



INDIAN INSTITUTE OF
INFORMATION
TECHNOLOGY

Basic Programming and Data Structures

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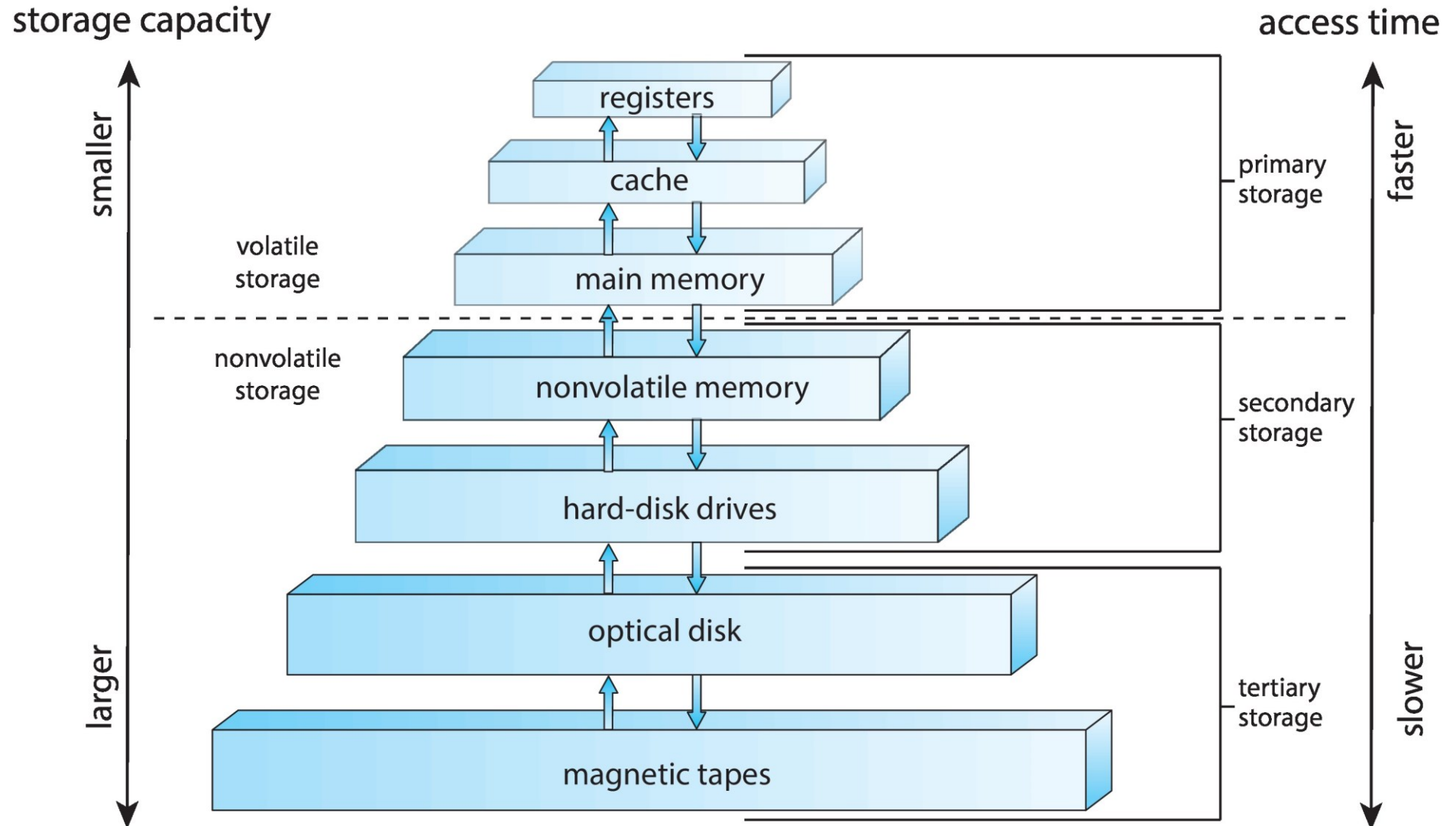
The
Alan Turing
Institute

Goals of the Course

- To become familiar with Data structures and Algorithms
 - To develop ability of problem solving skill in programming
 - To understand that Data structures are the building blocks of larger softwares
 - To develop ability for analyzing existing Data structures and Algorithms
 - To develop skills with the C, C++, Java for Data structures and Algorithms
-
- "Get your data structures correct first, and the rest of the program will write itself."
- David Jones

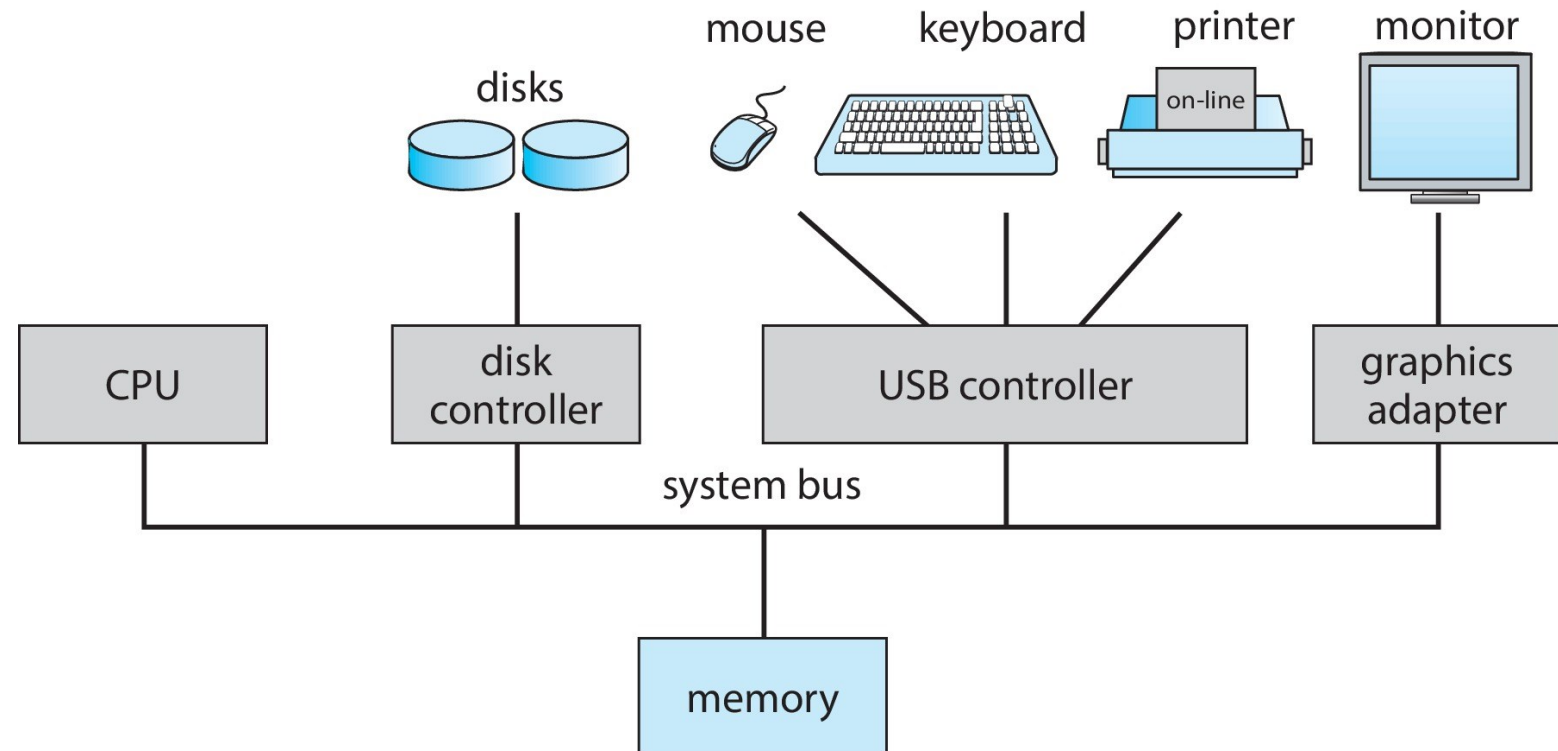
Basic Program Execution on CPU and Memory

Data Storage Device Hierarchy



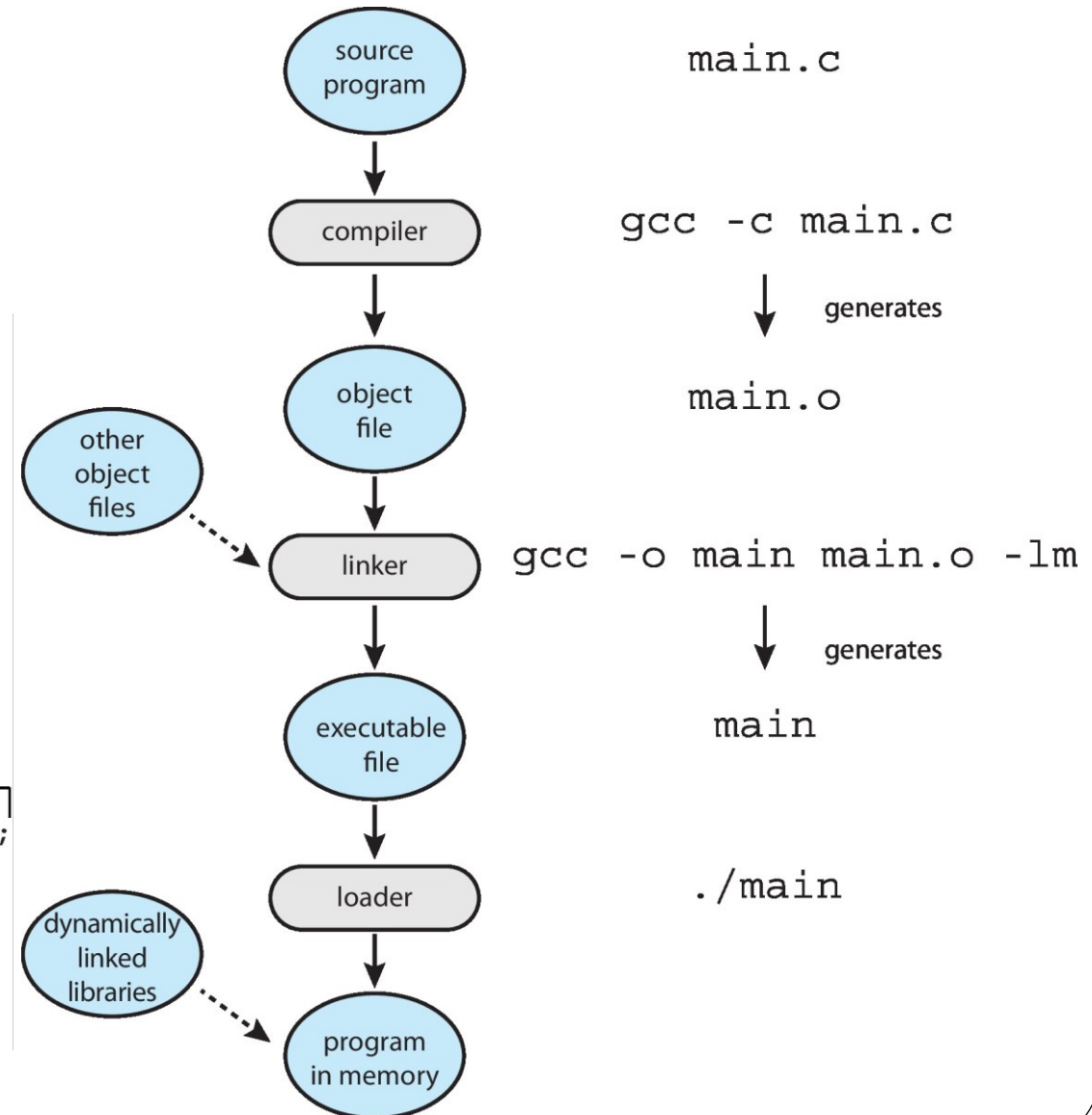
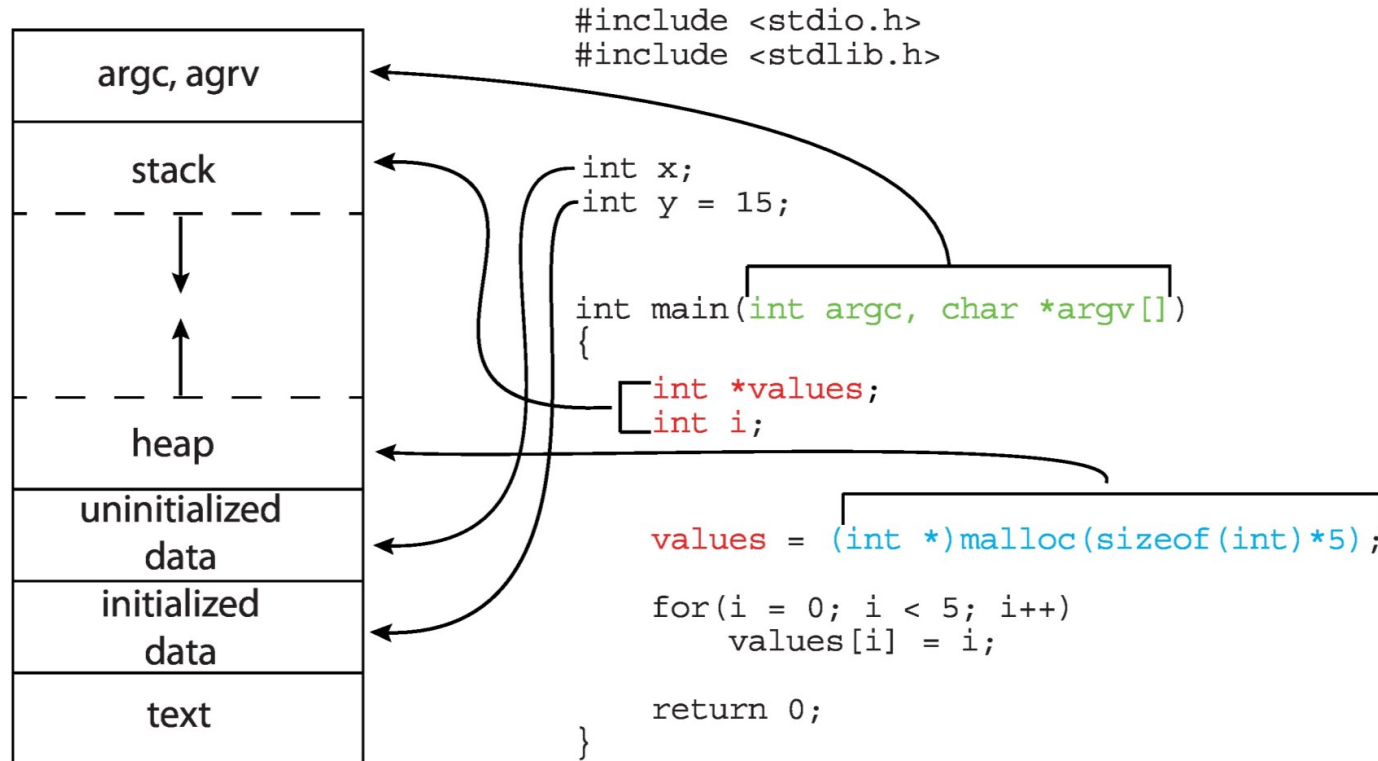
Computer System Organization

- Computer-system operation
 - One or more CPUs, device controllers connect through common **bus** providing access to shared memory
 - Concurrent execution of CPUs and devices competing for memory cycles



Program to Process

- When you run an exe file, the OS creates a process = a running program

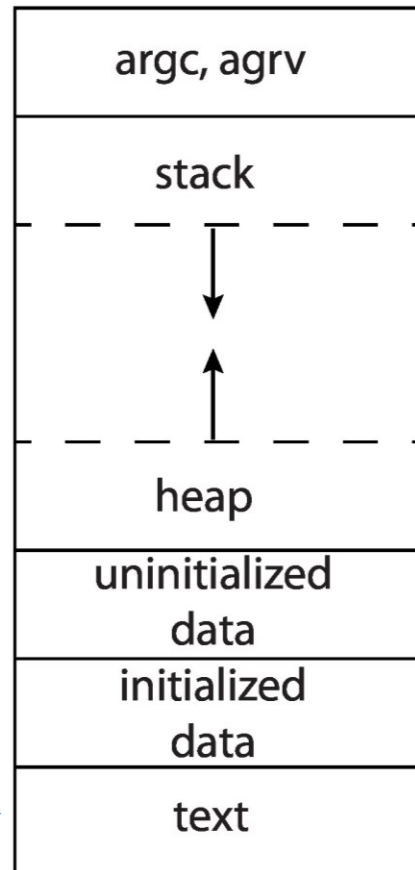


Motivation: Program Code to Memory

- **Abstraction** of complex usage Program as a Memory (RAM or Cache).
- Conversion of **High level language to Low level language**
- Static/global variables are allocated in the executable

- Local variables of a function on Stack
- Dynamic allocation with malloc on the heap

Process as
a Memory



```
#include <stdio.h>
#include <stdlib.h>
```

```
int x;
int y = 15;
```

```
int main(int argc, char *argv[])
{
```

```
    int *values;
    int i;
```

```
    values = (int *)malloc(sizeof(int)*5);
```

```
    for(i = 0; i < 5; i++)
        values[i] = i;
```

```
    return 0;
```

```
}
```

Program as a Code

Program to Process

- Virtual address space is setup by OS during process creation

Simplified OS: places entire memory image in one chunk

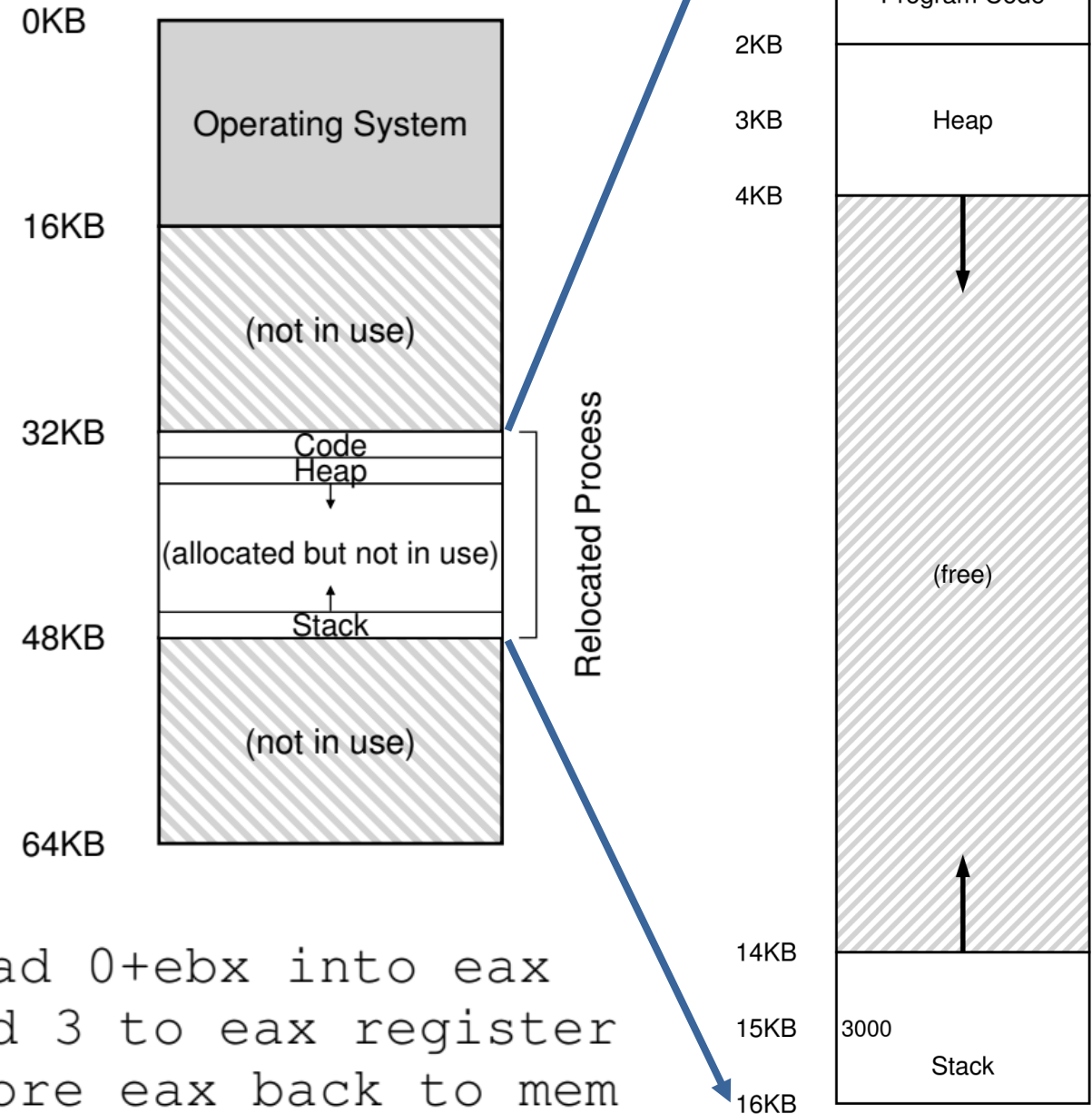
```
void func() {  
    int x = 3000;  
    x = x + 3;  
    ...
```



Compiler

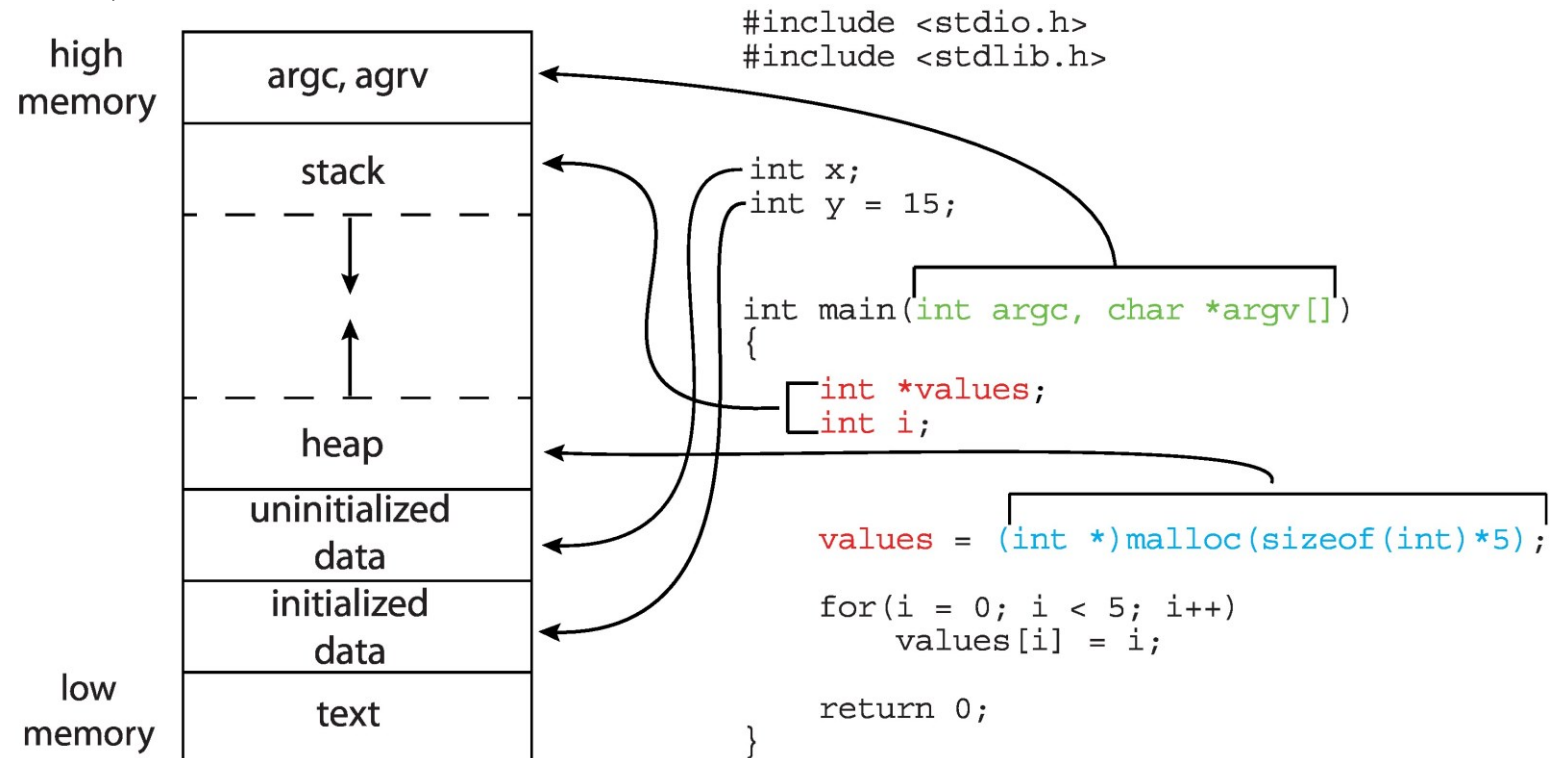
```
128: movl 0x0(%ebx), %eax  
132: addl $0x03, %eax  
135: movl %eax, 0x0(%ebx)
```

```
;load 0+ebx into eax  
;add 3 to eax register  
;store eax back to mem
```

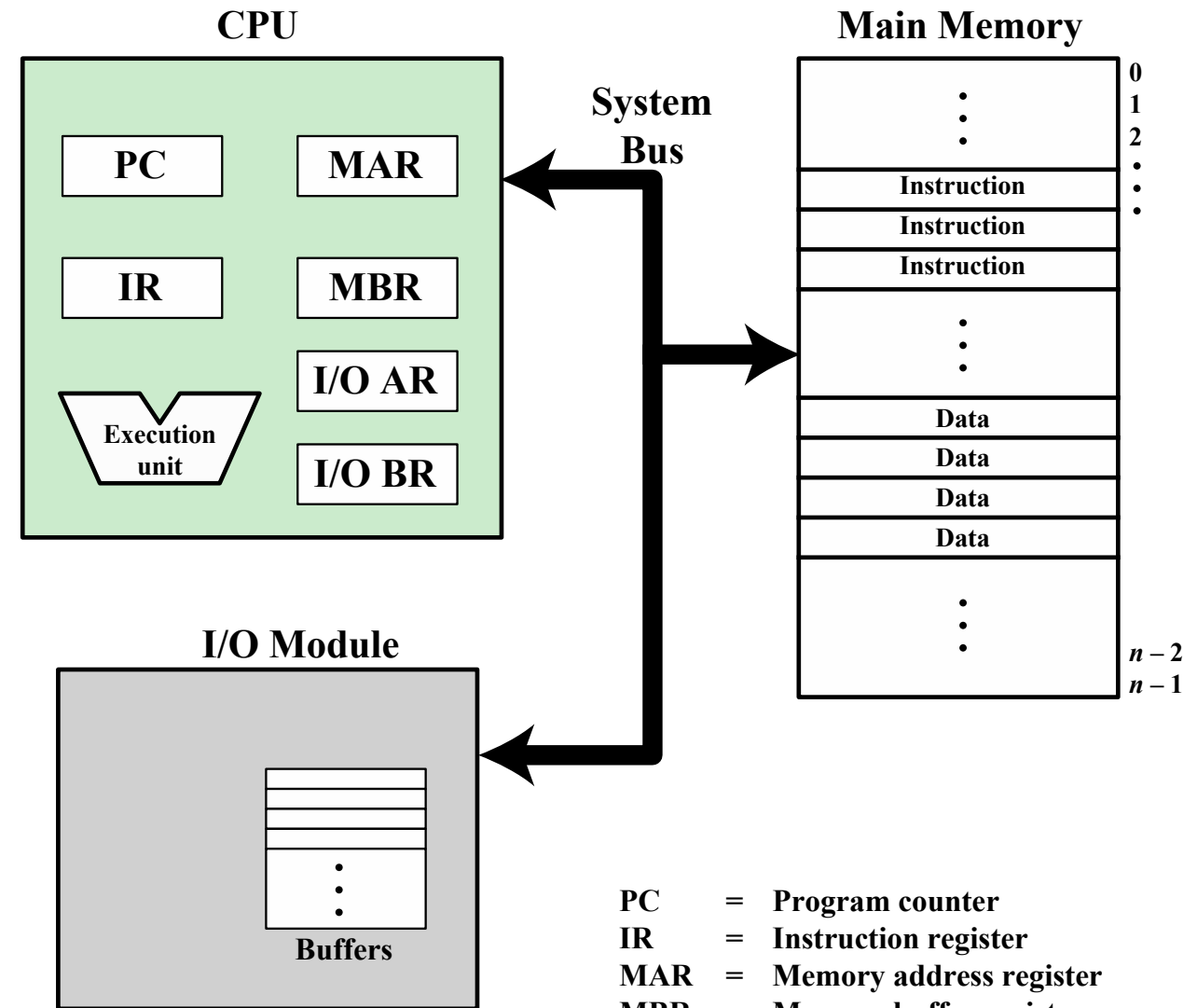
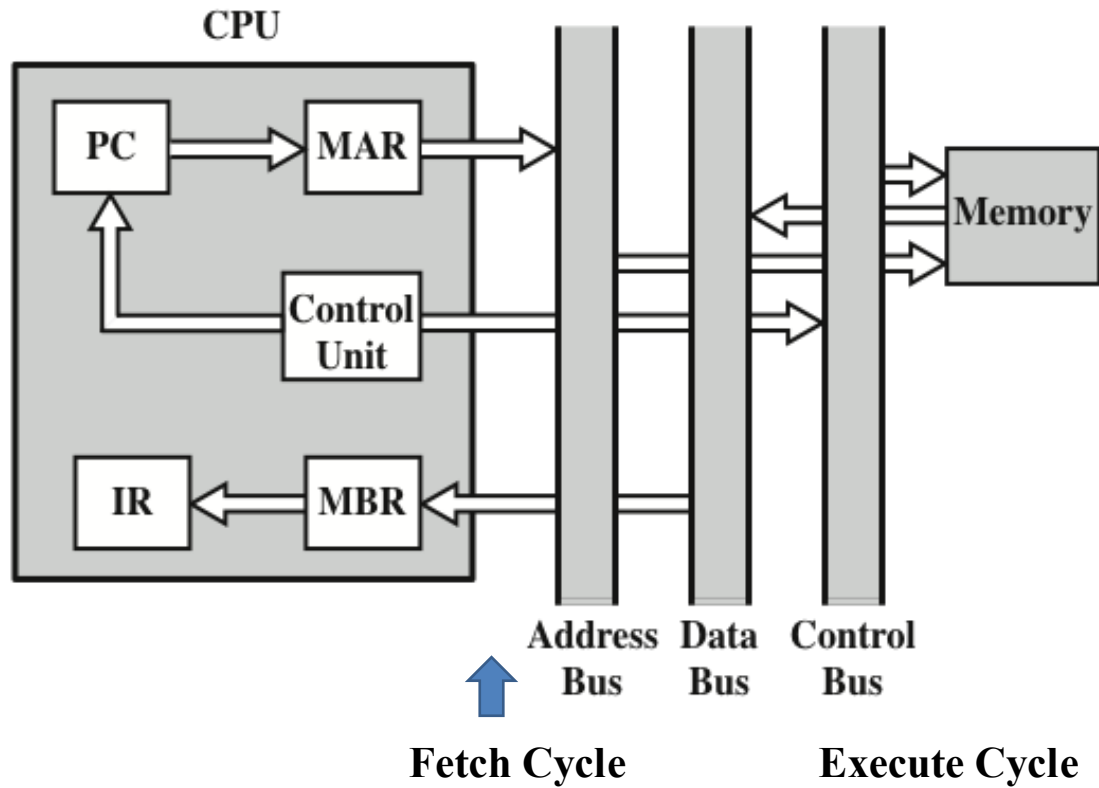


Program and Process

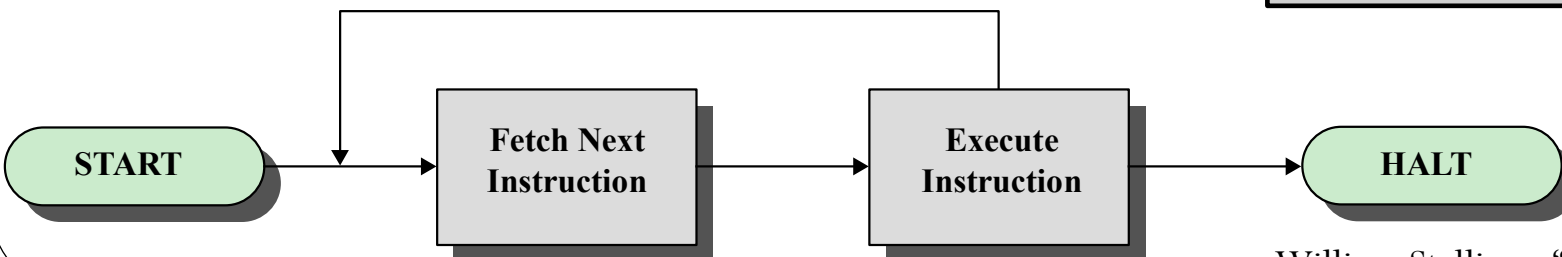
- A unique identifier
- Points CPU program counter to current instruction – Other registers may store operands, return values etc.
- CPU context: registers
 - Program counter
 - Current operands
 - Stack pointer



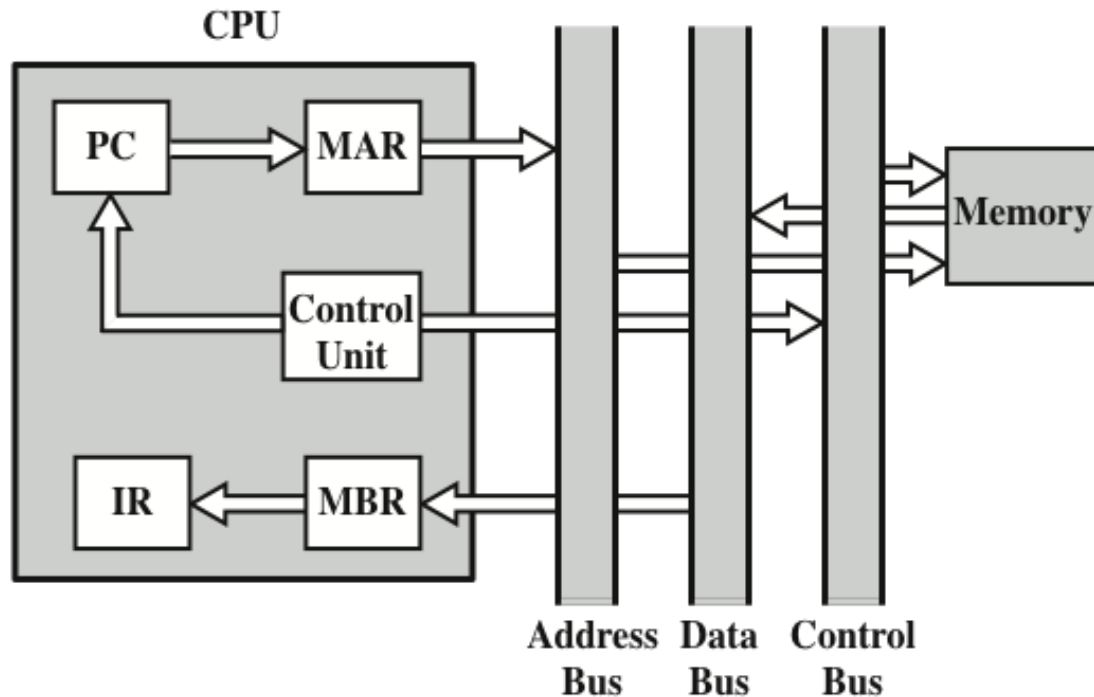
CPU and Memory



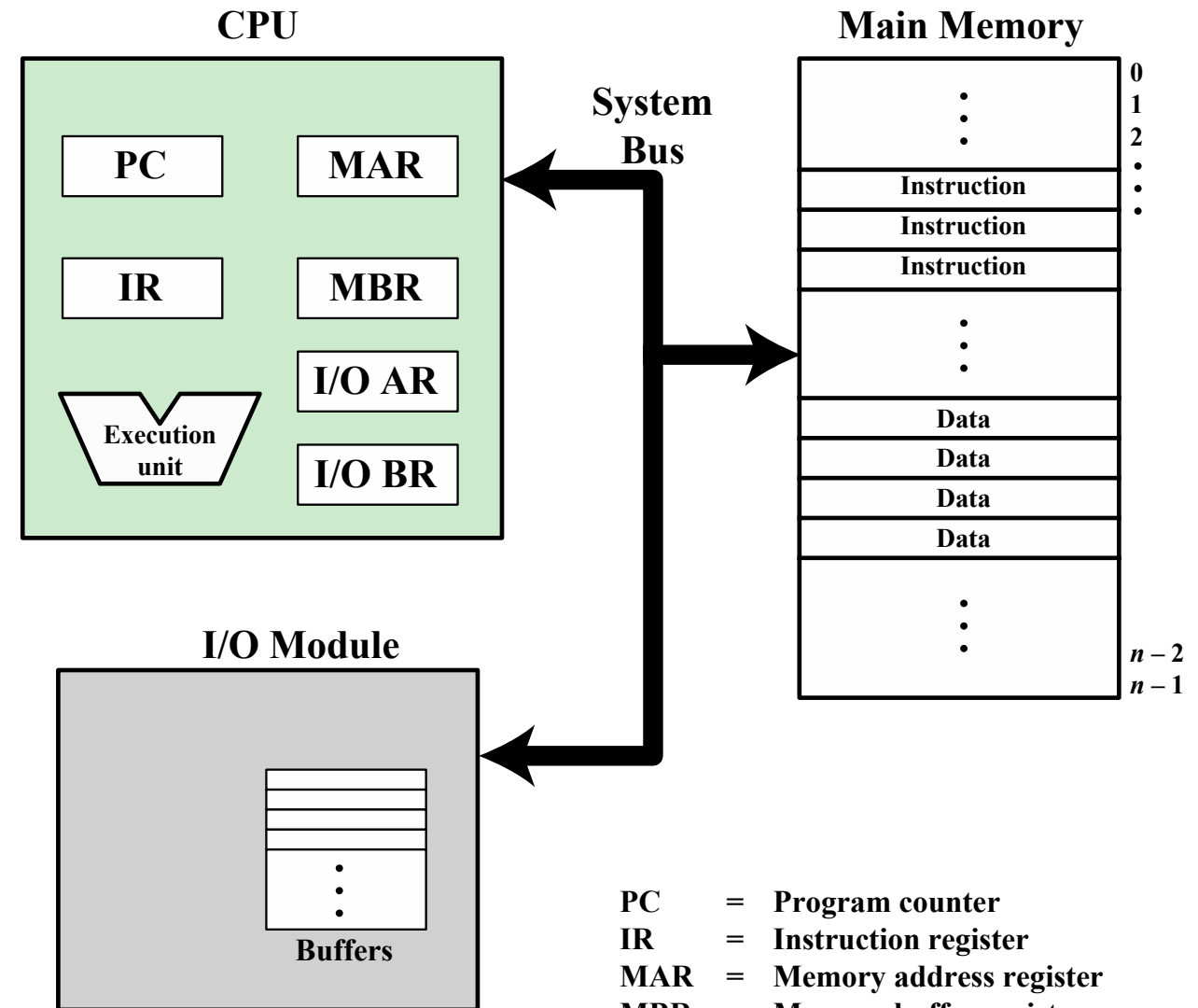
PC = Program counter
 IR = Instruction register
 MAR = Memory address register
 MBR = Memory buffer register
 I/O AR = Input/output address register
 I/O BR = Input/output buffer register



CPU and Memory



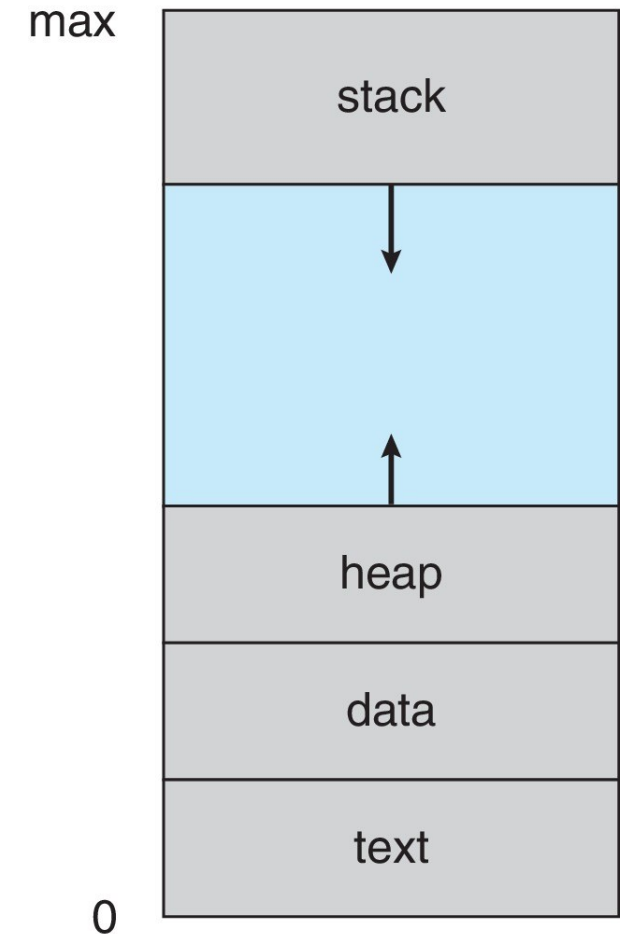
t1 : MAR ← PC
 t2 : MBR ← MEMORY
 PC ← (PC) + I
 t3 : IR ← (MBR)



PC = Program counter
 IR = Instruction register
 MAR = Memory address register
 MBR = Memory buffer register
 I/O AR = Input/output address register
 I/O BR = Input/output buffer register

Program and Process

- OS allocates memory and creates memory image
 - Loads code, data from disk exe
 - Creates runtime stack, heap
 - Opens basic files – STD IN, OUT, ERR
 - Initializes CPU registers – PC points to first instruction
- Memory image
 - Code & data (static)
 - Stack and heap (dynamic)



Basic Data Structures

Programing (Coding)

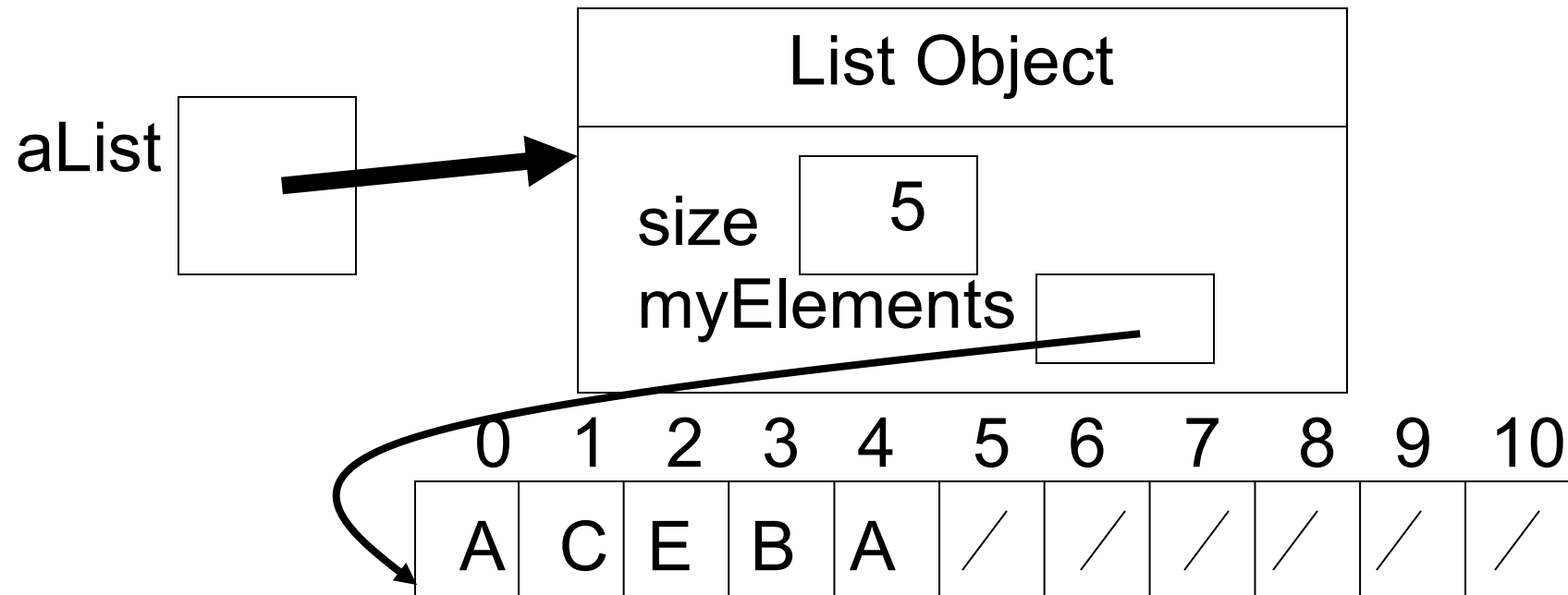
- All programs (or process) has data
 - To *store, display, gather*
 - In the form of *information, numbers, images, sound*
- Programmer decide to structure data
- Several option leads to program development
- Program properties
 - execution speed
 - memory requirements
 - maintenance (debugging, extending, etc.)

Code Implementation

- Theoretically
 - abstract base class describes ADT
 - inherited implementations implement data structures
 - can change data structures transparently (to client code)
- Practice
 - different implementations sometimes suggest different interfaces
(generality vs. simplicity)
 - performance of a data structure may influence form of client code
(time vs. space, one operation vs. another)

Data Structures

- A *Data Structure* is:
 - an implementation of an abstract data type *and*
 - "An organization of information, usually in computer memory", for better algorithm efficiency."



Data structures

Ideal data structure:

fast, elegant, memory efficient

Generates tensions:

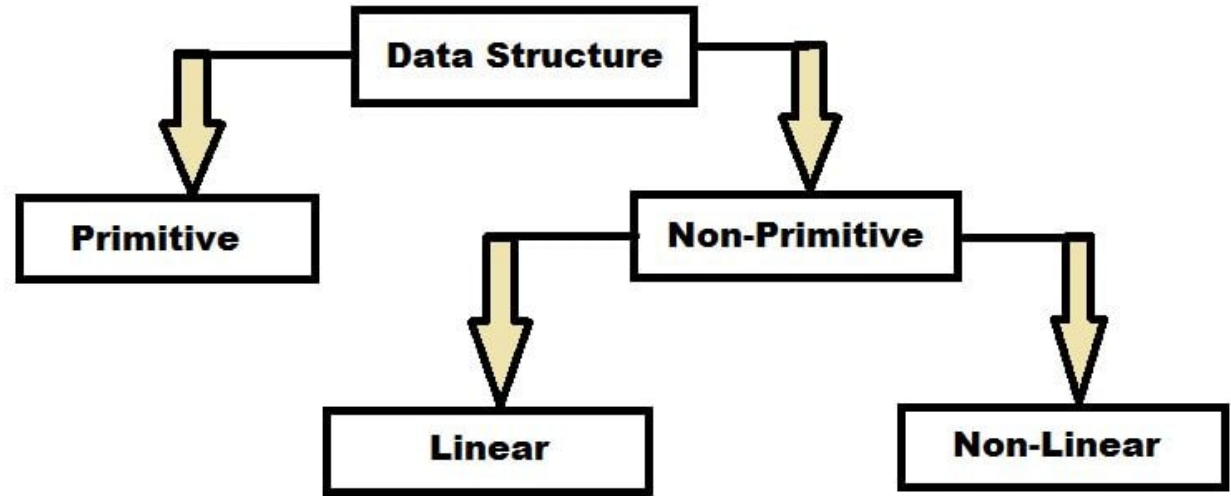
- time *vs.* space
- performance *vs.* elegance
- generality *vs.* simplicity
- one operation's performance *vs.* another's

Dictionary ADT

- list
- binary search tree
- AVL tree
- Splay tree
- Red-Black tree
- hash table

Data structures

- Data Structures are containers:
 - they hold other data
 - arrays are a data structure
 - ... so are lists
- Other types of data structures:
 - stack, queue, tree, binary search tree, hash table, dictionary or map, set, and on and on
 - www.nist.gov/dads/
 - en.wikipedia.org/wiki/List_of_data_structures
- Different types of data structures are optimized for certain types of operations



Data Structures Operations

- Data Structures will have 3 core operations
 - a way to add things
 - a way to remove things
 - a way to access things
- Details of these operations depend on the data structure
 - Example: List, add at the end, access by location, remove by location
- More operations added depending on what data structure is designed to do

Built-in Data Type

- There are five basic data types associated with variables
 - int - integer: a whole number
 - float - floating point value: a number with a fractional part
 - double - a double-precision floating point value
 - char - a single character
 - void - valueless special purpose type
- `int a = 4000;` // positive integer data type
- `float b = 5.2324;` // float data type
- `char c = 'Z';` // char data type
- `long d = 41657;` // long positive integer data type
- `long e = -21556;` // long -ve integer data type
- `int f = -185;` // -ve integer data type
- `short g = 130;` // short +ve integer data type
- `short h = -130;` // short -ve integer data type
- `double i = 4.1234567890;` // double float data type
- `float j = -3.55;` // float data type

Built-in Data Type

Advantage

- Simple: Really simple! Only FIVE types of data!!
- Easy to handle: Allocation of memory and operations are already defined
- Built-in support by programming language
 - The C library are there to deal with them

Limitations

- There is a need for storing and handling variety of data types: Image, text, video, etc.
- Limited range
- Waste of memory
- No flexibility
- Error prone programming

User-Defined Data Types

- User can define their own data type
- Also, called Custom Data Type, Abstract Data Type (ADT), etc.
- All logically related data can be grouped into a form called structure
- Each member into the group may be a built-in data type or any other user defined data type
- No recursion, that is, a structure cannot include itself
- Examples:

Complex number: $z = x + i y$

Matrices: $A_{(m \times n)}$

Date: dd/mm/yy

Date: {int dd, int mm, int yy}

User-Defined Data Types

Advantage

- It is always convenient for handling a group of logically related data items.
- Examples: Student's record, name, roll number, and marks.
- Elements in a set: Used in relational algebra, database, etc.
- A non non-trivial data structure becomes a trivial.
 - Helps in organizing complex data in a more meaningful way

Abstraction

- Because details of the implementation are hidden.
- When you do some operation on the list, say insert an element, you just call a function.
- Details of how the list is implemented or how the insert function is written is no longer required.

Abstract Data Types

- Algorithm: Description of a step-by-step process to solve a problem
 - independent of High Level Language (HLL)
- Data Structure
 - A set of algorithms which implement an Abstract Data Type (ADT)
 - Data Structures: Arrays, Linked lists, Stacks, Queues, Matrices, Trees, Graphs
 - Usage: Searching, Sorting
- Abstract Data Type
 - An opportunity for an acronym
 - Mathematical description of an object and the set of operations on the object

Abstract Data Types

- Present an ADT
- Motivate with some applications
- Repeat until browned entirely through
 - develop a data structure for the ADT
 - analyze its properties
 - efficiency
 - correctness
 - limitations
 - ease of programming
- Contrast data structure's strengths and weaknesses
 - understand when to use each one

Abstract Data Types

- Abstract Data Types (aka ADTs) are descriptions of how a data type will work without implementation details
- Description can be a formal, mathematical description
- Java interfaces are a form of ADTs
 - some implementation details start to creep in

Abstract Data Types

- Programming languages usually have a library of data structures
 - [Java collections framework](#)
 - [C++ standard template library](#)
 - .Net framework (small portion of VERY large library)
 - Python lists and tuples
 - Lisp lists

Structure in C

Defining a Structure

```
struct tag {  
    member 1;  
    member 2;  
    :  
    member m;  
};
```

- **struct** is the required keyword
- **tag** is the name of the structure
- **member 1**, **member 2**,.. are individual member declarations

Defining a Structure

```
struct student {  
    char name[30];  
    int roll_number;  
    int total_marks;  
    char dob[10];  
};
```

```
struct student s1, sList[100];
```



A new data-type

- Each member in a structure can be accessed with (.) operator called scope resolution operator

```
s1.name; sList[5].roll_number;
```

Structures (records)

```
struct {  
    char name[10];  
    int age;  
    float salary;  
} person;
```

```
strcpy(person.name, "james");  
person.age=10;  
person.salary=35000;
```

```
typedef struct human_being {  
    char name[10];  
    int age;  
    float salary;  
};
```

or


```
typedef struct {  
    char name[10];  
    int age;  
    float salary;  
} human_being;
```

```
human_being person1, person2;
```


Set Manipulation Structure

Set Manipulation


```
struct nodeS {  
    int element;  
    struct nodeS *next;  
};
```



Structure
definition

```
typedef struct nodeS set;
```

```
set *union (set a, set b);  
set *intersect (set a, set b);  
set *minus (set a, set b);  
void insert (set a, int x);  
void delete (set a, int x);  
int size (set a);
```



Function
prototypes

Complex Numbers Structure

```
#include <stdio.h>
```

```
main()
```

```
{
```

```
    struct complex
```

```
    {
```

```
        float real;
```

```
        float complex;
```

```
    } a, b, c;
```

```
    scanf ("%f %f", &a.real, &a.complex);
```

```
    scanf ("%f %f", &b.real, &b.complex);
```

```
    c.real = a.real + b.real;
```

```
    c.complex = a.complex + b.complex;
```

```
}
```

Structure definition
and
Variable Declaration

Reading a member variable

Accessing members

Scope
restricted
within
main()

Complex Numbers Structure

```
struct typeX {  
    float re;  
    float im;  
};
```

Structure
definition

```
typedef struct typeX complex;
```

```
complex *add (complex a, complex b);  
complex *sub (complex a, complex b);  
complex *mul (complex a, complex b);  
complex *div (complex a, complex b);  
complex *read();  
void print (complex a);
```

Function
prototypes

Add Two Complex Numbers Structure

```
#include <stdio.h>
typedef struct complex
{
    float real;
    float imag;
} complex;

int main()
{
    complex n1, n2, temp;

    printf("For 1st complex number \n");
    printf("Enter re & im part respectively:\n");
    scanf("%f %f", &n1.real, &n1.imag);

    printf("\nFor 2nd complex number \n");
    printf("Enter re & im part respectively:\n");
    scanf("%f %f", &n2.real, &n2.imag);

    temp = add(n1, n2);
    printf("Sum = %.1f + %.1fi", temp.real, temp.imag);
    return 0;
}
```

```
complex add(complex n1, complex n2)
{
    complex temp;

    temp.real = n1.real + n2.real;
    temp.imag = n1.imag + n2.imag;

    return(temp);
}
```

OUTPUT

For 1st complex number
Enter re & im part respectively: 2.3
4.5

For 2nd complex number
Enter re & im part respectively: 3.4
5
Sum = 5.7 + 9.5i

Comparing Dates Structure

```
#include <stdio.h>
struct date { int dd, mm, yy;    };

int date_cmp(struct date d1, struct date d2);
void date_print(struct date d);

int main(){
    struct date d1 = {7, 3, 2015};
    struct date d2 = {24, 10, 2015};

    int cmp = date_cmp(d1, d2);
    date_print(d1);
    if (cmp == 0)
        printf(" is equal to");
    else if (cmp > 0)
        printf(" is greater, i.e., later than ");
    else printf(" is smaller, i.e., earlier than");

    date_print(d2);
    return 0;
}
```

```
/* compare given dates d1 and d2 */

int date_cmp(struct date d1, struct date d2) {

    if (d1.dd == d2.dd && d1.mm == d2.mm && d1.yy == d2.yy)
        return 0;
    else if (d1.yy > d2.yy || d1.yy == d2.yy && d1.mm > d2.mm ||
            d1.yy == d2.yy && d1.mm == d2.mm && d1.dd > d2.dd)
        return 1;
    else return -1;
}

/* print a given date */

void date_print(struct date d) {
    printf("%d/%d/%d", d.dd, d.mm, d.yy);
}
```

OUTPUT:

7/3/2015 is smaller, i.e., earlier than 24/10/2015

Sparse Matrices – Data Structure

1-D Array Representation

- Implementation of the abstract list data structure using programming language
 - “Backing” Data Structure
- Arrays are contiguous memory locations with fixed capacity
- Allow elements of same type to be present at specific positions in the array
- Index in a List can be mapped to a Position in the Array
 - Mapping function from list index to array position

Matrix Multiplication

// Given 2-D arrays: a[n][n], b[n][n]

// Output 2-D array: c[n][n] initialized to 0

for (i = 0; i < N; i++)

 for (j = 0; j < N; j++)

 for (k = 0; k < N; k++)

 c[i][j] += a[i][k] * b[k][j];

Symmetric Matrix

- An $n \times n$ matrix can be represented using 1-D array of size $n(n+1)/2$ by storing either the lower or upper triangle of the matrix
- Use one of the methods for a triangular matrix
- Optimization: The elements that are not explicitly stored may be computed from those that are stored.

2	4	6	0
4	1	9	5
6	9	4	7
0	5	7	0

Sparse Matrices

- Only a small subset of items are populated in matrix
 - Students and courses taken, faculty and courses taught
 - Adjacency matrix of social network graph
 - vertices are people, edges are “friends”
- Rows and columns are people, cell has 0/1 value
- Why not use regular 2-D matrix?
 - 1-D representation
 - Array of arrays representation

Sparse Matrix

- A matrix is **sparse**
 - if many of its elements are zero
- A matrix that is not sparse is **dense**
- The boundary is not precisely defined
 - Diagonal and tridiagonal matrices are sparse
 - We classify triangular matrices as dense
- Two possible representations
 - array
 - linked list

s p a r s e

	7				6	
	7	6	3		4	
	4	3				
4	2					
				3	2	4

Dense Matrix

1	2	31	2	9	7	34	22	11	5
11	92	4	3	2	2	3	3	2	1
3	9	13	8	21	17	4	2	1	4
8	32	1	2	34	18	7	78	10	7
9	22	3	9	8	71	12	22	17	3
13	21	21	9	2	47	1	81	21	9
21	12	53	12	91	24	81	8	91	2
61	8	33	82	19	87	16	3	1	55
54	4	78	24	18	11	4	2	99	5
13	22	32	42	9	15	9	22	1	21

Sparse Matrix

1	.	3	.	9	.	3	.	.	.
11	.	4	.	.	.	.	.	2	1
.	.	1	.	.	.	4	.	1	.
8	.	.	.	3	1	.	.	.	.
.	.	.	9	.	.	1	.	17	.
13	21	.	9	2	47	1	81	21	9
.
.	.	.	.	19	8	16	.	.	55
54	4	.	.	.	11	.	.	.	.
.	.	2	.	.	.	.	22	.	21

Array Representation of Sparse Matrix

- The nonzero entries may be mapped into a 1D array in row-major order
- To reconstruct the matrix structure, need to record the row and column each nonzero comes from

0	0	8	0	0	0
0	7	0	0	0	0
0	0	0	0	0	5
0	3	0	0	0	0
0	0	0	0	1	0



Rows	Columns	values
5	6	5
0	2	8
1	1	7
2	5	5
3	1	3
4	4	1

```

0 0 0 2 0 0 1 0
0 6 0 0 7 0 0 3
0 0 0 9 0 8 0 0
0 4 5 0 0 0 0 0
    
```

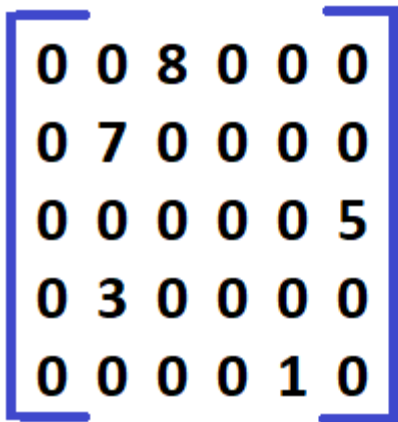
(a) A 4×8 matrix

a[]	0	1	2	3	4	5	6	7	8
row	1	1	2	2	2	3	3	4	4
col	4	7	2	5	8	4	6	2	3
value	2	1	6	7	3	9	8	4	5

(b) Its representation

Array Representation of Sparse Matrix

```
template<class T>
class Term {
private:
    int row, col;
    T value;
};
```



0	0	8	0	0	0
0	7	0	0	0	0
0	0	0	0	0	5
0	3	0	0	0	0
0	0	0	0	1	0



Rows	Columns	values
5	6	5
0	2	8
1	1	7
2	5	5
3	1	3
4	4	1

```
template<class T>
class sparseMatrix {
private:
    int rows, cols,
    int terms;
    Term<T> *a;
    int MaxTerms;

public:
    // ...
};
```

Linked Representation of Sparse Matrix

- A shortcoming of the 1-D array of a sparse matrix is that we need to know the number of nonzero terms in each of the sparse matrices when the array is created
- A linked representation can overcome this shortcoming

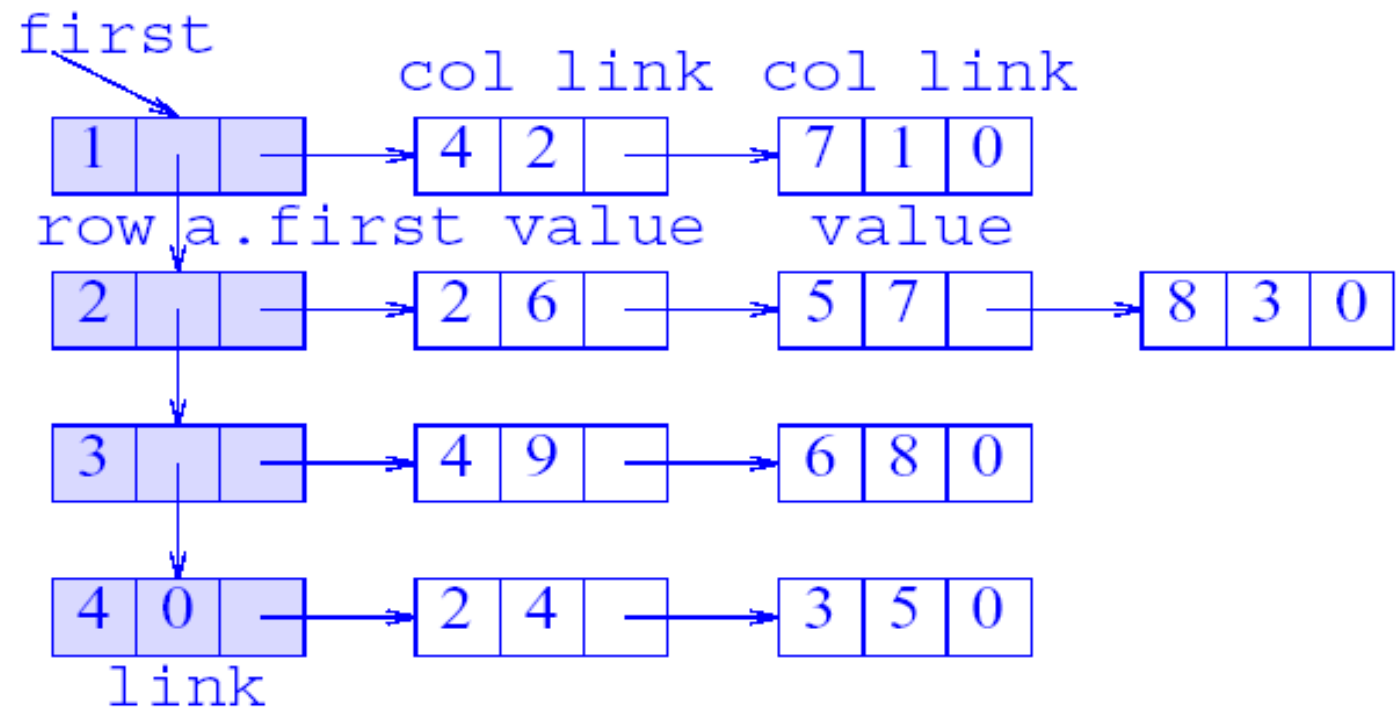
```

0 0 0 2 0 0 1 0
0 6 0 0 7 0 0 3
0 0 0 9 0 8 0 0
0 4 5 0 0 0 0 0
    
```

(a) A 4×8 matrix

a[]	0	1	2	3	4	5	6	7	8
row	1	1	2	2	2	3	3	4	4
col	4	7	2	5	8	4	6	2	3
value	2	1	6	7	3	9	8	4	5

(b) Its representation



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ขอบคุณ

Thai

Grazie
Italian

תודה רבה
Hebrew

धन्यवादः
Sanskrit

ಧನ್ಯವಾದಗಳು
Kannada

Ευχαριστώ
Greek

Thank You
English

Gracias
Spanish

Спасибо
Russian

Obrigado
Portuguese

شكراً
Arabic

<https://sites.google.com/site/animeshchaturvedi07>

Merci
French

多謝
Traditional
Chinese

धन्यवाद
Hindi

Danke
German

多谢
Simplified
Chinese

நன்றி
Tamil

ありがとうございました
Japanese

감사합니다
Korean