - **BSR STEP:** Calling the subroutine that has address of PC+STEP

    <SP> ← PC(low), SP ← SP-1

    <SP> ← PC(high), SP ← SP-1

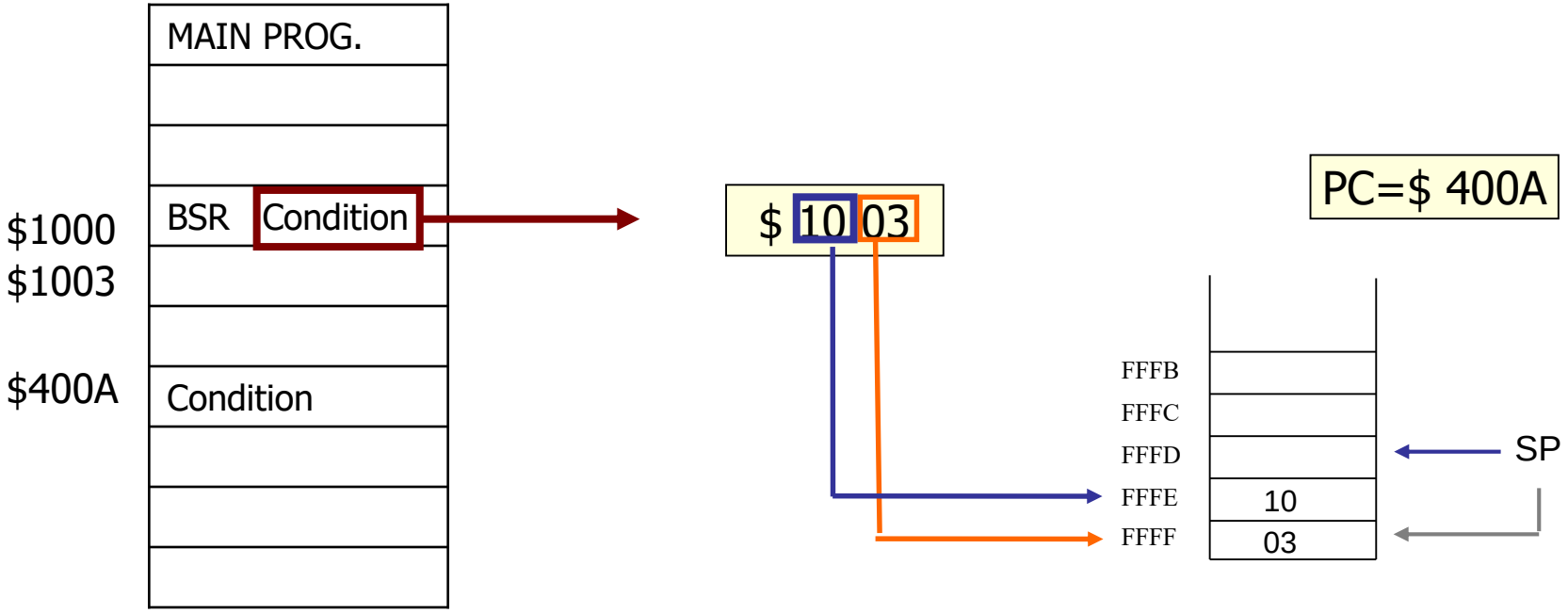
    PC ← PC + STEP
  - **RTS:** Return back to main program.

    SP ← SP + 1, PC(high) ← <SP>

    SP ← SP + 1, PC(low) ← <SP>

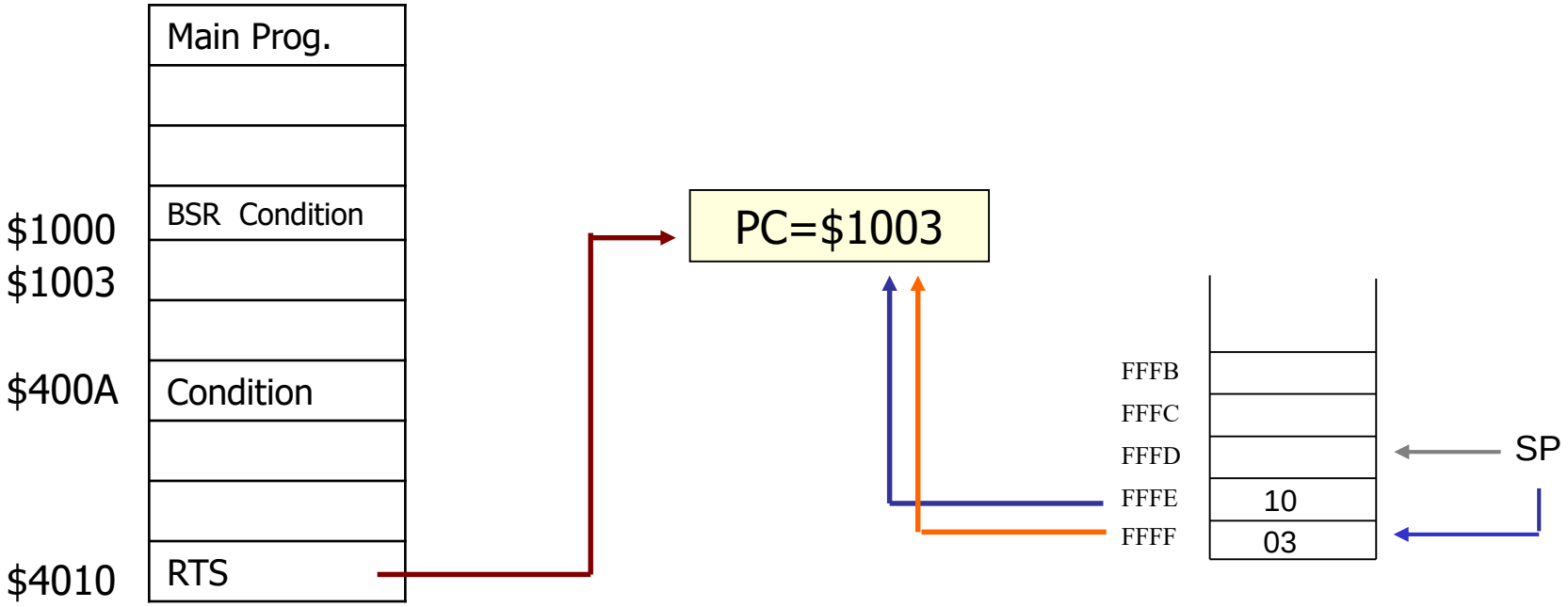
BSR Instruction

- When BSR is executed:
  - Push the address of the instruction immediately following the **`BSR`** onto the stack
  - Load the program counter with the 16-bit address supplied with the **`BSR`** instruction.

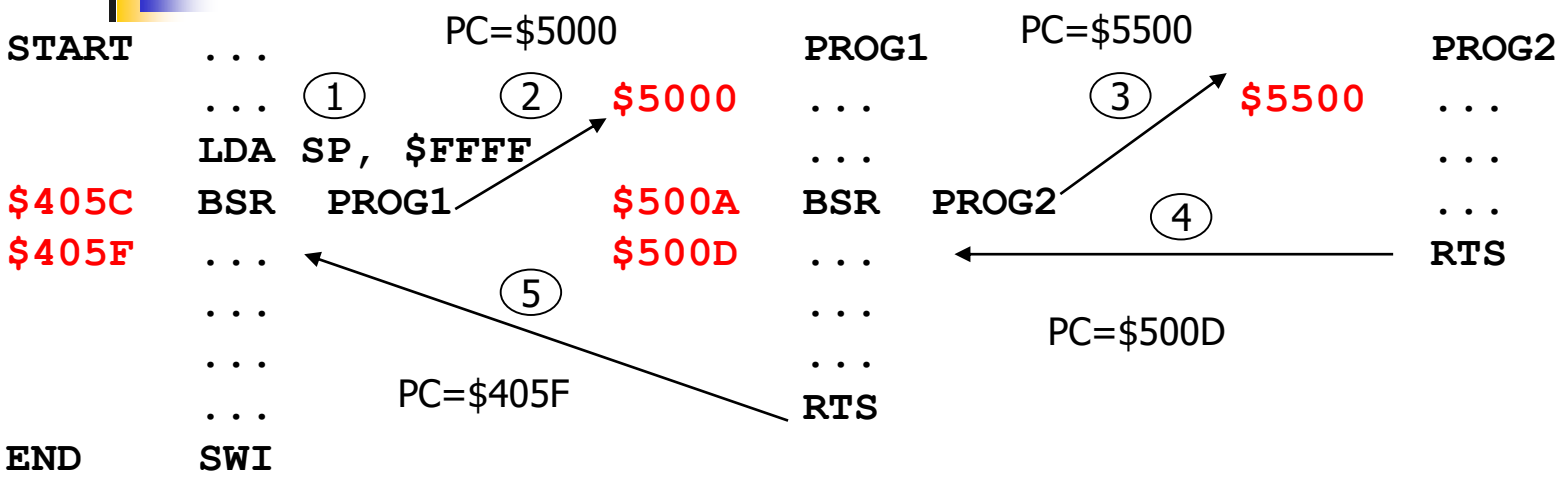


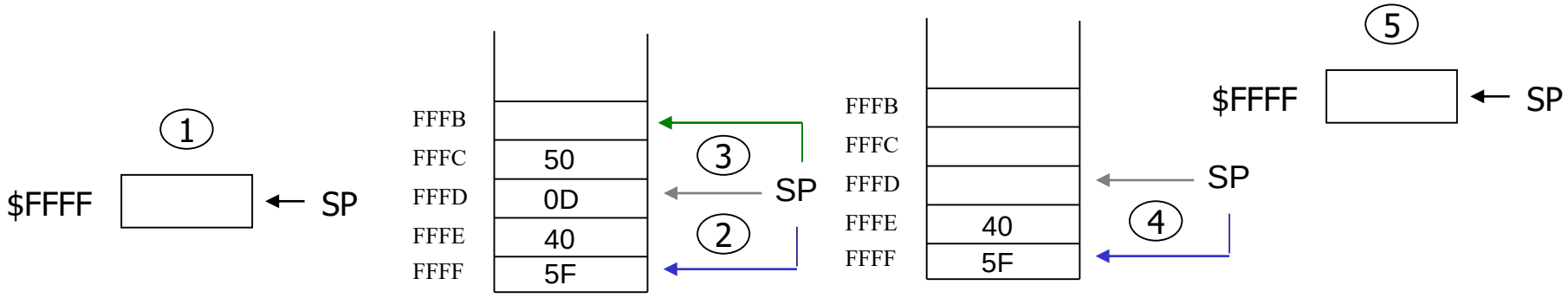
RTS Instruction

- **`RTS`** (return from subroutine) returns to the main program
  - Retrieve the return address from the top of the stack
  - Load the program counter with the return address.



Subroutine



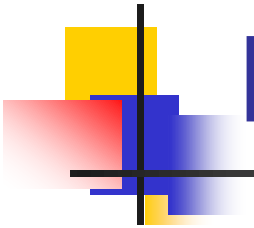


You must initialize the stack in any program that calls subroutines. If you don't, return addresses may overwrite other important data, or not be recorded because the memory at the address the SP points to is either ROM or just empty space (i.e., not installed).

Example-2 (Call-by-value)

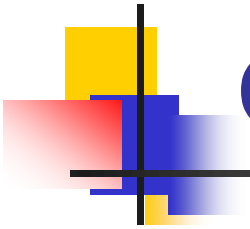
A program to find the absolute value of numbers.
Compute magnitude (absolute value) of single-byte signed number in A. Return unsigned result in A.

```
START     LDA   SP,$FFFF
          LDA   A,$A9        % neg
          STA   A,<$1000>
          LDA   A,$75        % pos
          STA   A,<$100A>
          BSR   ABSVAL
          LDA   A,<$1000>
          BSR   ABSVAL
          STA   A,<$1000>
FINISH    SWI
---------------------------
ABSVAL    TST   A,$80
          BEQ   END
          NEG   A
END       RTS
```



Passing Data to a Subroutine

- In Assembly Language data is passed to a subroutine through **registers**.
  - The data is stored in one of the registers by the calling program and the subroutine uses the value from the register.
- The other possibility is to use **agreed upon memory locations**.
  - The calling program stores the data in the memory location and the subroutine retrieves the data from the location and uses it.
- **Stack** can be used for parameter passing
  - Data are pushed to stack before calling the subroutine.



Call by Reference vs. Call by Value

- **Call by value:** The values of parameters are transferred to the subroutine.

- **Call by reference:** The addresses of the parameters are transferred to the subroutine.

Values of the parameters were transferred to subroutine in Example 2

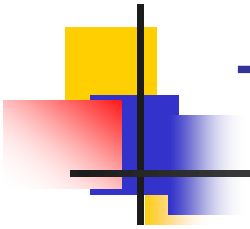
If the address of a parameter is passed to the subroutine, the contents of this memory location (original value of the parameter) can be modified by the subroutine.

Example-3 (Call-by-reference)

We write the previous example again. This time the address of the number is sent to the subroutine using the IX register. The subroutine writes the result over original value.

```
START     LDA   SP,$FFFF
          LDA   A,$A9
          STA   A,<$1000>
          LDA   A,$75
          STA   A,<$100A>
          LDA   IX,$100A
          BSR   ABSVAL
          LDA   A,<$1000>
          LDA   IX,$1000
          BSR   ABSVAL
END       SWI
-----------------------------------
ABSVAL    PSH   A
          LDA   A,<IX+0>
          TST   A,$80
          BEQ   FNSHD
          NEG   A
          STA   A,<IX+0>
FNSHD     POP   A
          RTS
```

Call by reference using index register



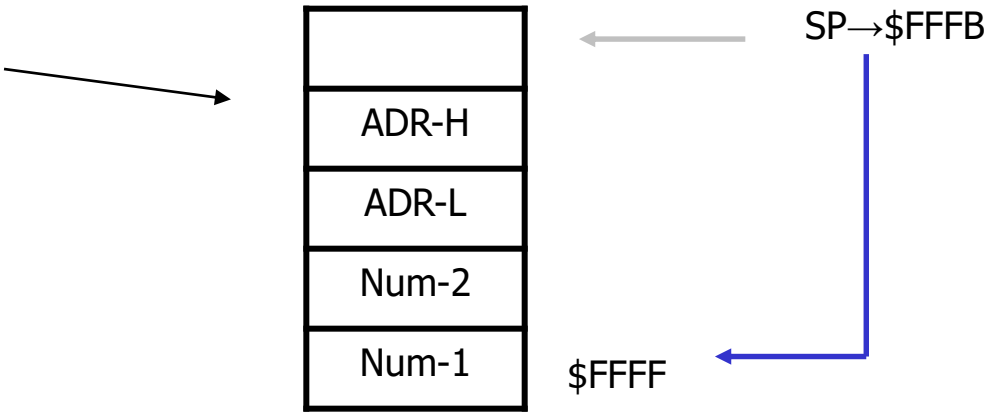
The role of the stack in subroutine calls

- Stack saves the **return address for the PC**
- Stack can be used for **parameter passing**
  - The main program writes parameters (value or address) into stack (push) and the subroutine reads these parameters from stack (pull). The stack is a shared memory. The value of SP is known by main and the subroutine.
- Stack can be used to **store the register values**
- Stack can be used to **allocate local variables** for the subroutine

Example-4 (Use of stack)

A subroutine to add two numbers. Parameters are passed via stack, using call-by-value technique. Return value is in AccA.

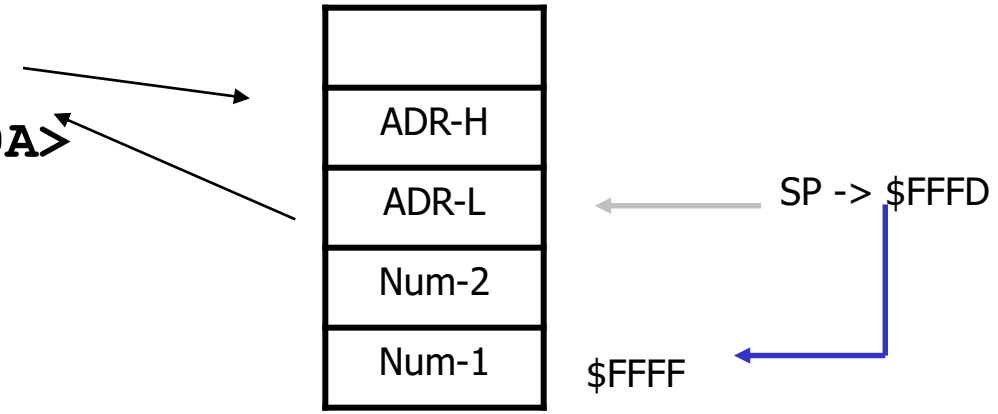
```
START   LDA   SP,$FFFF
        LDA   A,$A9
        STA   A,<$1000>
        PSH   A
        LDA   A,$75
        STA   A,<$1005>
        PSH   A
        BSR   ADDTN

ADDTN   LDA   A,<SP+4>
        ADD   A,<SP+3>
```



Example-4 (Use of stack)

A subroutine to add two numbers. Parameters are passed via stack, using call-by-value technique. Return value is in AccA.

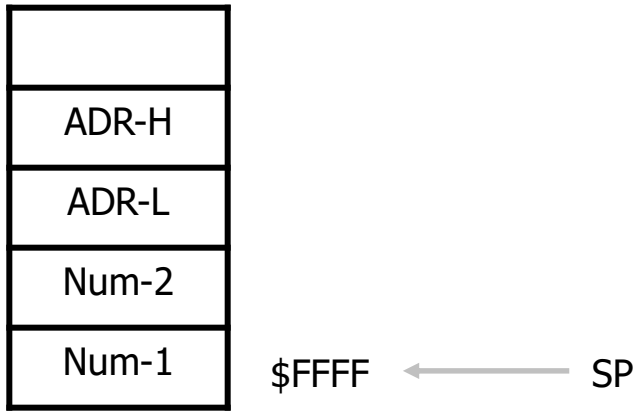
```
START   LDA   SP,$FFFF
        LDA   A,$A9
        STA   A,<$1000>
        PSH   A
        LDA   A,$75
        STA   A,<$1005>
        PSH   A
        BSR   ADDTN
        STA   A,<$100A>

ADDTN   LDA   A,<SP+4>
        ADD   A,<SP+3>
        RTS
```



Example-4 (Use of stack)

A subroutine to add two numbers. Parameters are passed via stack, using call-by-value technique. Return value is in AccA.

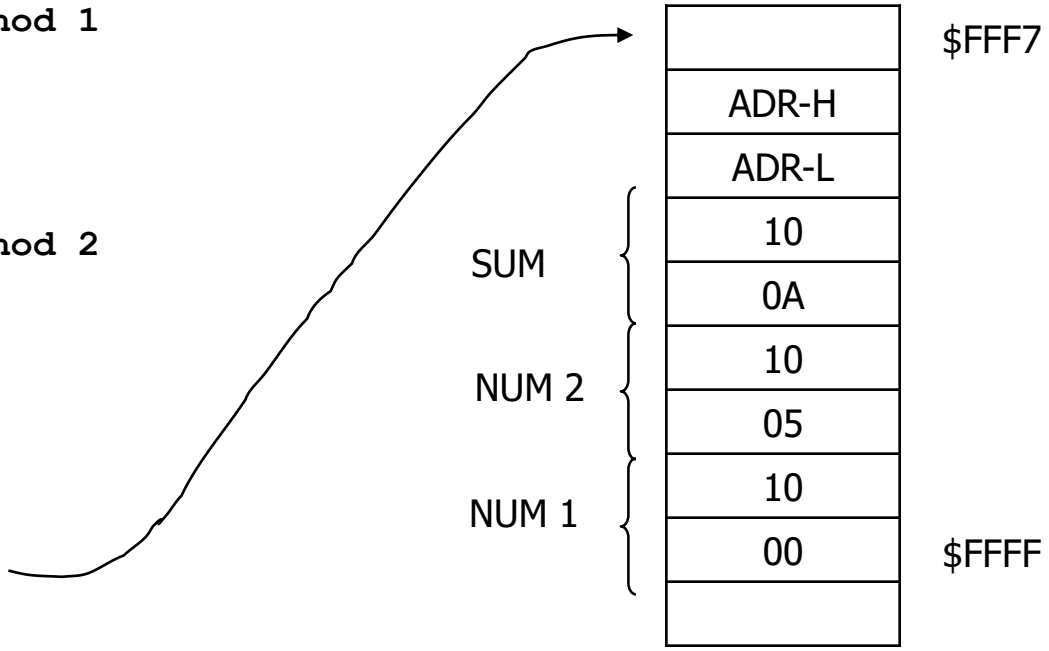
```
START   LDA   SP,$FFFF
        LDA   A,$A9
        STA   A,<$1000>
        PSH   A
        LDA   A,$75
        STA   A,<$1005>
        PSH   A
        BSR   ADDTN
        STA   A,<$100A>
        POP   A
        POP   A
END     SWI

ADDTN   LDA   A,<SP+4>
        ADD   A,<SP+3>
        RTS
```



Example-5

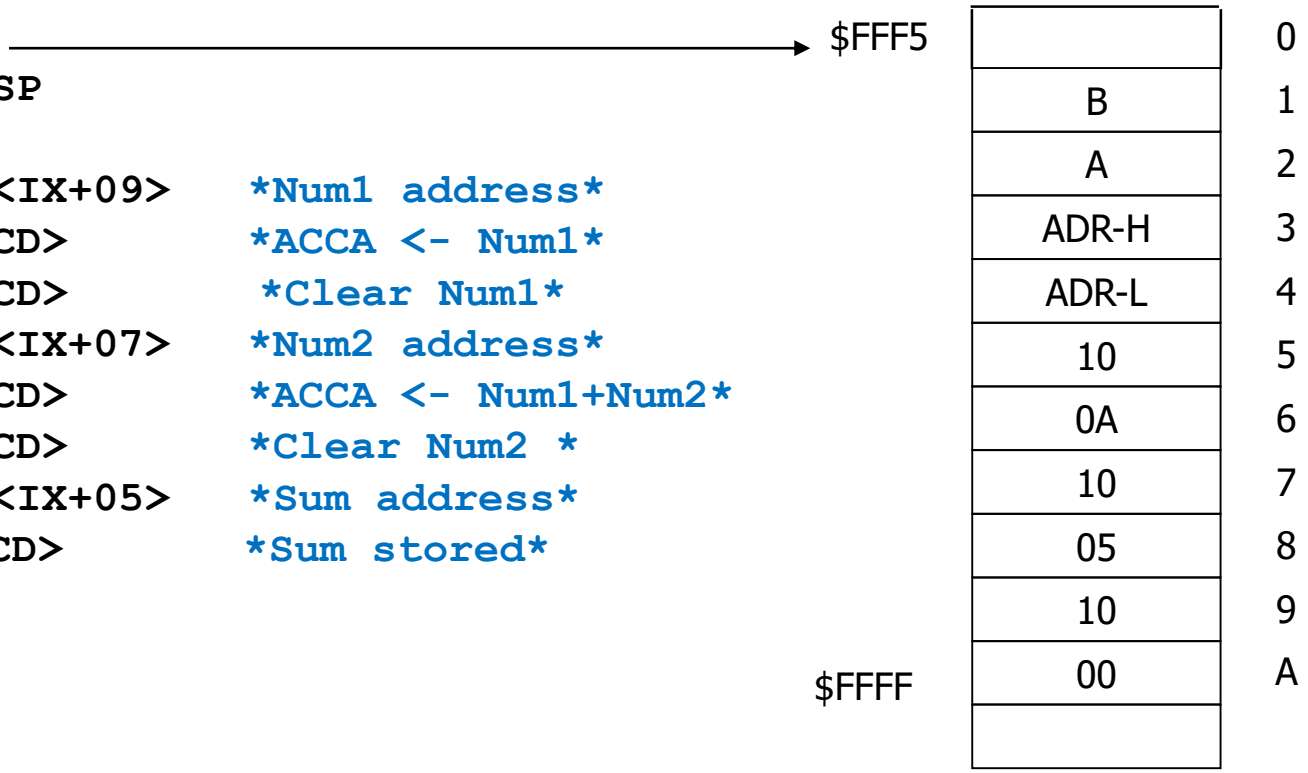
The addresses of two numbers to be added and the addresses of the result are transferred to the subroutine. In the subroutine (SUMCLR) two numbers are added, these numbers are cleared and the result is put in the destination location.

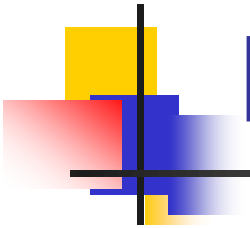
```
START   LDA   SP,$FFFF
        LDA   A,$A9
        STA   A,<$1000>
        LDA   IX,$1000
        T     AB,IX   % Method 1
        PSH   B
        PSH   A
        LDA   A,$75
        STA   A,<$1005>
        LDA   A,$05   % Method 2
        PSH   A
        LDA   A,$10
        PSH   A
        LDA   IX,$100A
        T     AB,IX
        PSH   B
        PSH   A
        BSR   SUMCLR
END     SWI
```



Example-5

```
SUMCLR   PSH   A
         PSH   B
         T     IX,SP
         CLR   B
         LDA   CD,<IX+09>    *Num1 address*
         LDA   A,<CD>        *ACCA <- Num1*
         STA   B,<CD>         *Clear Num1*
         LDA   CD,<IX+07>    *Num2 address*
         ADD   A,<CD>        *ACCA <- Num1+Num2*
         STA   B,<CD>        *Clear Num2 *
         LDA   CD,<IX+05>    *Sum address*
         STA   A,<CD>        *Sum stored*
         POP   B
         POP   A
         RTS
```





Local Variables

- Local variables are kept in stack by the subroutine. The subroutine must allocate and deallocate necessary memory space for local variables.

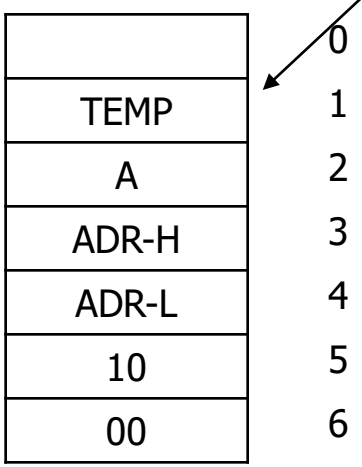
Example: Swap the high and low bytes of a 16-bit number stored in memory.

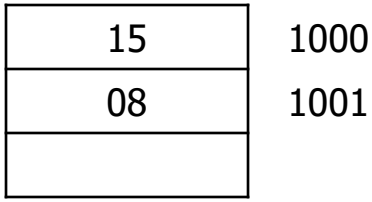
```
void swap(short int *number)
{
   char temp;
   temp = *number;
   *number = *(number + 1);
   *(number + 1) = temp;
}
```

Example-6

```
START   LDA   SP,$FFFF
        LDA   IX,$1000
        T     AB,IX
        PSH   B
        PSH   A
        LDA   A,$44
        BSR   SWAP
```

```
SWAP    PSH   A
        DEC   SP        *place for local variable *
```





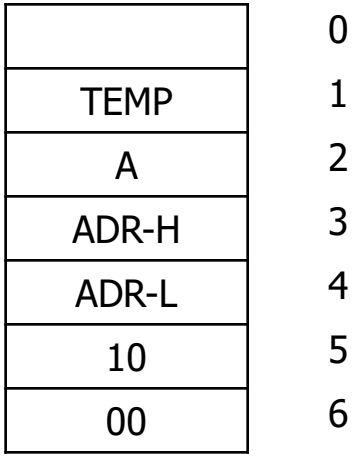

```
void swap(short int *number)
{
      char temp;
```

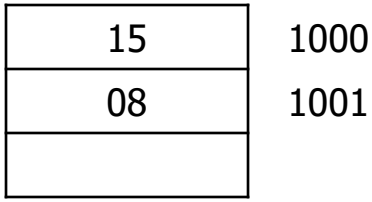
Example-6

```
START   LDA   SP,$FFFF
        LDA   IX,$1000
        T     AB,IX
        PSH   B
        PSH   A
        LDA   A,$44
        BSR   SWAP
```

```
SWAP    PSH   A
        DEC   SP          *place for local variable *
        T     IX,SP
        LDA   CD,<IX+05>  *address for high byte*
        LDA   A,<CD>      *ACCA <- High byte*
```

IX ← FFF9
CD ← 1000
A ← 15






```
void swap(short int *number)
{
      char temp;
```

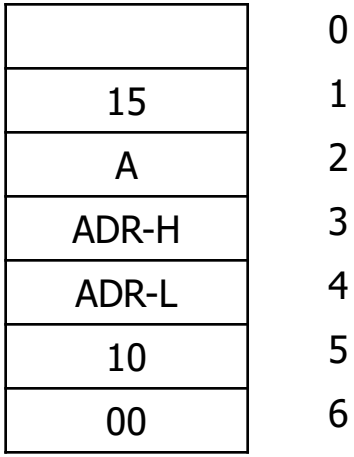
Example-6

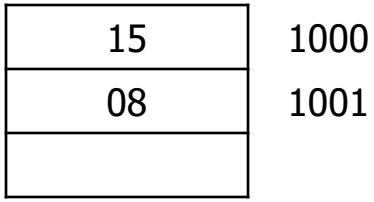
```
START   LDA   SP,$FFFF
        LDA   IX,$1000
        T     AB,IX
        PSH   B
        PSH   A
        LDA   A,$44
        BSR   SWAP
```

```
SWAP    PSH   A
        DEC   SP          *place for local variable *
        T     IX,SP
        LDA   CD,<IX+05>  *address for high byte*
        LDA   A,<CD>      *ACCA <- High byte*
        STA   A,<IX+1>    *temp <- High byte *
        INC   CD          *address for low byte*
        LDA   A,<CD>      *ACCA <- Low byte*
        DEC   CD
```

IX ← FFF9
CD ← 1000
A ← 15

CD ← 1001
A ← 08
CD ← 1000






```
void swap(short int *number)
{
        char temp;
        temp = *number;
```

Example-6

```
START   LDA   SP,$FFFF
        LDA   IX,$1000
        T     AB,IX
        PSH   B
        PSH   A
        LDA   A,$44
        BSR   SWAP
```

```
SWAP    PSH   A
        DEC   SP          *place for local variable *
        T     IX,SP
        LDA   CD,<IX+05>  *address for high byte*
        LDA   A,<CD>      *ACCA <- High byte*
        STA   A,<IX+1>    *temp <- High byte *
        INC   CD          *address for low byte*
        LDA   A,<CD>      *ACCA <- Low byte*
        DEC   CD
        STA   A,<CD>      *swap*
        LDA   A,<IX+1>    *ACCA <- temp*
        INC   CD
```

IX ← FFF9
CD ← 1000
A ← 15

CD ← 1001
A ← 08
CD ← 1000

A ← 15
CD ← 1001

	0
15	1
A	2
ADR-H	3
ADR-L	4
10	5
00	6

08	1000
08	1001

```
void swap(short int *number)
{
        char temp;
        temp = *number;
        *number = *(number + 1);
```

Example-6

```
START   LDA   SP,$FFFF
        LDA   IX,$1000
        T     AB,IX
        PSH   B
        PSH   A
        LDA   A,$44
        BSR   SWAP
        POP   A
        POP   B
END     SWI
```

	0
15	1
A	2
ADR-H	3
ADR-L	4
10	5
00	6

```
SWAP    PSH   A
        DEC   SP          *place for local variable *
        T     IX,SP
        LDA   CD,<IX+05>  *address for high byte*
        LDA   A,<CD>      *ACCA <- High byte*
        STA   A,<IX+1>    *temp <- High byte *
        INC   CD          *address for low byte*
        LDA   A,<CD>      *ACCA <- Low byte*
        DEC   CD
        STA   A,<CD>      *swap*
        LDA   A,<IX+1>    *ACCA <- temp*
        INC   CD
        STA   A,<CD>      *high byte to <$1001>*
        INC   SP          *deallocate temp*
        POP   A
        RTS
```

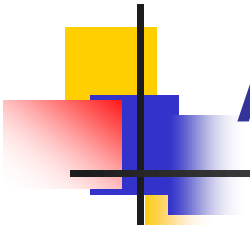
IX ← FFF9
CD ← 1000
A ← 15

CD ← 1001
A ← 08
CD ← 1000

A ← 15
CD ← 1001

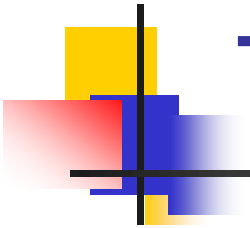
08	1000
15	1001

```
void swap(short int *number)
{
        char temp;
        temp = *number;
        *number = *(number + 1);
        *(number + 1) = temp;
}
```



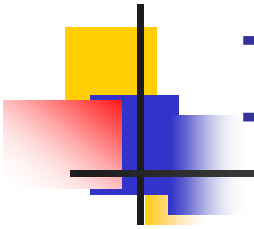
Attention!!

- In **`PUSH`** and **`POP`** instructions, the variables should be in reverse order (LIFO)
- # of **`PUSH`** instructions should be equal to the # of **`POP`** instructions
  - Otherwise wrong return address is retrieved from stack by RTS instruction. So program gives error.
- It is not recommended to have **`PUSH`** and **`POP`** within loops
- Return from subroutine with RTS instruction



Topics

- Stack
- Subroutine
- Interrupt

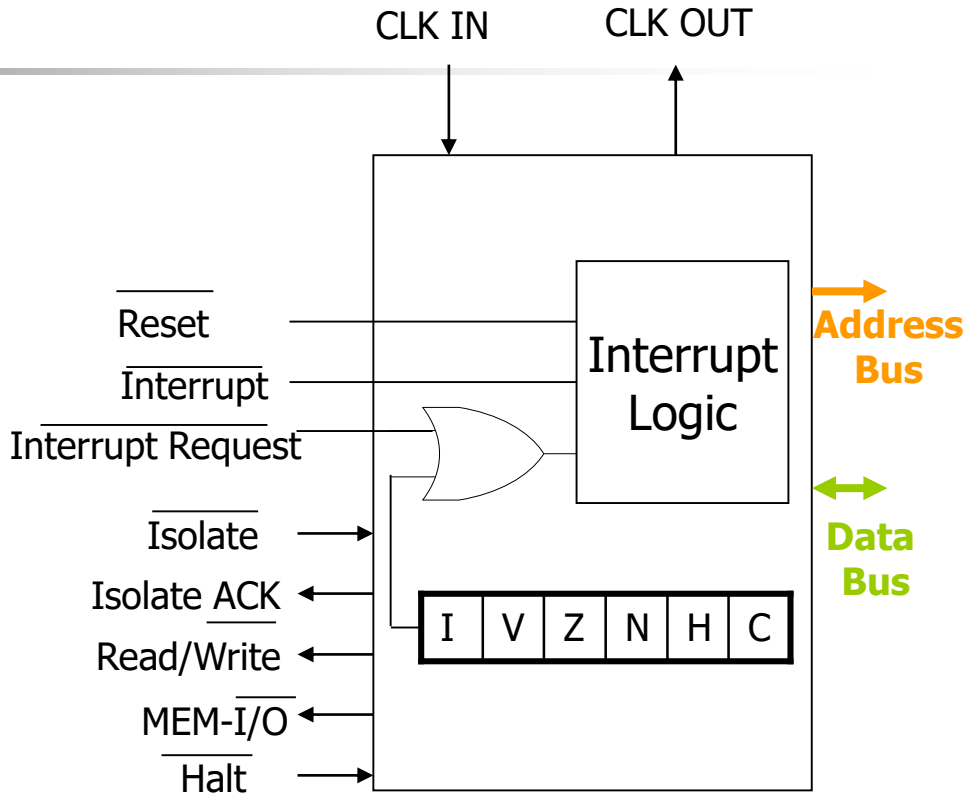


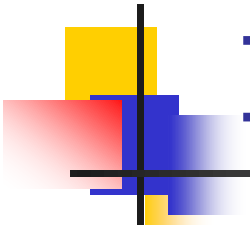
Interrupt

- Interrupt can be considered to be an emergency signal.
  - The Microprocessor should respond to it as soon as possible.
  - When the Microprocessor receives an interrupt signal, it suspends the currently executing program (after executing its current instruction) and jumps to an **Interrupt Service Routine (ISR)** to respond to the incoming interrupt.
  - Each interrupt will most probably have its own ISR.

Interrupt

- **Non-maskable interrupt:** CPU responses the interrupt
- **Maskable interrupt:**
  CPU responses the interrupt based on the interrupt bit of status register.
  - I=1: Blocking the interrupt
  - I=0: CPU responds to interrupt request
- **Reset:** Brings the computer into the startup state.
- **Priorities:** Reset>NMI>MI





Interrupt

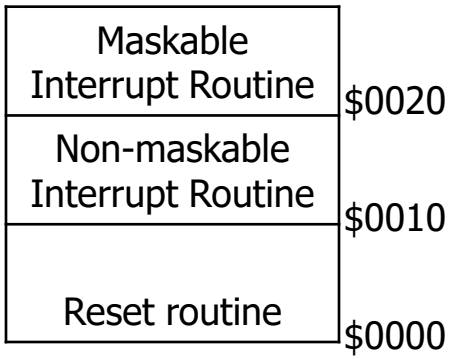
- Responding to an interrupt may be immediate or delayed depending on whether the interrupt is maskable or non-maskable and whether interrupts are being masked or not.

- There are two ways of redirecting the execution to the ISR depending on whether the interrupt is **non-vectored** or **vectored**.

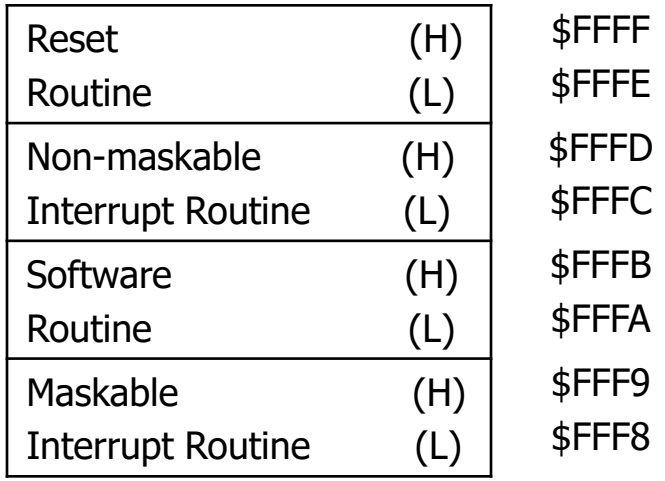
- If user has to provide address of subroutine using CALL instruction then it is known as **non-vectored interrupt.**

Interrupt Vector

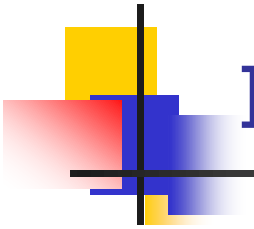
- **Vectored interrupt:**
  1. The vector is already known to the Microprocessor
  2. The device will have to supply the vector to the Microprocessor
- An interrupt vector is a pointer to where the ISR is stored in memory.
- **Interrupt Vector Table:** A table of interrupt vectors



Option 1



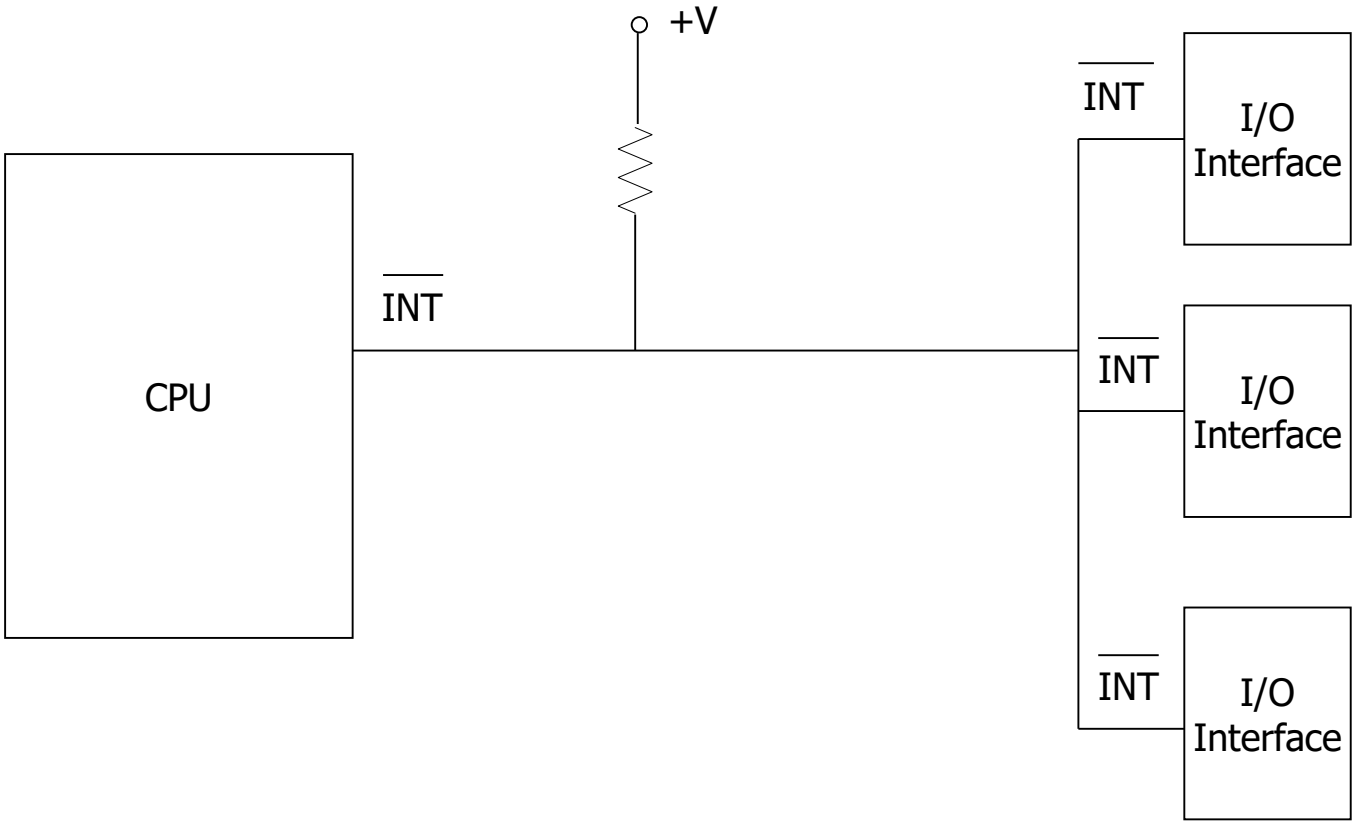
Option 2



Interrupt in Educational CPU

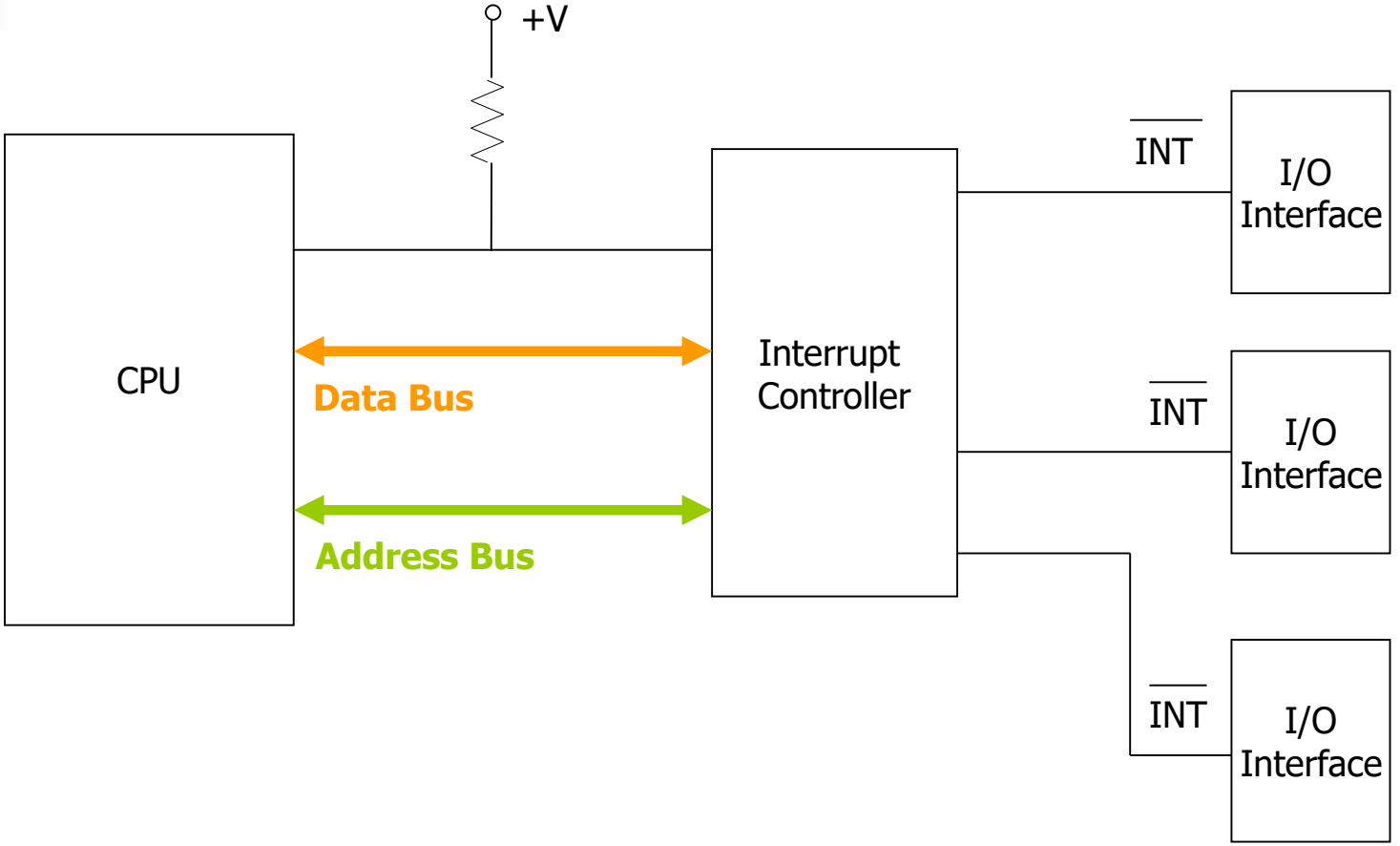
- When a hardware NMI or IRQ is received:
  - Need to understand where the interrupt is coming from using the following methods
    - Polling : Check the PIA and ACIA status bits. Polling order determines the interrupt priority.
    - Interrupt Controller Chip : Configures interrupt priorities and indicates interrupt source
  - Execute the interrupt routine associated with the interrupt source

Polling

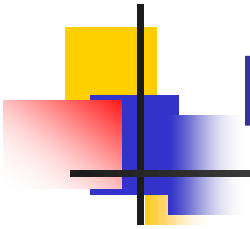


- The interrupt line is lowered if there is an interrupt.
- CPU reads status registers of I/Os to determine which interrupt service routine will be executed

Interrupt Controller



- When I/O interrupt occurs, interrupt controller sends interrupt to CPU
- CPU reads the register or interrupt controller to determine which interrupt routine will be executed



Branching to ISR

- Interrupt service routines are like subroutines.
- When the CPU accesses the ISR, it pushes the current value of the program counter (PC) onto stack
- Upon return from the interrupt, the CPU should continue with where it left from with the same register contents
- The interrupt routine returns to the main program with the RTI (Return from Interrupt) instruction

I/O Interrupt Processing