Computer Structure and Language

The 8086/8088 Assembly Language

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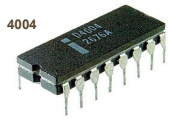
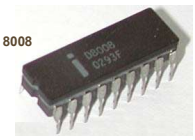
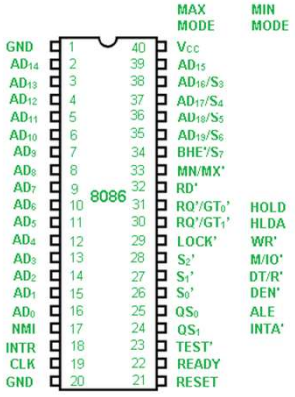
Intel's 4004 to 8086 Microprocessor

4004: 4-bit microprocessor designed for desktop printing calculator (2300 Transistors), 1971
8008: Early byte-oriented microprocessors (3500 Transistors), 1972
4040: Successor to 4004 (3000 Transistors), 1974
8080: Second 8-bit microprocessor (6000 Transistors), 1974
8085: 8-bit microprocessor (8080 software-binary compatible, 6500 Transistors), 1976
8086: 16-bit microprocessor (29000 Transistors), 1978







NOTE. Wafer Scale Engine (WSE) has 1.2 trillion (1200 000 000 000) transistors with a die area of 46225 mm² (with 400000 cores for AI/ML processing and 18 GB on-die SRAM (reported at HotChips 2019).

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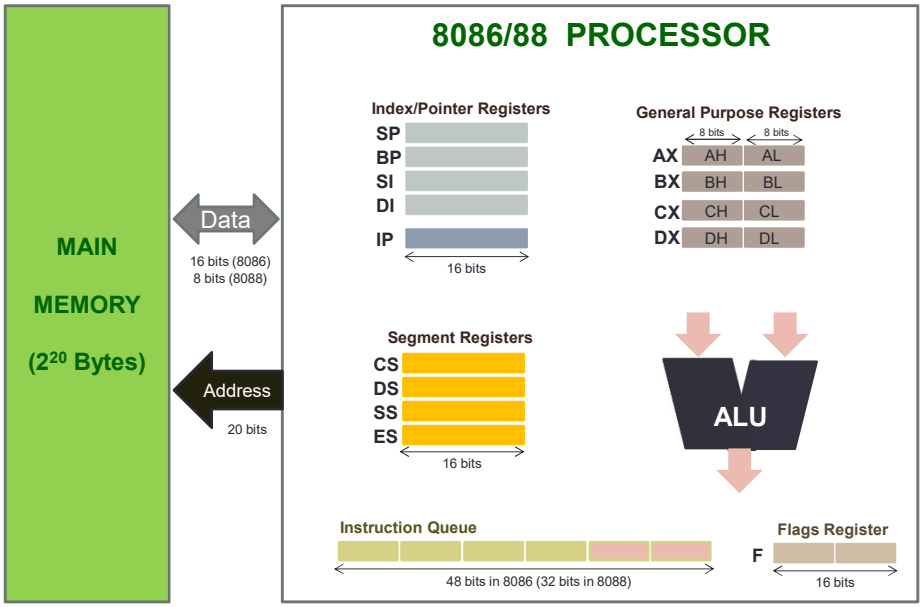
The 8086 System Structure



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8086/88 features:

- First 16-bit microprocessor (8088 has an 8-bit data bus)
- 2^{20}-byte addressable segmented main memory (20-bit address), Little Endian
- Data types:
  - 8/16/32 bit (byte, word, double-word) binary (signed, unsigned),
  - 8/16 bit decimal BCD (partially supported),
  - Character, String
- Addressing modes:
  - Implied
  - Immediate (d8, d16)
  - Direct (register, memory): AX, BX, CX, …, and d16
  - Indirect (register, memory): (BX), (SI), (DI), (BP)
  - Indexed: (SI)±d8, (SI)±d16, (DI)±d8, (DI)±d16
  - Base-displacement: (BX)±d8, (BX)±d16, (BP)±d8, (BP)±d16
  - Base-indexed: (SI)+(BX), (DI)+(BX), (SI)+(BP), (DI)+(BP)
  - Base-displacement-indexed: (SI)+(BX)±d8, (DI)+(BX)±d8, (SI)+(BP)±d8, (DI)+(BP)±d8, (SI)+(BX)±d16, (DI)+(BX)±d16, (SI)+(BP)±d16, (DI)+(BP)±d16
  - Segmented addressing as 8086's *base addressing mode*

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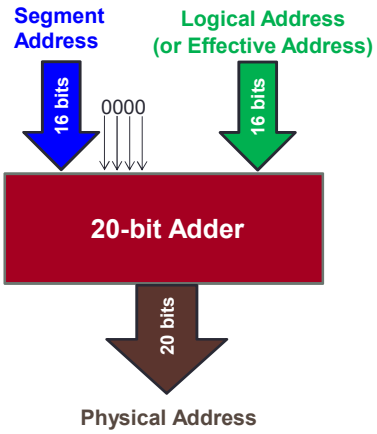
Address Generation Scheme (Segmented)

Physical Address = 16 x Segment Address + Logical (Effective) Address



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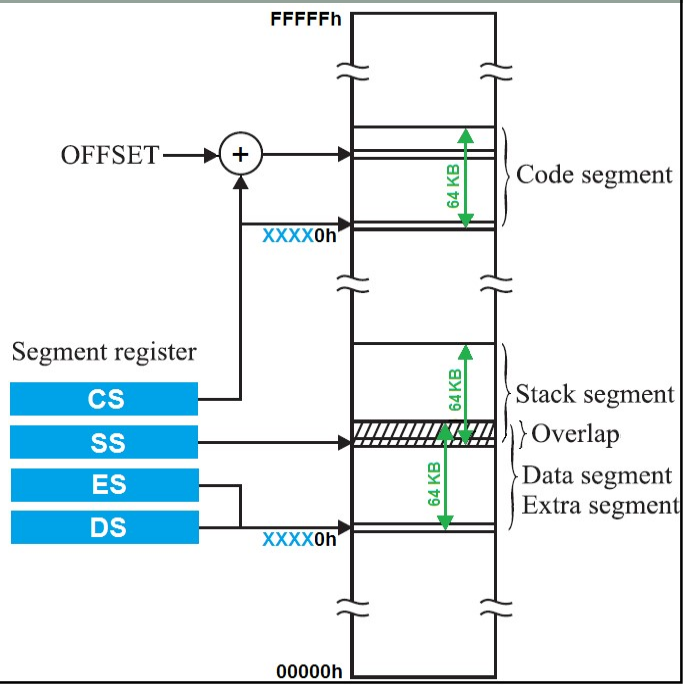
8086/88 Segmented Memory



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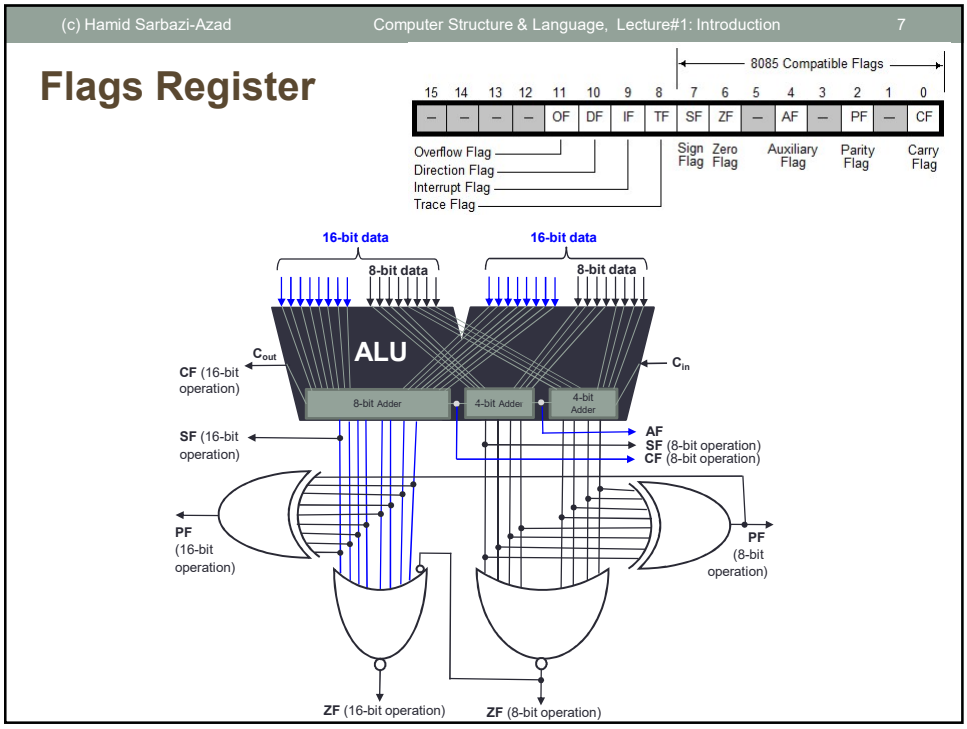
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Computer Structure & Language, Lecture#1: Introduction
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Flags Register
8085 Compatible Flags
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
– – – – OF DF IF TF SF ZF – AF – PF – CF
Overflow Flag
Direction Flag
Interrupt Flag
Trace Flag
Sign Flag
Zero Flag
Auxiliary Flag
Parity Flag
Carry Flag
16-bit data
8-bit data
16-bit data
8-bit data
ALU
Cout
Cin
CF (16-bit operation)
8-bit Adder
4-bit Adder
4-bit Adder
SF (16-bit operation)
AF
SF (8-bit operation)
CF (8-bit operation)
PF (16-bit operation)
PF (8-bit operation)
ZF (16-bit operation)
ZF (8-bit operation)

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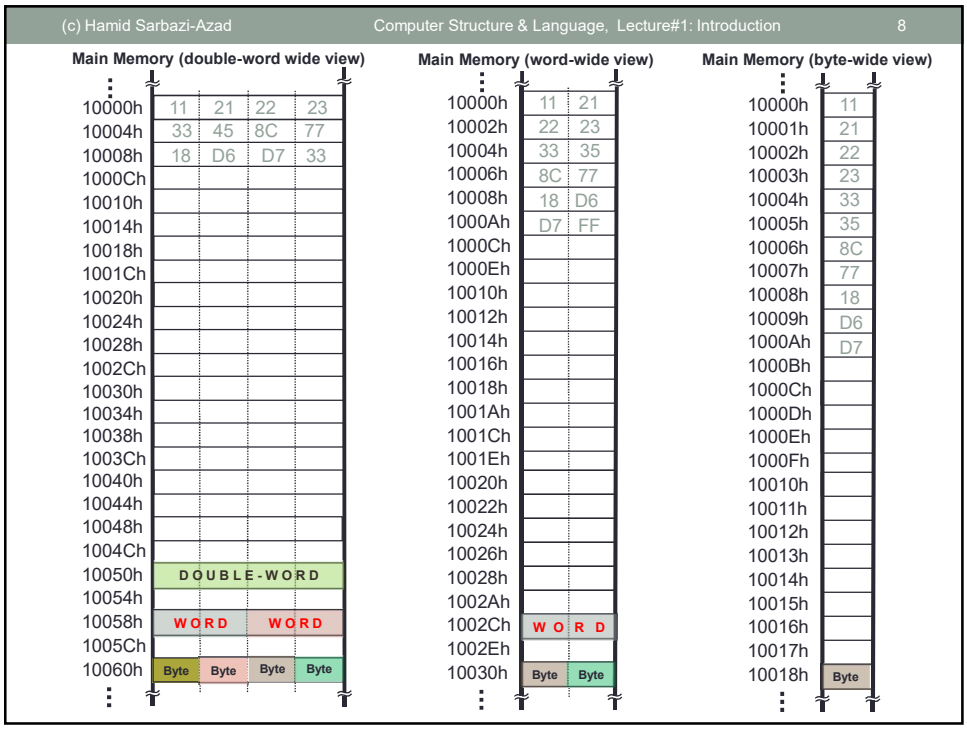
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Main Memory (double-word wide view)
10000h 11 21 22 23
10004h 33 45 8C 77
10008h 18 D6 D7 33
1000Ch
10010h
10014h
10018h
1001Ch
10020h
10024h
10028h
1002Ch
10030h
10034h
10038h
1003Ch
10040h
10044h
10048h
1004Ch
10050h DOUBLE-WORD
10054h
10058h WORD WORD
1005Ch
10060h Byte Byte Byte Byte
Main Memory (word-wide view)
10000h 11 21
10002h 22 23
10004h 33 35
10006h 8C 77
10008h 18 D6
1000Ah D7 FF
1000Ch
1000Eh
10010h
10012h
10014h
10016h
10018h
1001Ah
1001Ch
1001Eh
10020h
10022h
10024h
10026h
10028h
1002Ah
1002Ch WORD
1002Eh
10030h Byte Byte
Main Memory (byte-wide view)
10000h 11
10001h 21
10002h 22
10003h 23
10004h 33
10005h 35
10006h 8C
10007h 77
10008h 18
10009h D6
1000Ah D7
1000Bh
1000Ch
1000Dh
1000Eh
1000Fh
10010h
10011h
10012h
10013h
10014h
10015h
10016h
10017h
10018h Byte

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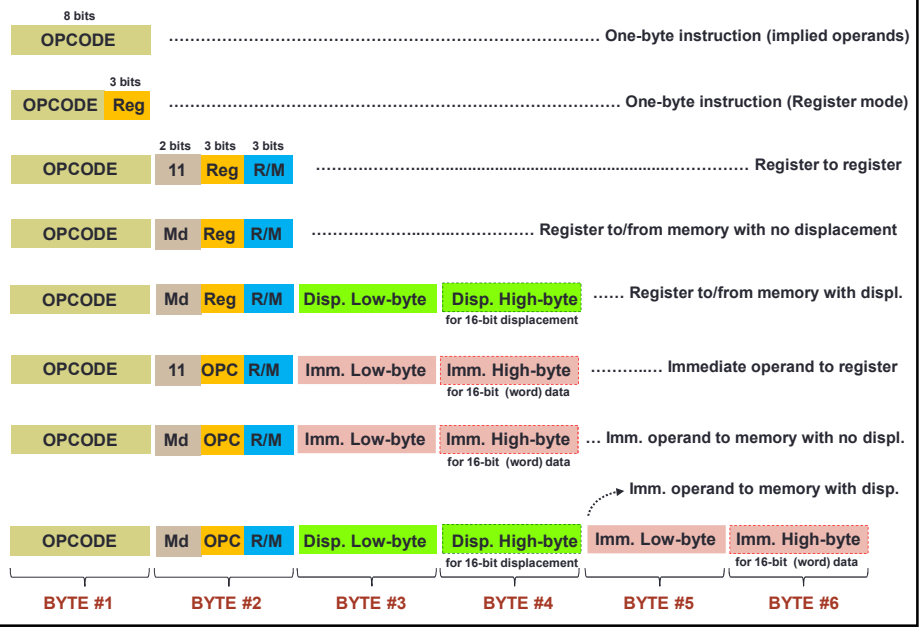
The 8086/88 Instruction Format



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Memory address calculation using Md and R/M fields

		Memory mode			Register mode		
		Md = 00	Md = 01	Md = 10	Md = 11		
		SR : EA	SR : EA	SR : EA	W = 0	W = 1	
R/M	000	DS : (BX)+(SI)	DS : (BX)+(SI)+d8	DS : (BX)+(SI)+d16	AL	AX	000
	001	DS : (BX)+(DI)	DS : (BX)+(DI)+d8	DS : (BX)+(DI)+d16	CL	CX	001
	010	SS : (BP)+(SI)	SS : (BP)+(SI)+d8	SS : (BP)+(SI)+d16	DL	DX	010
	011	SS : (BP)+(DI)	SS : (BP)+(DI)+d8	SS : (BP)+(DI)+d16	BL	BX	011
	100	DS : (SI)	DS : (SI)+d8	DS : (SI)+d16	AH	SP	100
	101	DS : (DI)	DS : (DI)+d8	DS : (DI)+d16	CH	BP	101
	110	DS : d16	SS : (BP)+d8	SS : (BP)+d16	DH	SI	110
	111	DS : (BX)	DS : (BX)+d8	DS : (BX)+d16	BH	DI	111
							Reg

SR: Segment Register **EA:** Effective Address

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The 8086/88 supports 7 types of instructions:

1. **Data Transfer Instructions:** mov,push,pop,pusha,popa,xchg,xlat,in, out,lea,lds,les,lahf,sahf,pushf,popf
2. **Arithmetic Instructions:** add,adc,inc,aaa,daa,sub,sbb,dec,neg,cmp, aas,das,mul,imul,aam,div, idiv,aad,cbw,cwd
3. **Bit Manipulation Instructions:** not,and,or,xor,test,shl/sal,shr,sar,rol,ror, rcr,rcl
4. **String Instructions:** rep,repe/repz,repne/repnz,movs/movsb/movsw, cmps/cmpsb/cmpsw,ins/insb/insw,outs/outsb/outsw,scas/sacsb/scasw, lods/lodsb/lodsw
5. **Program Execution Transfer Instructions:** call,ret,jmp,ja/jnbe, jae/jnb,jbe/jna,jc,je/jz,jg/jnle,jge/jnl,jl/jnge,jle/jng,jnc,jne/jnz,jno,jnp/jpo, jns,jo,jp/jpe,js,loop,loope/loopz,loopne/loopnz,jcxz
6. **Processor Control Instructions:** stc,clc,cmc,std,cld,sti,cli
7. **Interrupt Instructions:** int,into,iret

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The 8086/88 Program Structure/Layout:

```
Seg_name1   SEGMENT
            .
            .   Directives/instructions
            .
Seg_name1   ENDS

Seg_name2   SEGMENT
            .
            .   Directives/instructions
            .
Seg_name2   ENDS

            .
            .

Seg_nameX   SEGMENT

Start_label:.
            .   Directives/instructions
            .
Seg_nameX   ENDS
            END  Start_label
```

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Useful notes:

- General format of an assembly instruction is:

  Label: Mnemonic Operand, Operand ;Comment to document and help readers

  Example: Loop: mov ax, array+100[bx] ; Load the next element of the array into accumulator
- You can use numbers in the assembly program in Decimal, Octal, Binary and Hexadecimal bases using D, O, B, and H suffixes. For example, we can write:

  Example: 000001010111B == 0127O == 87D or 87 == 057H
- You can use:
  - DB (define byte), DW (define word), DD (define double-word) directives to define a variable and initialize it; (sophisticated ways to define more complex types)
  - prefix SEGMENT (OFFSET) before a label to get its Segment address (Offset within its segment)
  - prefix PTR is used before an address or expression to indicate its type (byte, word, dword) or its reference distance (near, far)
  - EQU (Equate) directive to define a constant/variable/expression and name it.

    Example: Ten EQU 10 ; then use as: add AX,Ten == Add AX,10

    Convert_byte_to_word EQU CBW ; then use as: Convert_byte_to_word == CBW
  - ORG (Originate) directive to move Location Counter at a given address.

    Example: ORG 100h
  - EVEN directive to move Location Counter at next even address (pass one byte if the current address is odd).

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Examples of Variable Definition:

```
        ....
; Let us assume Location Counter = 0018h here.
var1:  db 10, 2 dup(-1), 101b, 76O, 2 dup (0, 11h)  ;@var1= 0018h
var2:  dw -2, 7689h, 256, 2 dup (-1,?)   ; my words (@var2 = 0021h)
ham:  dd  100, ?, 12345678h    ; @ham = 002Fh
my_vector:  db 10 dup (?)        ; @my_vector = 003Bh
my_str:  db  'abcdefg', 0, -1, 2, 3 dup ('A')     ; @my_str = 0045h
Titan:     db  2 dup('allah', 0)                  ; @Titan = 0052h
Array5:  db       20 dup (101b)                   ; @Array5 = 005Eh
; Here Location Counter = 0072h
        ....
        ....
```

Symbol Table

Symbol	Address
var1	0018h
var2	0021h
ham	002Fh
my_vector	003Bh
My_str	0045h
Titan	0052h
Array5	005Eh

Memory Segment (logical view)

0018h	0A	FF	FF	05
001Ch	3E	00	11	00
0020h	11	FE	FF	89
0024h	76	00	01	FF
0028h	FF	??	??	FF
002Ch	FF	??	??	64
0030h	00	00	00	??
0034h	??	??	??	78
0038h	56	34	12	??
003Ch	??	??	??	??
0040h	??	??	??	??
0044h	??	61	62	63
0048h	64	65	66	67
004Ch	00	FF	02	41
0050h	41	41	61	6C
0054h	6C	61	68	00
0058h	61	6C	6C	61
005Ch	68	00	05	05
0060h	05	05	05	05
0064h	05	05	05	05
0068h	05	05	05	05
006Ch	05	05	05	05
0070h	05	05		

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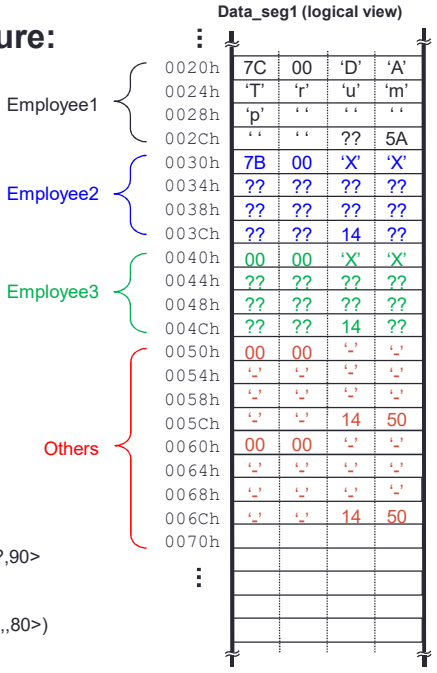
User Defined Type and Structure:

```
Structure name    STRUC
      .
      .     Sequence of DB, DW,
      .     and DD directives
      .
Structure name    ENDS
```

Example:

```
Personnel_data    STRUC
            ID          DW          0
            Initials    DB          'XX'
            Last_name   DB          10 Dup (?)
            Age         DB          20
            Weight      DB          ?
Personnel_data    ENDS

Data_seg1    SEGMENT
              ....
; Location counter =20h here
    Employee1   Personnel_data  <124, 'DA', 'Trump     ',?,90>
    Employee2   Personnel_data  <123,,,,>
    Employee3   Personnel_data  < >
    Others      Personnel_data  2 Dup (<,'- -',10 dup('-'),,80>)
Data_seg1    ENDS
```



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User Defined Records:

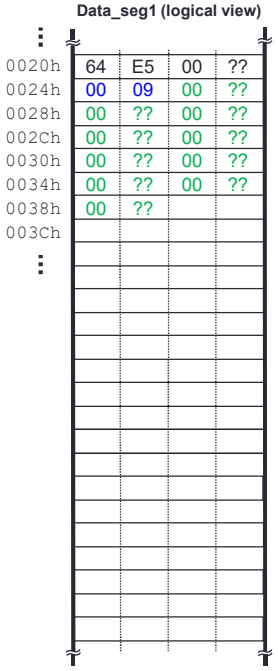
```
Record name    RECORD   field specification, …, field specification
```

Example:

```
Pattern   RECORD  OPCODE:8=0,Md:2=3,Reg:3,R_M:3
```


```
....

Data_seg1    SEGMENT
              ....
; Location Counter =20h here
    Instruction1   Pattern  <100, ,4,5>, <>
    Instruction2   Pattern  <,0,1,1>
    Program        Pattern  10 Dup(<>)
Data_seg1    ENDS
```



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User Defined Type and Structure:

Example:

```
Pattern    RECORD   OPCODE:8=0,Md:2=3,Reg:3,R_M:3

Personnel_data    STRUC
            ID          DW          0
            Last_name DB          10 Dup (?)
            Age         DB          20
Personnel_data    ENDS

Data_seg1    SEGMENT
   Employees          Personnel_data 100  Dup (<1,10 dup(' '),>)
   New_Employee     Personnel_data <>
   Instr1               Pattern <>
   Instr2               Pattern <>
Data_seg1    ENDS
```

Now, we can write in our program:

```
            mov         New_employee.Age, AL
            add         Employees.ID[SI],1      ; SI can be incremented in a loop by 13 (structure size)
            mov         ax,Instr1
            or          ax, 1111011100111111B
            mov         Instr2,ax                   ; (Instr2) = 11110111 11 111 111B
```

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Questions?

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