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# Addressing Modes

Chapter 5  
S. Dandamudi

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## Outline

- Addressing modes
- Simple addressing modes
  - \* Register addressing mode
  - \* Immediate addressing mode
- Memory addressing modes
  - \* 16-bit and 32-bit addressing
    - » Operand and address size override prefixes
  - \* Direct addressing
  - \* Indirect addressing
  - \* Based addressing
  - \* Indexed addressing
  - \* Based-indexed addressing
- Examples
  - \* Sorting (insertion sort)
  - \* Binary search
- Arrays
  - \* One-dimensional arrays
  - \* Multidimensional arrays
  - \* Examples
    - » Sum of 1-d array
    - » Sum of a column in a 2-d array
- Performance: Usefulness of addressing modes

## Addressing Modes

- Addressing mode refers to the specification of the location of data required by an operation
- Pentium supports three fundamental addressing modes:
  - \* Register mode
  - \* Immediate mode
  - \* Memory mode
- Specification of operands located in memory can be done in a variety of ways
  - \* Mainly to support high-level language constructs and data structures

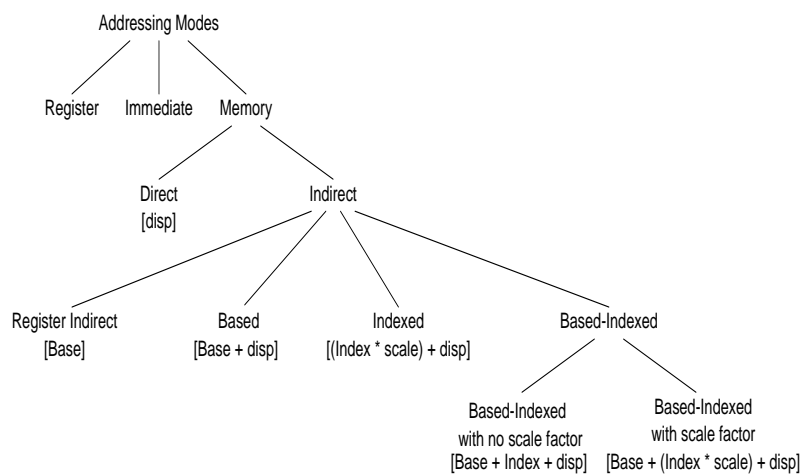
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## Pentium Addressing Modes (32-bit Addresses)



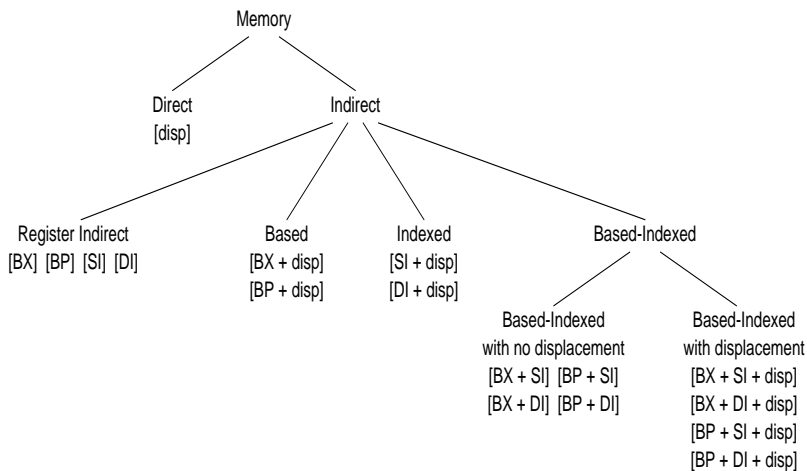
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## Memory Addressing Modes (16-bit Addresses)



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## Simple Addressing Modes

### *Register Addressing Mode*

- Operands are located in registers
- It is the most efficient addressing mode
  - \* No memory access is required
  - \* Instructions tend to be shorter
    - » Only 3 bits are needed to specify a register as opposed to at least 16 bits for a memory address
- An optimization technique:
  - \* Place the frequently accesses data (e.g., index variable of a big loop) in registers

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## Simple Addressing Modes (cont'd)

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### *Immediate Addressing Mode*

- Operand is stored as part of the instruction
- This mode is used mostly for constants
- It imposes several restrictions:
  - \* Typically used in instructions that require at least two operands (exceptions like **push** exist)
  - \* Can be used to specify only the source operands (not the destination operand)
  - \* Another addressing mode is required for specifying the destination operand
- Efficient as the data comes with the instructions (instructions are generally prefetched)

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## Memory Addressing Modes

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- Pentium offers several addressing modes to access operands located in memory
  - » Primary reason: To efficiently support high-level language constructs and data structures.
- Available addressing modes depend on the address size used
  - \* 16-bit modes (shown before)
    - » same as those supported by 8086
  - \* 32-bit modes (shown before)
    - » supported by Pentium
    - » more flexible set

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## 32-Bit Addressing Modes

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- These addressing modes use 32-bit registers

**Segment + Base + (Index \* Scale) + displacement**

CS	EAX	EAX	1	no displacement
SS	EBX	EBX	2	8-bit displacement
DS	ECX	ECX	4	32-bit displacement
ES	EDX	EDX	8	
FS	ESI	ESI		
GS	EDI	EDI		
	EBP	EBP		
	ESP			

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## Differences between 16- and 32-bit Modes

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	16-bit addressing	32-bit addressing
Base register	BX, BP	EAX, EBX, ECX, EDX, ESI, EDI, EBP, ESP
Index register	SI, DI	EAX, EBX, ECX, EDX, ESI, EDI, EBP
Scale factor	None	1, 2, 4, 8
Displacement	0, 8, 16 bits	0, 8, 32 bits

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## 16-bit or 32-bit Addressing Mode?

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- How does the processor know?
- Uses the D bit in the CS segment descriptor
  - D = 0
    - » default size of operands and addresses is 16 bits
  - D = 1
    - » default size of operands and addresses is 32 bits
- We can override these defaults
  - \* Pentium provides two size override prefixes
    - 66H operand size override prefix
    - 67H address size override prefix
- Using these prefixes, we can mix 16- and 32-bit data and addresses

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## Examples: Override Prefixes

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- Our default mode is 16-bit data and addresses

### Example 1: Data size override

```
mov AX,123 ==> B8 007B
```

```
mov EAX,123 ==> 66 | B8 0000007B
```

### Example 2: Address size override

```
mov AX,[EBX*ESI+2] ==> 67 | 8B0473
```

### Example 3: Address and data size override

```
mov EAX,[EBX*ESI+2] ==> 66 | 67 | 8B0473
```

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## Direct Addressing

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- Offset (i.e., effective address) is specified as part of the instruction
  - » The assembler replaces variable names by their offset values during the assembly process
  - » Useful to access only simple variables

### Example

```
total_marks =  
    assign_marks + test_marks + exam_marks
```

translated into

```
mov    EAX, assign_marks  
add    EAX, test_marks  
add    EAX, exam_marks  
mov    total_marks, EAX
```

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## Register Indirect Addressing

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- Effective address is placed in a general-purpose register
- In 16-bit segments
  - \* only BX, SI, and DI are allowed to hold an effective address

```
add    AX, [BX]    is valid  
add    AX, [CX]    is NOT allowed
```

- In 32-bit segments
  - \* any of the eight 32-bit registers can hold an effective address

```
add    AX, [ECX]    is valid
```

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## Register Indirect Addressing (cont'd)

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### Default Segments

- 16-bit addresses
  - \* BX, SI, DI : data segment
  - \* BP, SP : stack segment
- 32-bit addresses
  - \* EAX, EBX, ECX, EDX, ESI, EDI: data segment
  - \* EBP, ESP : stack segment
- Possible to override these defaults
  - \* Pentium provides segment override prefixes

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## Register Indirect Addressing (cont'd)

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### Overriding Default Segments

- Use CS, SS, DS, ES, FS, or GS as in
  - `add AX,SS:[BX]; uses stack segment`
  - `add AX,DS:[BP]; uses data segment`
- You **cannot use** these segment override prefixes to affect the default segment association in the following cases:
  - \* Destination of string instructions: always ES
  - \* Stack push and pop operations: always SS
  - \* Instruction fetch: always CS

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## Based Addressing

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- Effective address is computed as  
     base + signed displacement
  - \* Displacement:
    - 16-bit addresses: 8- or 16-bit number
    - 32-bit addresses: 8- or 32-bit number
- Useful to access fields of a structure or record
  - » Base register ==> points to the base address of the structure
  - » Displacement ==> relative offset within the structure
- Useful to access arrays whose element size is not 2, 4, or 8 bytes
  - » Displacement ==> points to the beginning of the array
  - » Base register ==> relative offset of an element within the array

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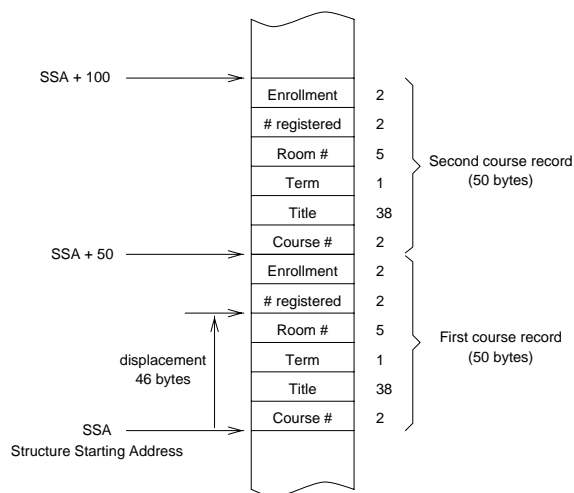
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## Based Addressing (cont'd)

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## Indexed Addressing

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- Effective address is computed as  
(Index \* scale factor) + signed displacement
  - \* 16-bit addresses:
    - displacement: 8- or 16-bit number
    - scale factor: none (i.e., 1)
  - \* 32-bit addresses:
    - displacement: 8- or 32-bit number
    - scale factor: 2, 4, or 8
- Useful to access elements of an array (particularly if the element size is 2, 4, or 8 bytes)
  - » Displacement ==> points to the beginning of the array
  - » Index register ==> selects an element of the array (array index)
  - » Scaling factor ==> size of the array element

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## Indexed Addressing (cont'd)

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### Examples

**add AX, [DI+20]**

- We have seen similar usage to access parameters off the stack (in Chapter 4)

**add AX, marks\_table[ESI\*4]**

- Assembler replaces **marks\_table** by a constant (i.e., supplies the displacement)
- Each element of **marks\_table** takes 4 bytes (the scale factor value)
- ESI needs to hold the element subscript value

**add AX, table1[SI]**

- SI needs to hold the element offset in *bytes*
- When we use the scale factor we avoid such byte counting

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## Based-Indexed Addressing

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### Based-indexed addressing with no scale factor

- Effective address is computed as  
Base + Index + signed displacement
- Useful in accessing two-dimensional arrays
  - » Displacement ==> points to the beginning of the array
  - » Base and index registers point to a row and an element within that row
- Useful in accessing arrays of records
  - » Displacement ==> represents the offset of a field in a record
  - » Base and index registers hold a pointer to the base of the array and the offset of an element relative to the base of the array

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## Based-Indexed Addressing (cont'd)

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- Useful in accessing arrays passed on to a procedure
  - » Base register ==> points to the beginning of the array
  - » Index register ==> represents the offset of an element relative to the base of the array

### Example

Assuming BX points to **table1**

```
mov AX, [BX+SI]
```

```
cmp AX, [BX+SI+2]
```

compares two successive elements of **table1**

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## Based-Indexed Addressing (cont'd)

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### Based-indexed addressing with scale factor

- Effective address is computed as  
Base + (Index \* scale factor) + signed displacement
- Useful in accessing two-dimensional arrays when the element size is 2, 4, or 8 bytes
  - » Displacement ==> points to the beginning of the array
  - » Base register ==> holds offset to a row (relative to start of array)
  - » Index register ==> selects an element of the row
  - » Scaling factor ==> size of the array element

## Illustrative Examples

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- Insertion sort
  - \* **ins\_sort.asm**
  - \* Sorts an integer array using insertion sort algorithm
    - » Inserts a new number into the sorted array in its right place
- Binary search
  - \* **bin\_srch.asm**
  - \* Uses binary search to locate a data item in a sorted array
    - » Efficient search algorithm

## Arrays

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### One-Dimensional Arrays

- Array declaration in HLL (such as C)

```
int    test_marks[10];
```

specifies a lot of information about the array:

- » Name of the array (`test_marks`)
  - » Number of elements (10)
  - » Element size (2 bytes)
  - » Interpretation of each element (`int` i.e., signed integer)
  - » Index range (0 to 9 in C)
- You get very little help in assembly language!

## Arrays (cont'd)

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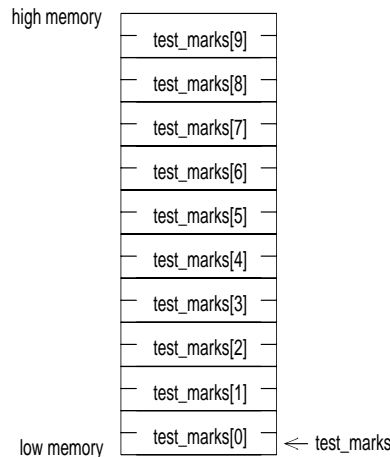
- In assembly language, declaration such as

```
test_marks    DW    10 DUP (?)
```

only assigns name and allocates storage space.
- You, as the assembly language programmer, have to "properly" access the array elements by taking element size and the range of subscripts.
- Accessing an array element requires its displacement or offset relative to the start of the array in *bytes*

## Arrays (cont'd)

- To compute displacement, we need to know how the array is laid out
  - » Simple for 1-D arrays
- Assuming C style subscripts (i.e., subscript starts at zero)
  - displacement = subscript \*  
element size in bytes
- If the element size is 2, 4, or 8 bytes, a scale factor can be used to avoid counting displacement in bytes



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## Multidimensional Arrays

- We focus on two-dimensional arrays
  - » Our discussion can be generalized to higher dimensions
- A  $5 \times 3$  array can be declared in C as

```
int class_marks[5][3];
```
- Two dimensional arrays can be stored in one of two ways:
  - \* Row-major order
    - Array is stored row by row
    - Most HLL including C and Pascal use this method
  - \* Column-major order
    - Array is stored column by column
    - FORTRAN uses this method

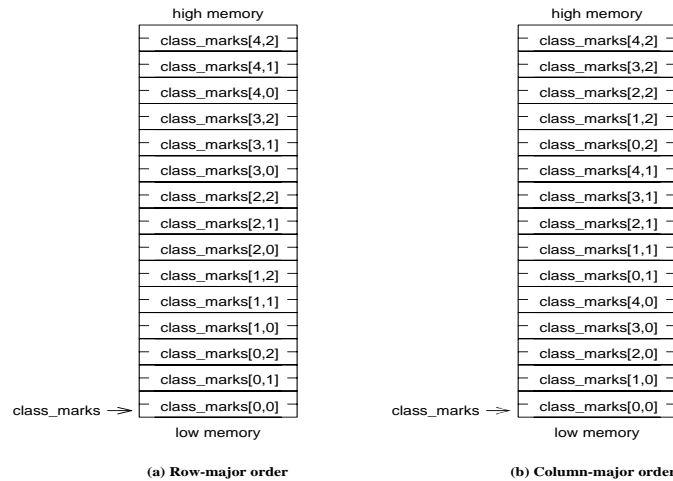
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## Multidimensional Arrays (cont'd)



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## Multidimensional Arrays (cont'd)

- Why do we need to know the underlying storage representation?
  - » In a HLL, we really don't need to know
  - » In assembly language, we need this information as we have to calculate displacement of element to be accessed
- In assembly language,
 

```
class_marks DW 5*3 DUP (?)
```

 allocates 30 bytes of storage
- There is no support for using row and column subscripts
  - » Need to translate these subscripts into a displacement value

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## Multidimensional Arrays (cont'd)

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- Assuming C language subscript convention, we can express displacement of an element in a 2-D array at row  $i$  and column  $j$  as

$$\text{displacement} = (i * \text{COLUMNS} + j) * \text{ELEMENT\_SIZE}$$

where

COLUMNS = number of columns in the array

ELEMENT\_SIZE = element size in bytes

**Example:** Displacement of

`class_marks[3,1]`

element is  $(3*3 + 1) * 2 = 20$

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## Examples of Arrays

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### Example 1

- One-dimensional array
  - » Computes array sum (each element is 4 bytes long e.g., long integers)
  - » Uses scale factor 4 to access elements of the array by using a 32-bit addressing mode (uses ESI rather than SI)
  - » Also illustrates the use of predefined location counter \$

### Example 2

- Two-dimensional array
  - » Finds sum of a column
  - » Uses "based-indexed addressing with scale factor" to access elements of a column

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## Performance: Usefulness of Addressing Modes

### Experiment 1

- 16-bit addressing modes
  - » Performance impact on insertion sort:
    - Only indirect mode vs. all addressing modes
  - » Shows the usefulness of providing more flexible addressing modes than the basic indirect addressing mode

### Experiment 2

- Impact of mixing 16- and 32-bit addressing modes
  - » Brings out the overheads involved with using mixed addressing modes (size override prefix takes a clock cycle)
  - » Tradeoff: convenience vs. performance
  - » Try not to use mixed addressing modes

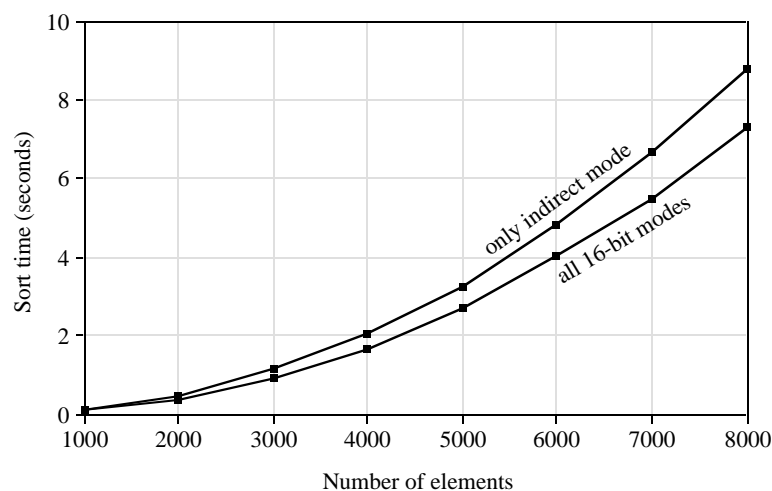
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### Experiment 1



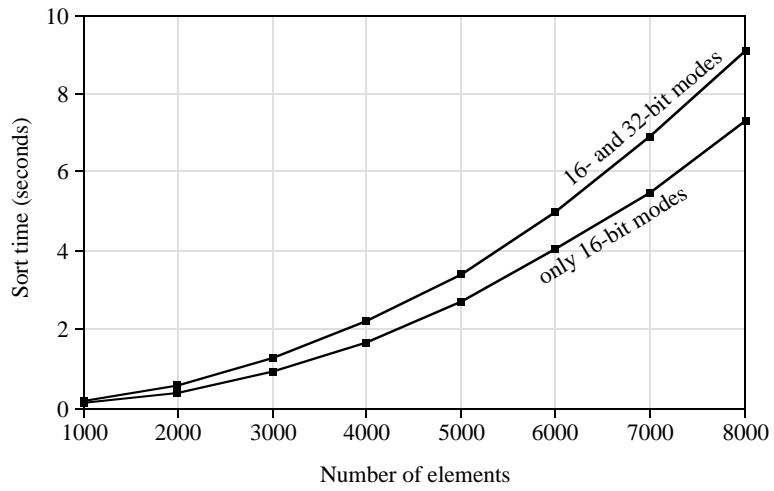
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## Experiment 2



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