INDIAN INSTITUTE OF INFORMATION TECHNOLOGY

Dharwad

ज्ञानेन विकासः

Basic Programming and Data Structures

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Indian Institute of Information Technology, Design and Manufacturing, Jabalpur

The Alan Turing Institute

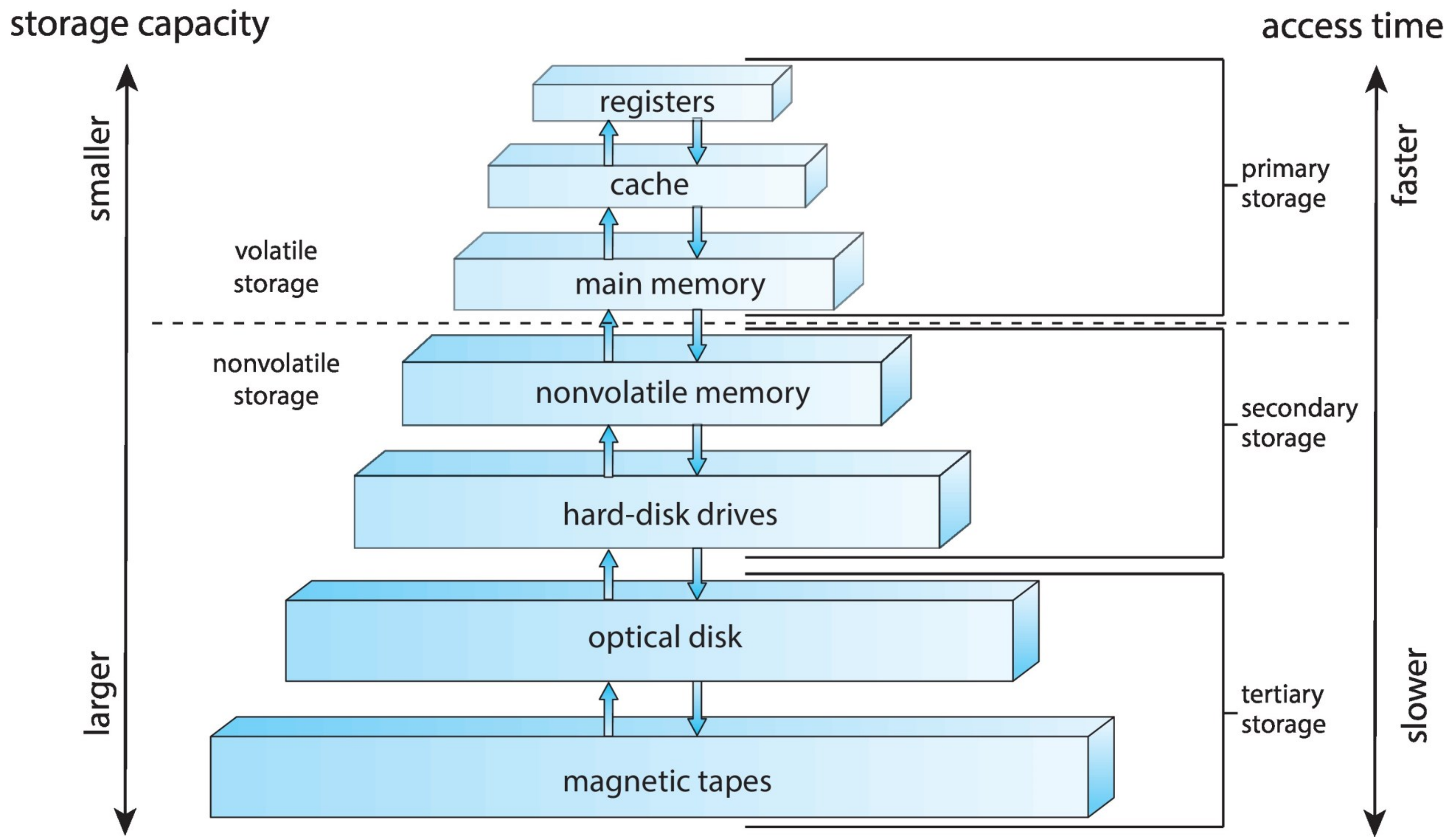
Goals of the Course

- 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

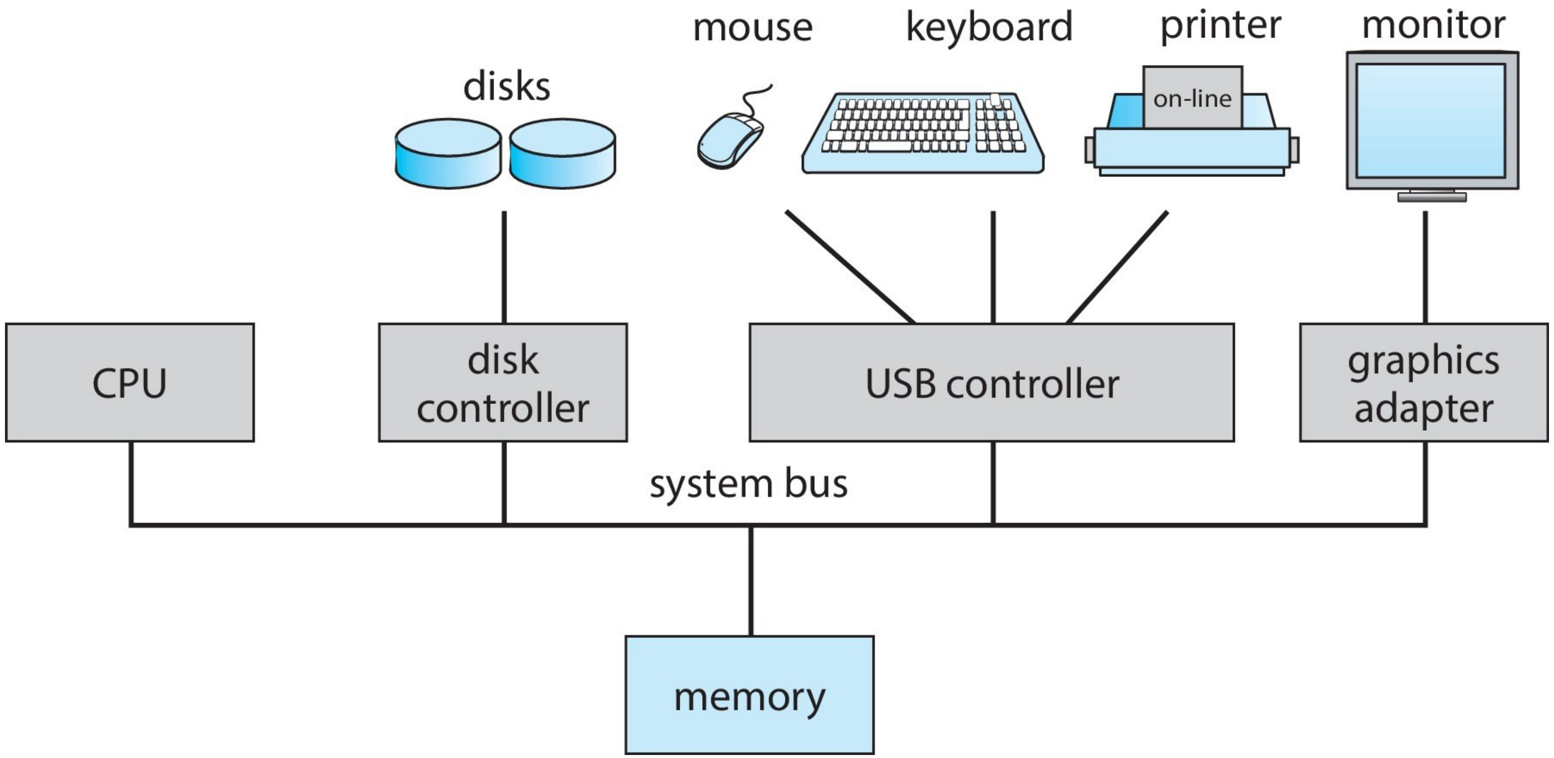
Basic Program Execution on CPU and Memory

Data Storage Device Hierarchy



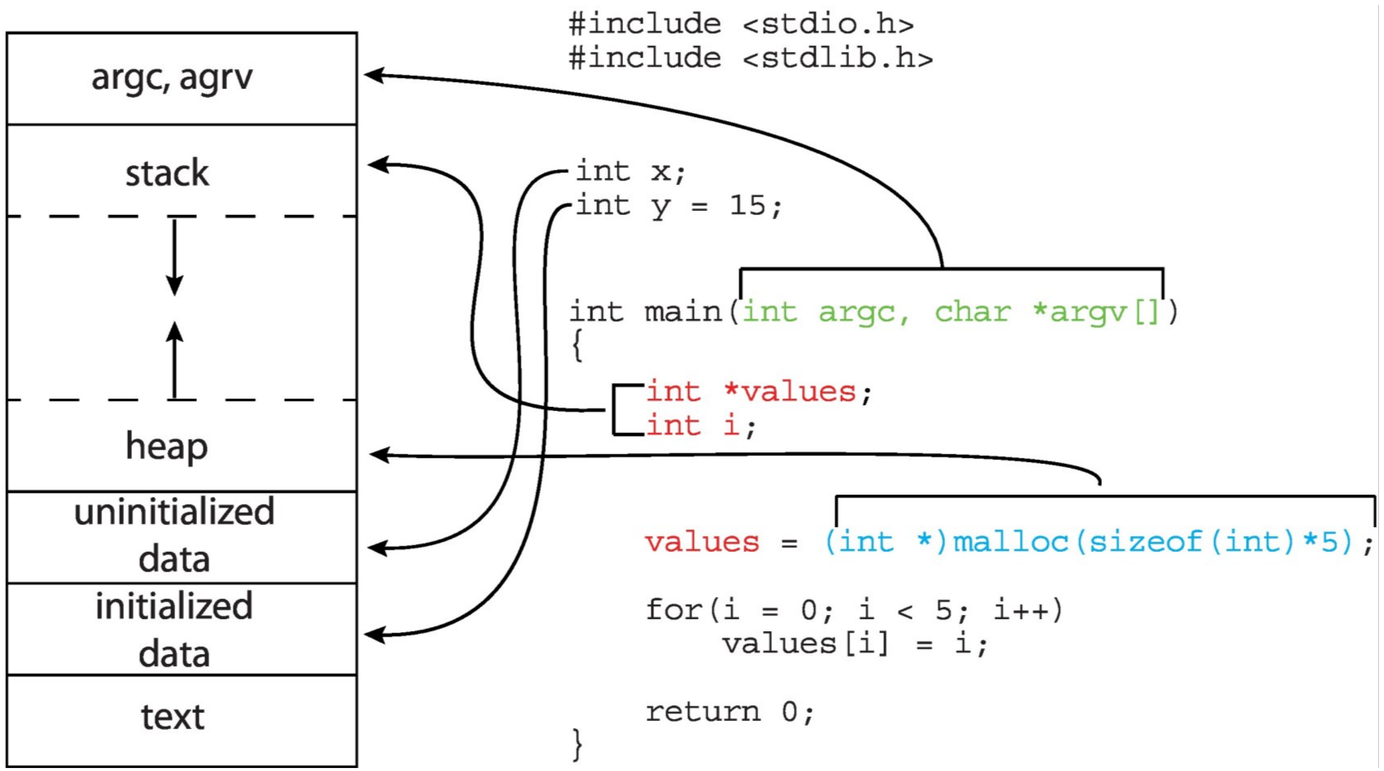
Computer System Organization

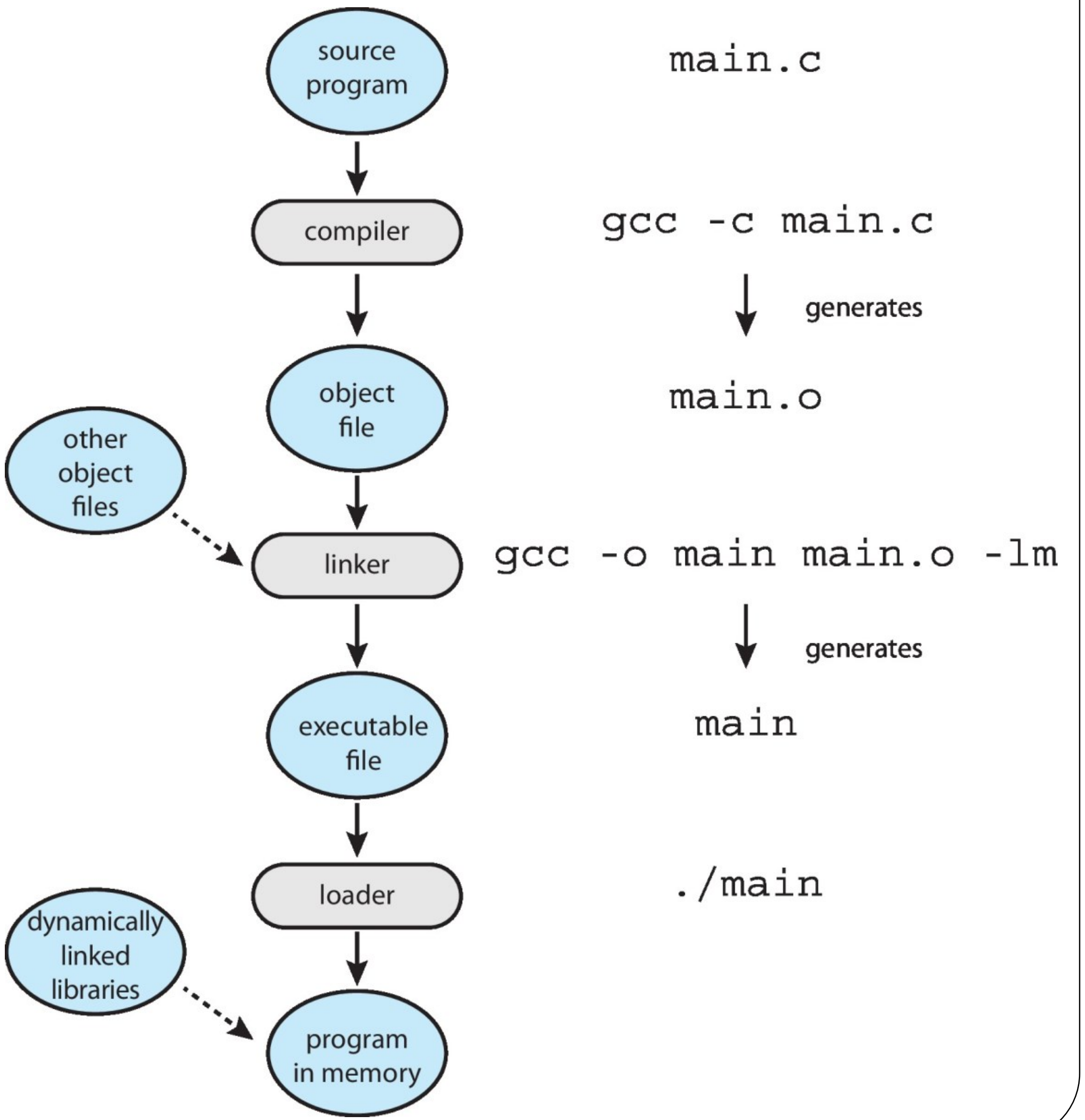
- Computer-system operation
  - One or more CPUs, device controllers connect through common **bus** providing access to shared memory
  - Concurrent execution of CPUs and devices competing for memory cycles



Program to Process

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

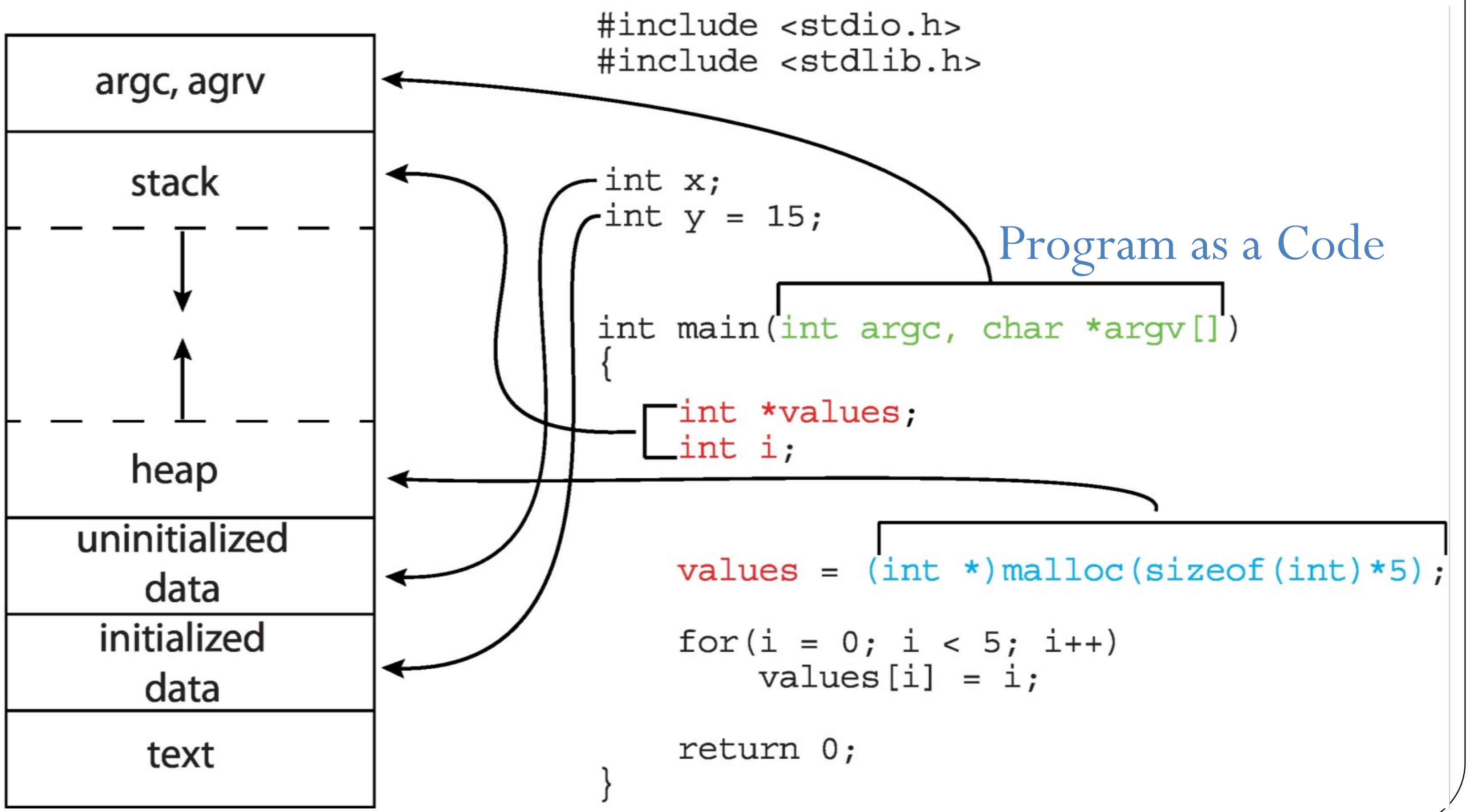




Motivation: Program Code to Memory

- **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



Program to Process

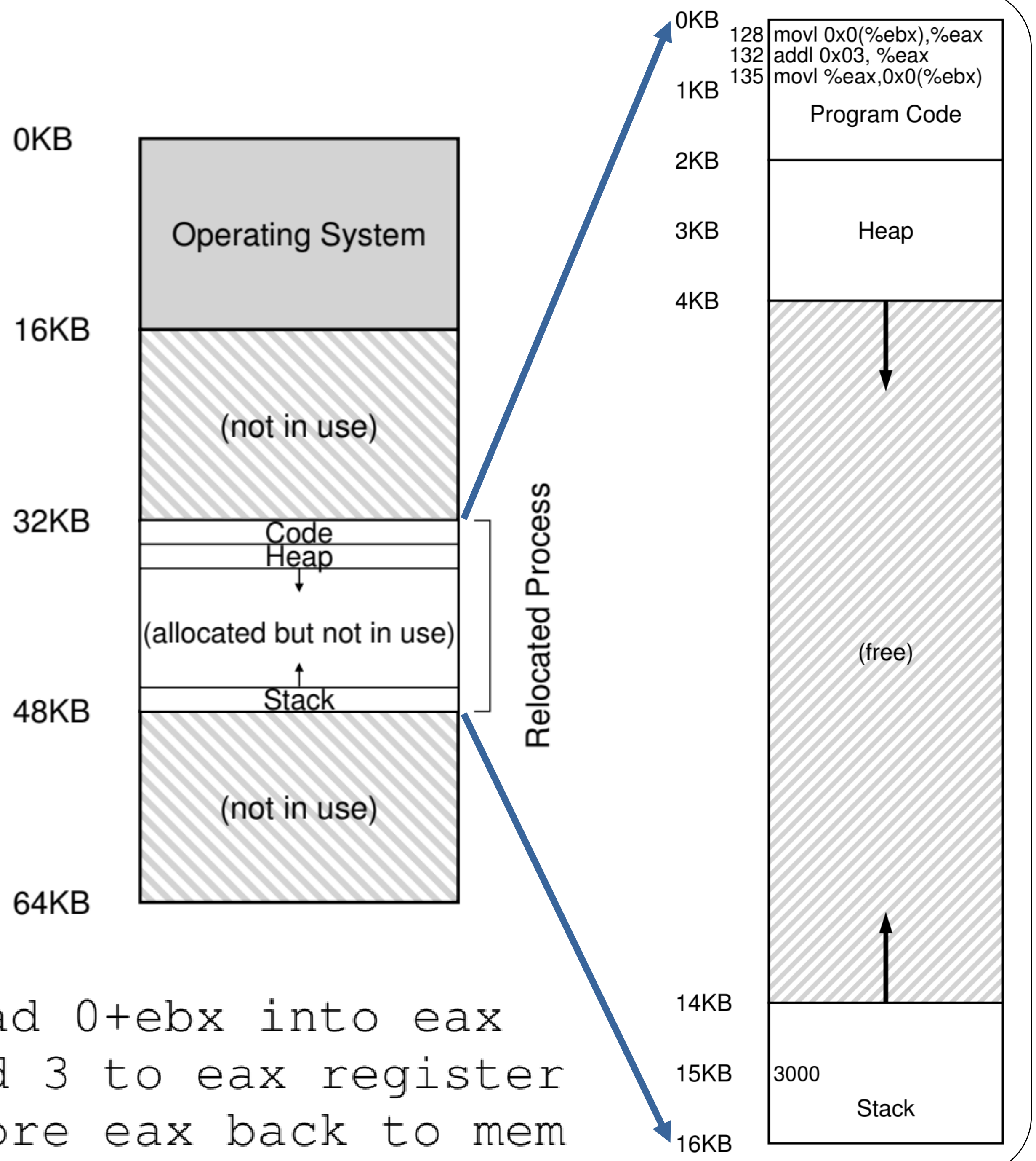
- Virtual address space is setup by OS during process creation

Simplified OS: places entire memory image in one chunk

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

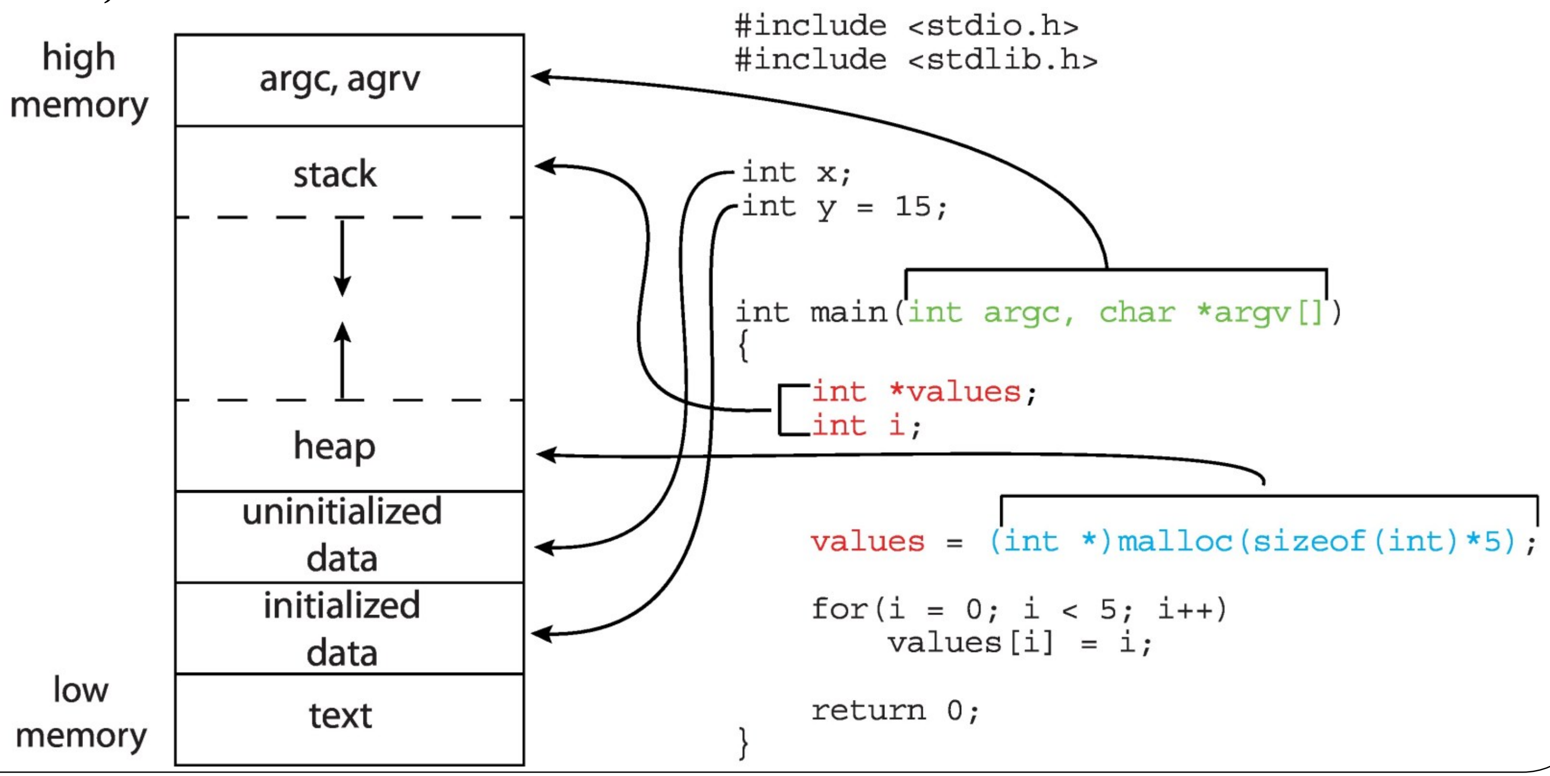
Compiler

```
128: movl 0x0(%ebx), %eax      ;load 0+ebx into eax
132: addl $0x03, %eax          ;add 3 to eax register
135: movl %eax, 0x0(%ebx)      ;store eax back to mem
```

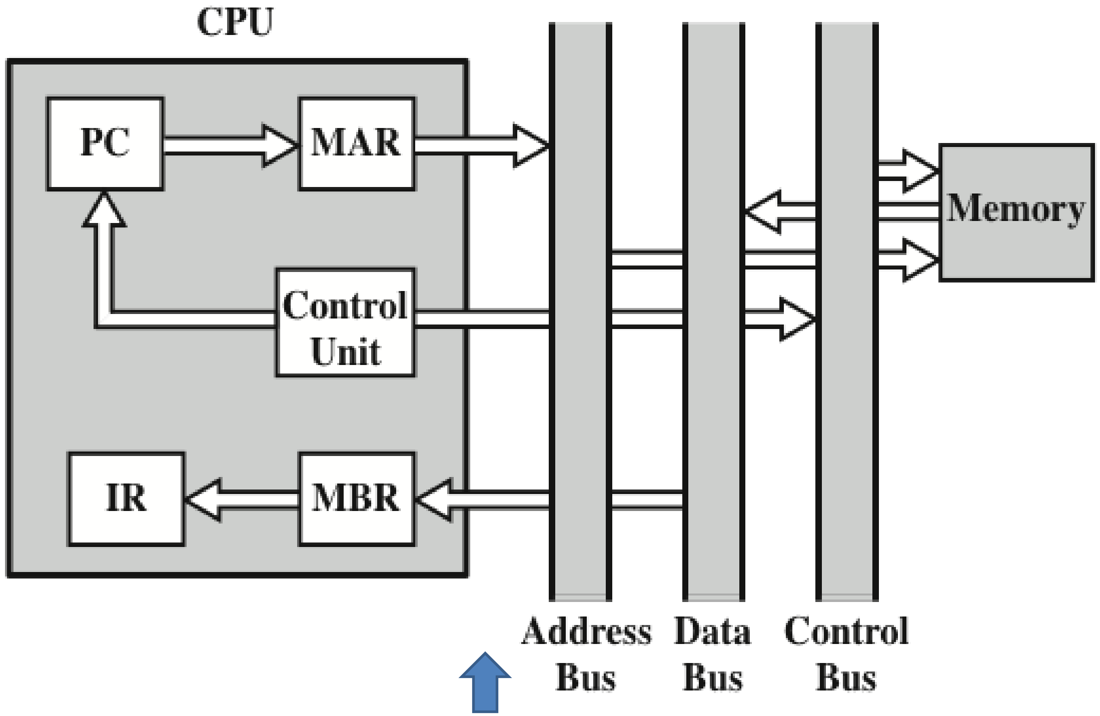


Program and Process

- 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

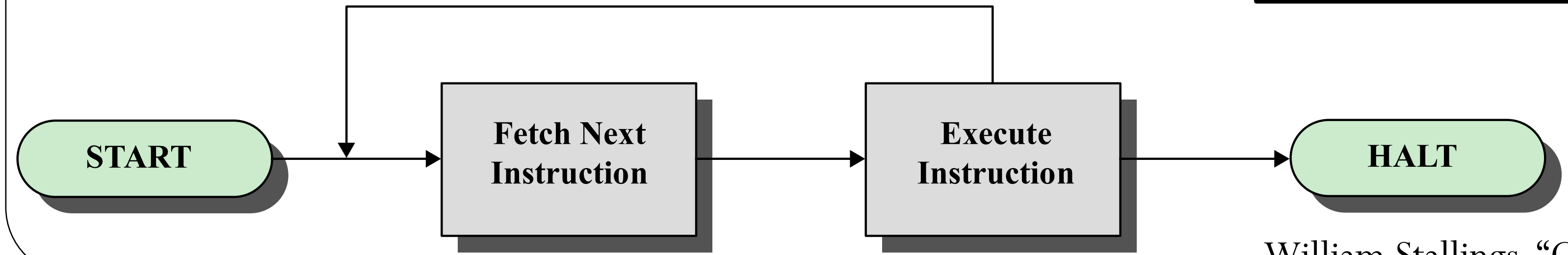


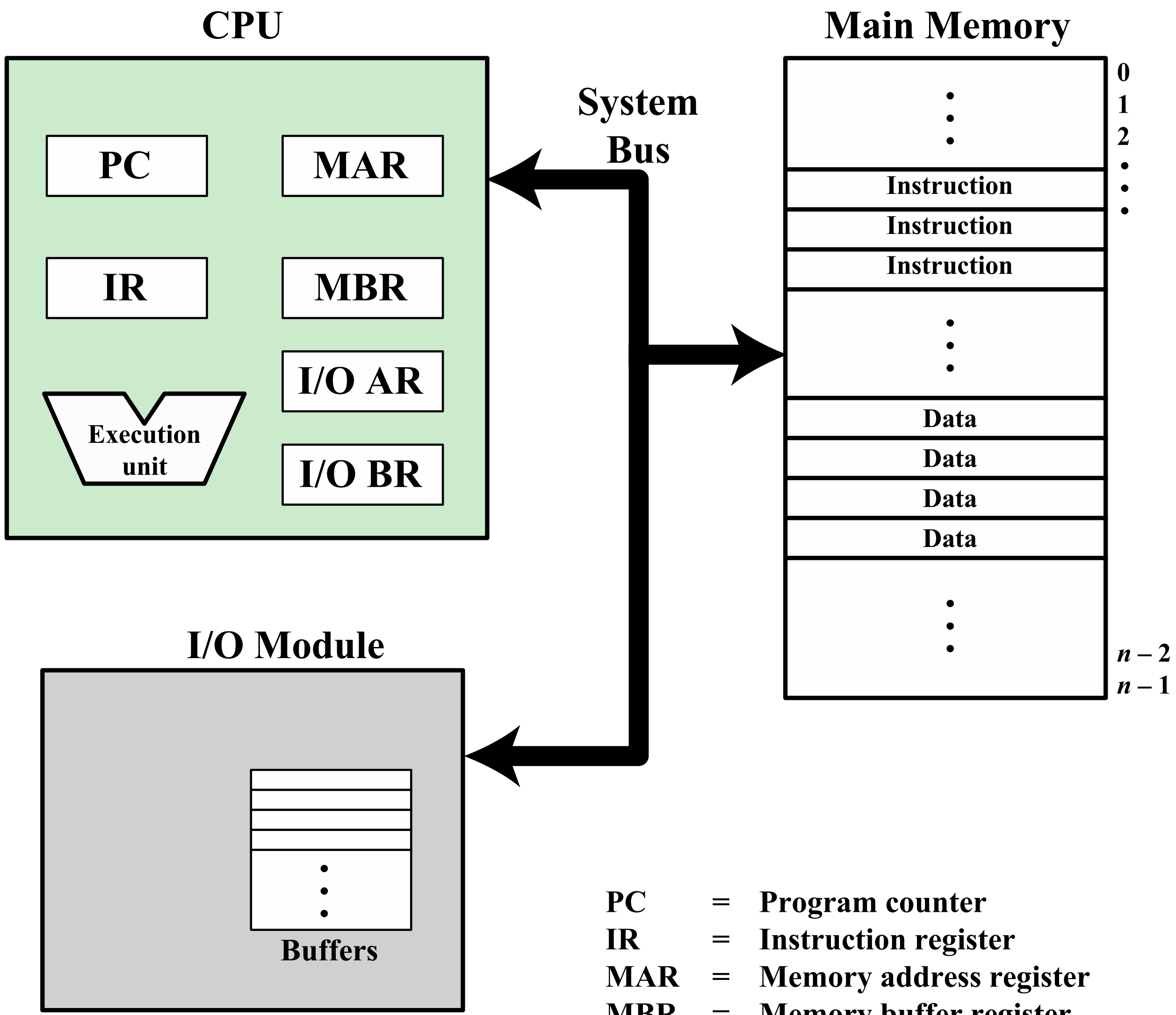
CPU and Memory



Fetch Cycle

Execute Cycle





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

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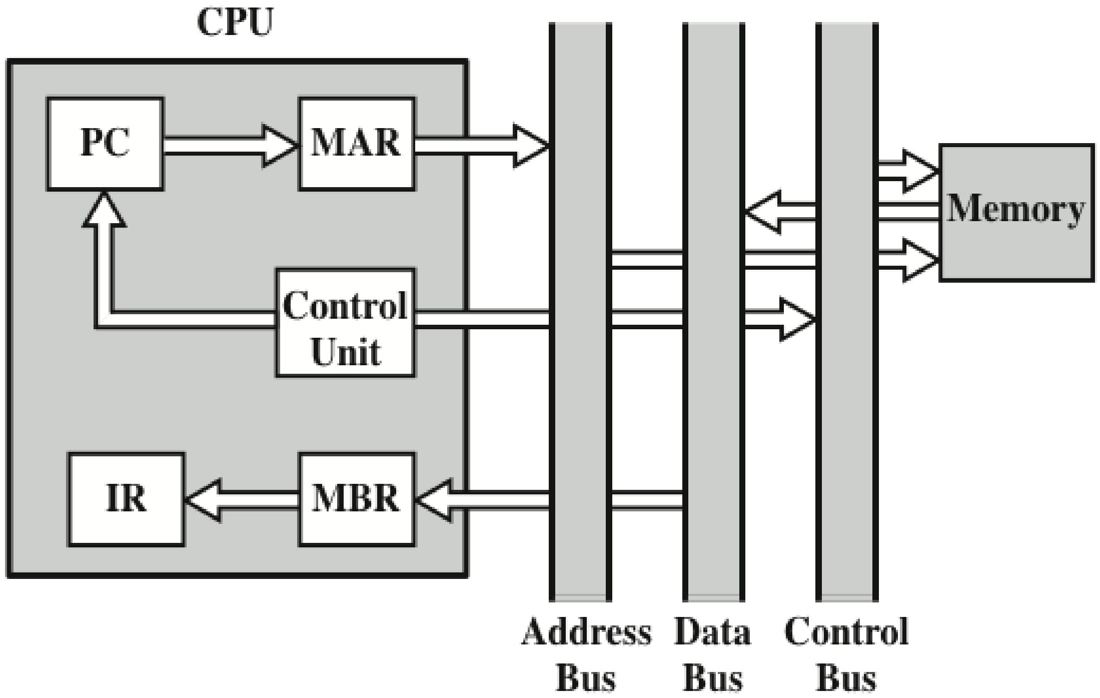
CPU and Memory

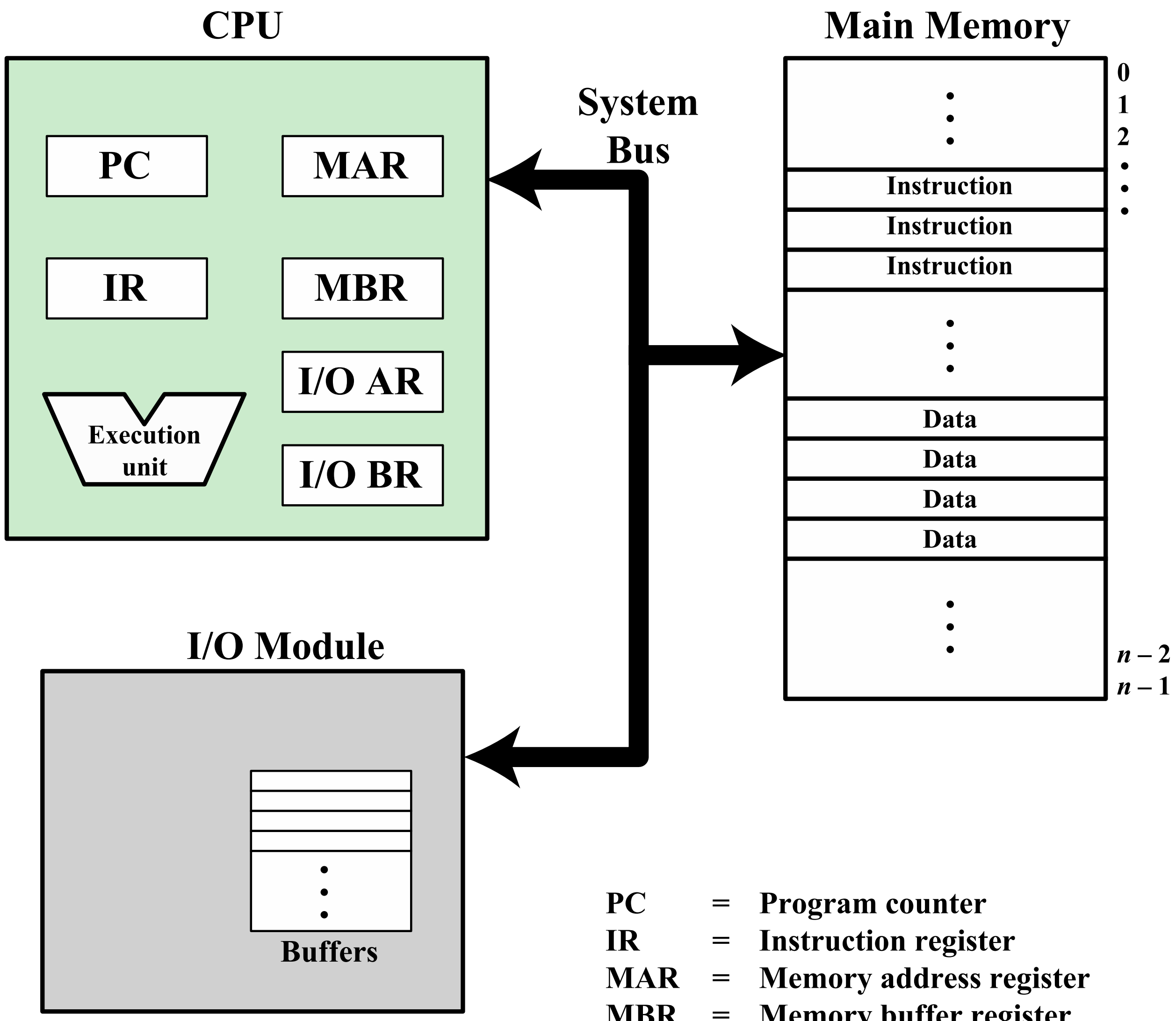


t1 : MAR ⟵ PC

t2 : MBR ⟵ MEMORY

PC ⟵ (PC) + I

t3 : IR ⟵ (MBR)



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IR = Instruction register
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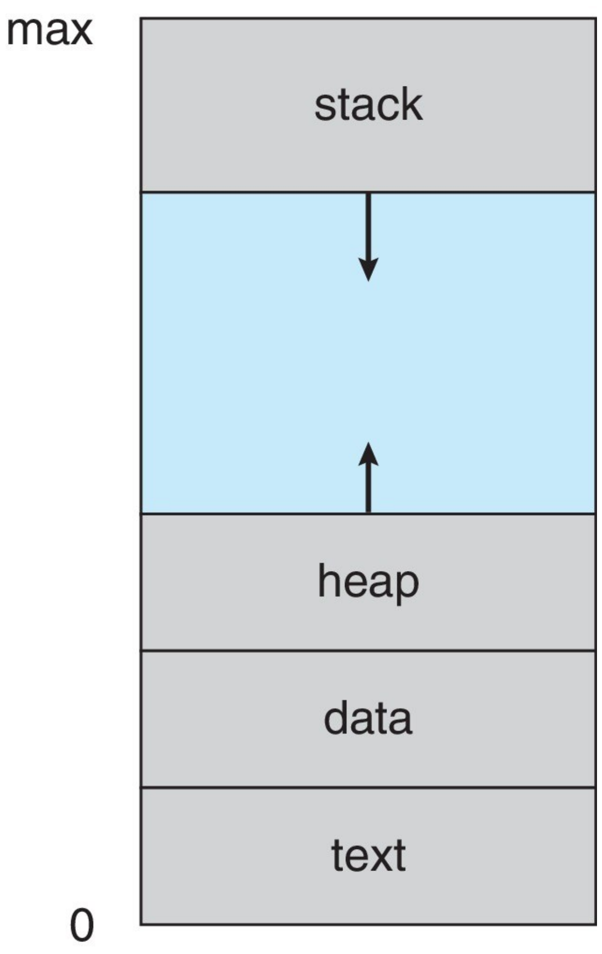
William Stallings. "Computer Organization and Architecture". 10th Edition

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)

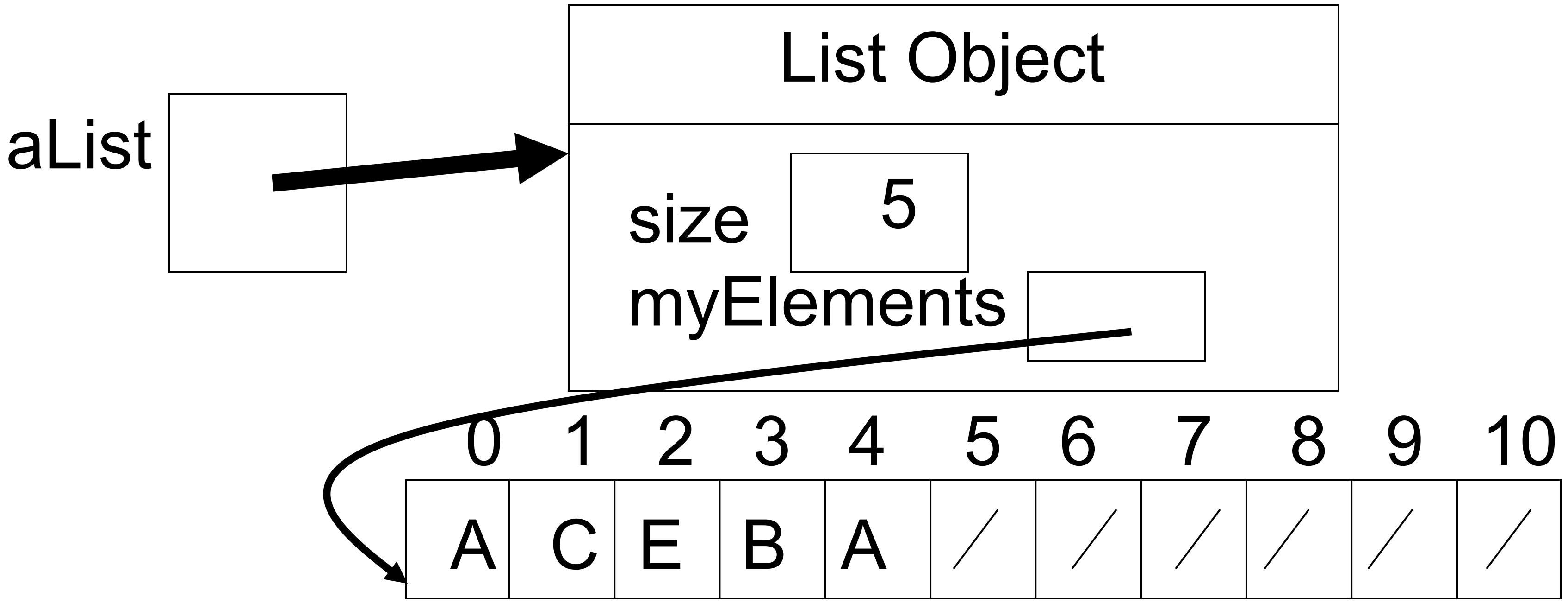
- All programs (or process) has data
  - To *store, display, gather*
  - In the form of *information, numbers, images, sound*
- Programmer decide to structure data
- Several option leads to program development
- Program properties
  - execution speed
  - memory requirements
  - maintenance (debugging,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

student → 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 <u>either</u> 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.

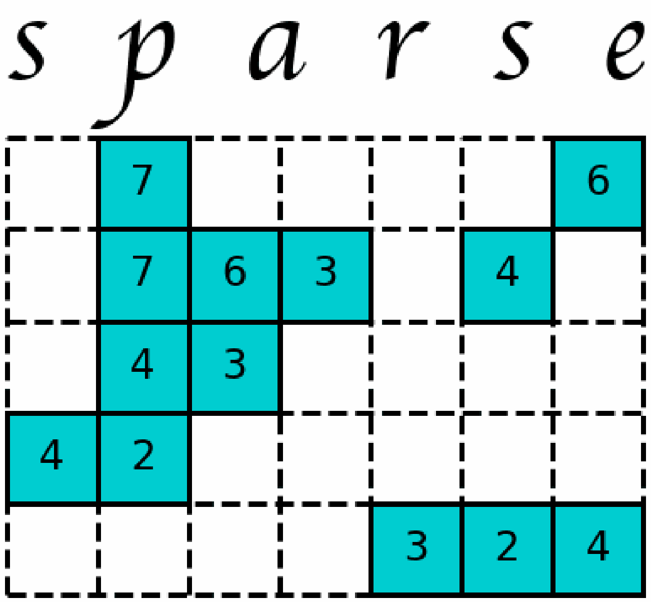
$$\begin{matrix} 2 & 4 & 6 & 0 \\ 4 & 1 & 9 & 5 \\ 6 & 9 & 4 & 7 \\ 0 & 5 & 7 & 0 \end{matrix}$$

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



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

$$\begin{bmatrix} 0 & 0 & 8 & 0 & 0 & 0 \\ 0 & 7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 \\ 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

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

$$\begin{matrix} 0 & 0 & 0 & 2 & 0 & 0 & 1 & 0 \\ 0 & 6 & 0 & 0 & 7 & 0 & 0 & 3 \\ 0 & 0 & 0 & 9 & 0 & 8 & 0 & 0 \\ 0 & 4 & 5 & 0 & 0 & 0 & 0 & 0 \end{matrix}$$

(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;
};
```

$$\begin{bmatrix} 0 & 0 & 8 & 0 & 0 & 0 \\ 0 & 7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 \\ 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

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

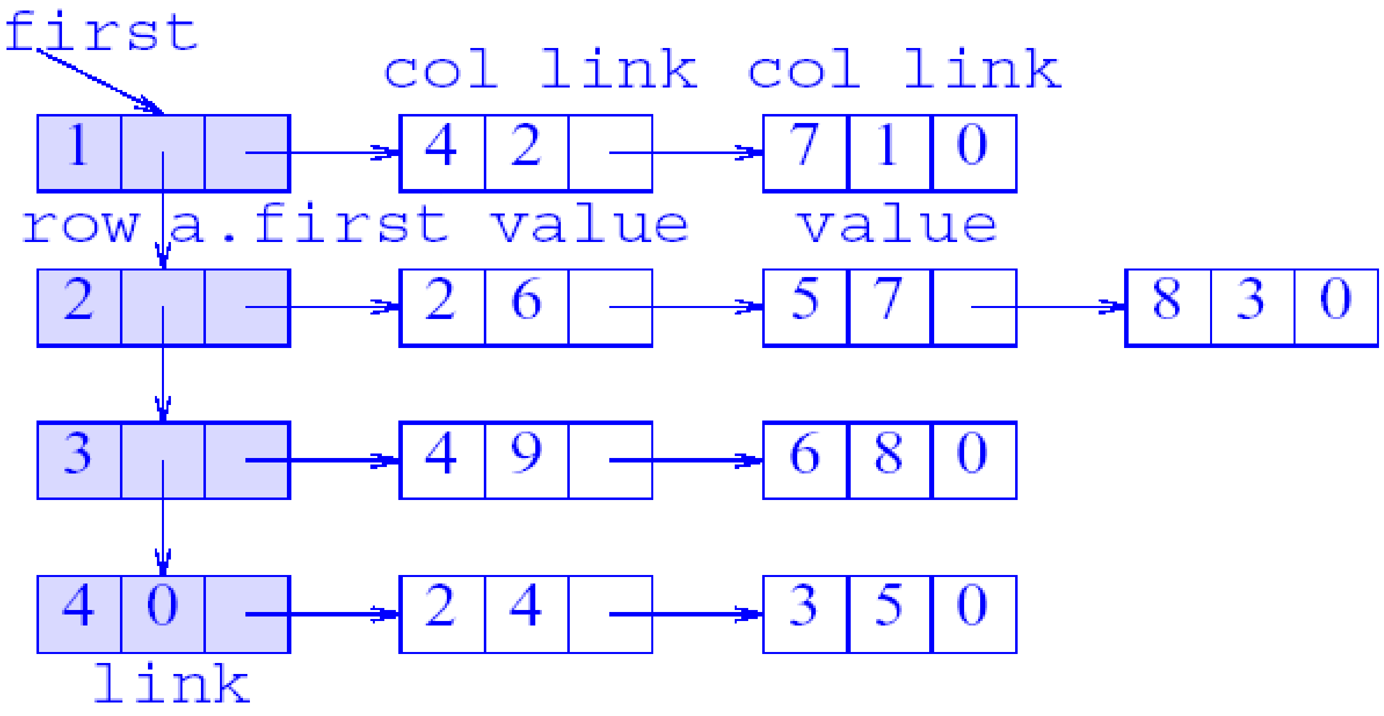
- A shortcoming of the 1-D array of a sparse matrix is that we need to know the number of nonzero terms in each of the sparse matrices when the array is created
- A linked representation can overcome this shortcoming

$$
\begin{matrix}
0 & 0 & 0 & 2 & 0 & 0 & 1 & 0 \\
0 & 6 & 0 & 0 & 7 & 0 & 0 & 3 \\
0 & 0 & 0 & 9 & 0 & 8 & 0 & 0 \\
0 & 4 & 5 & 0 & 0 & 0 & 0 & 0
\end{matrix}
$$

(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

Tamil

ありがとうございました

Japanese

감사합니다

Korean