INDIAN INSTITUTE OF INFORMATION TECHNOLOGY

Dharwad
ज्ञानेन विकासः

Introduction to Programming and Data Structures

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The Alan Turing Institute

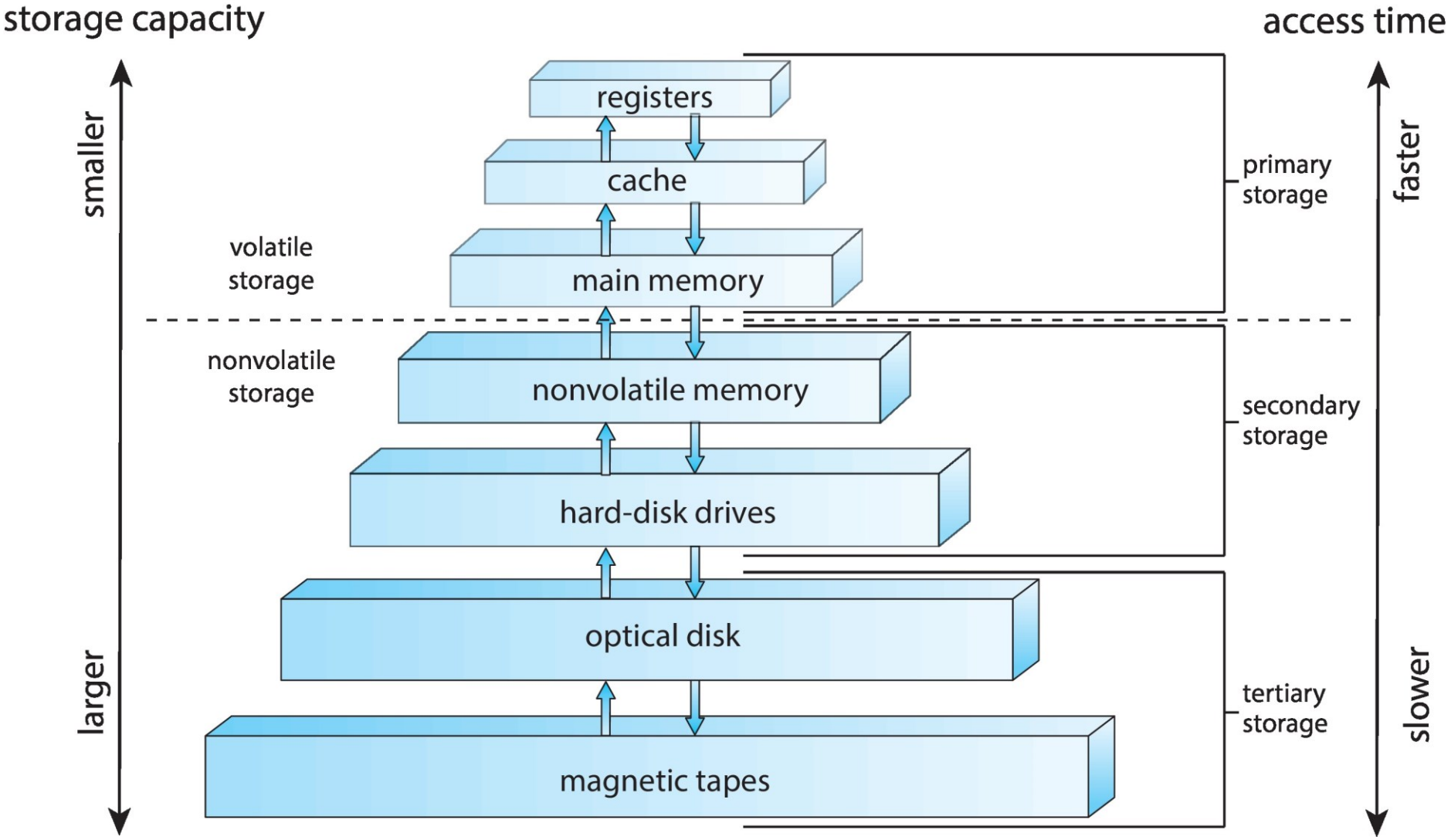
Goals of the Course

- 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

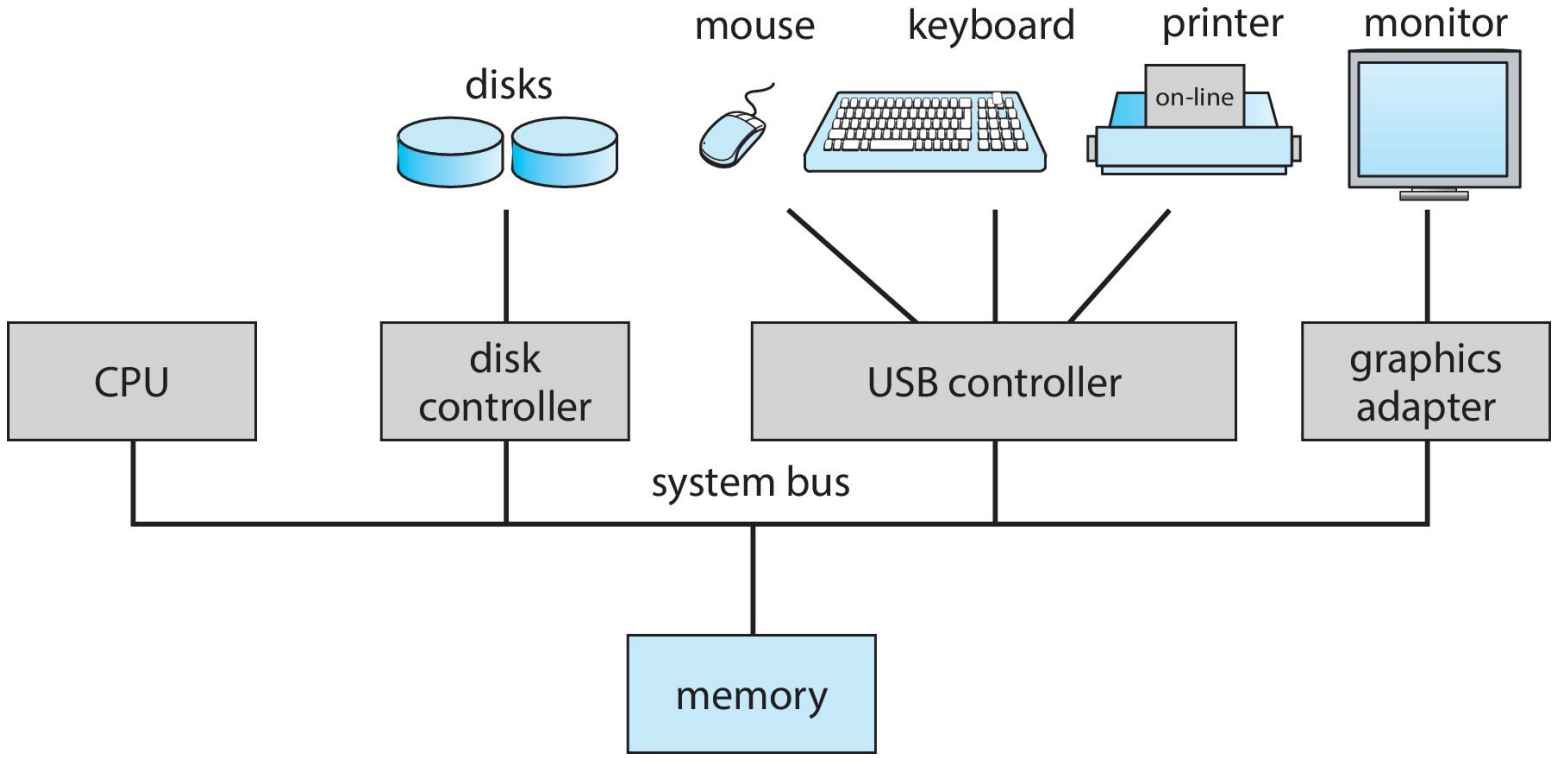
Basic Program Execution on CPU and Memory

Data Storage Device Hierarchy



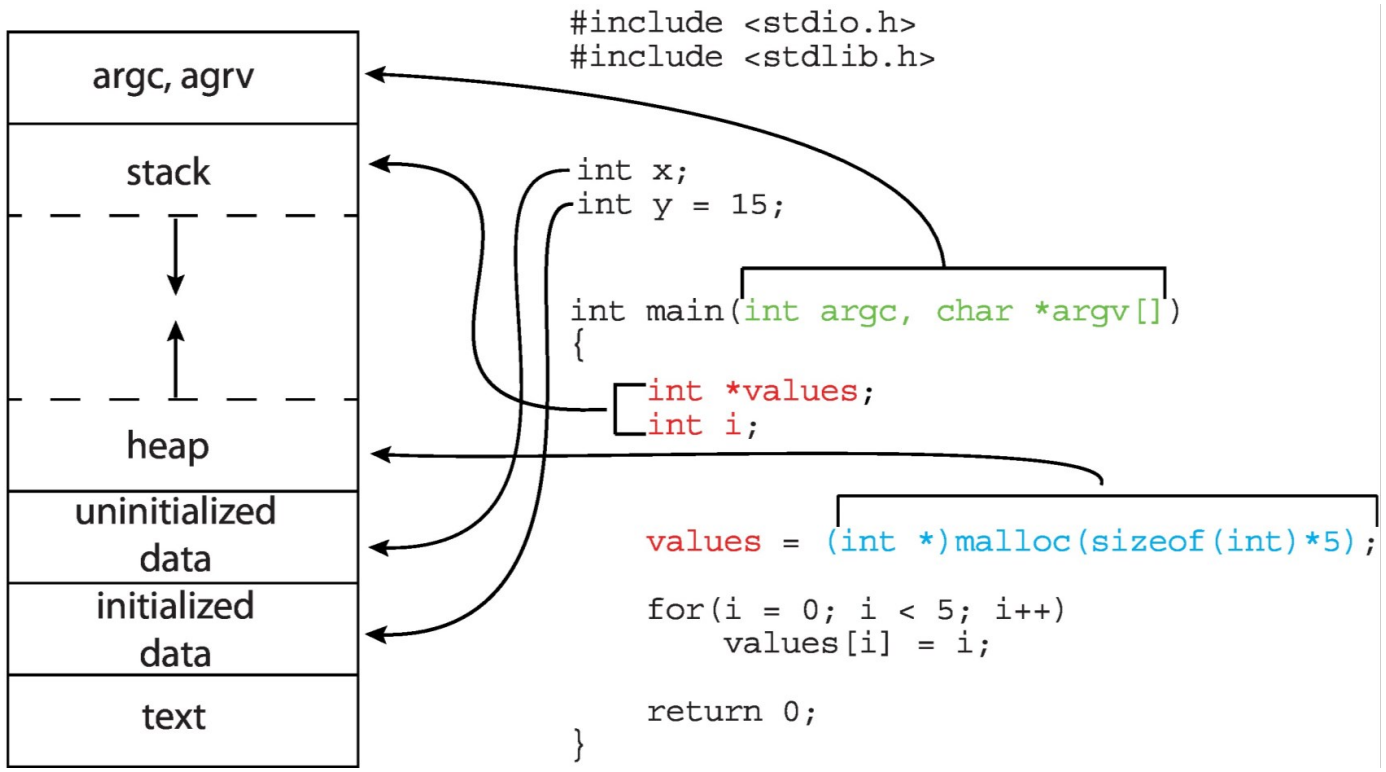
Computer System Organization

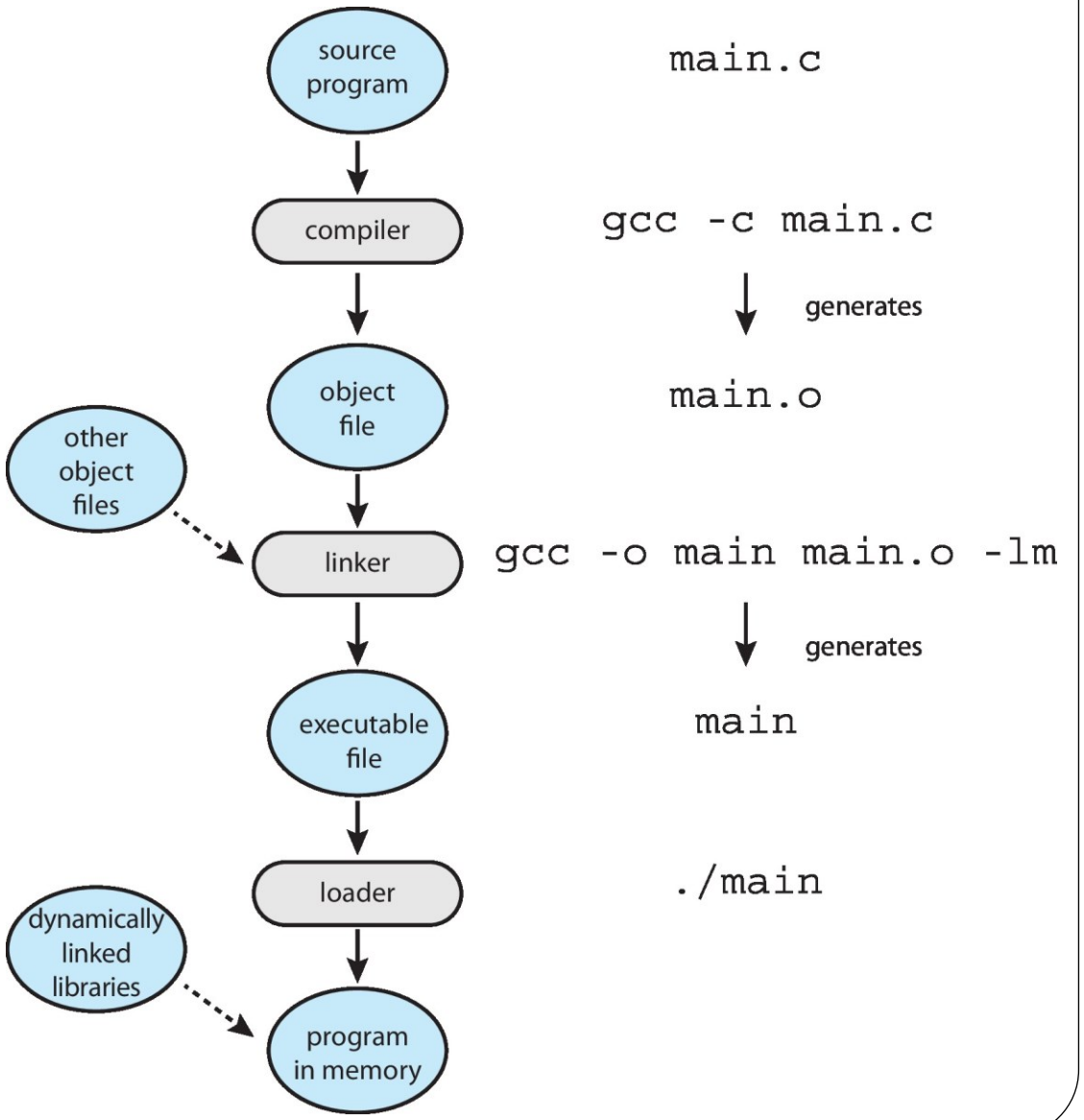
- Computer-system operation
  - One or more CPUs, device controllers connect through common **bus** providing access to shared memory
  - Concurrent execution of CPUs and devices competing for memory cycles



Program to Process

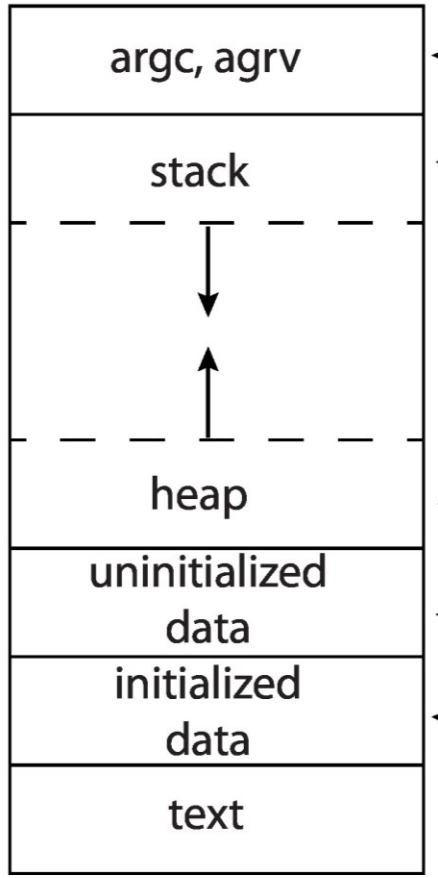
- When you run an exe file, the OS creates a process = a running program





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

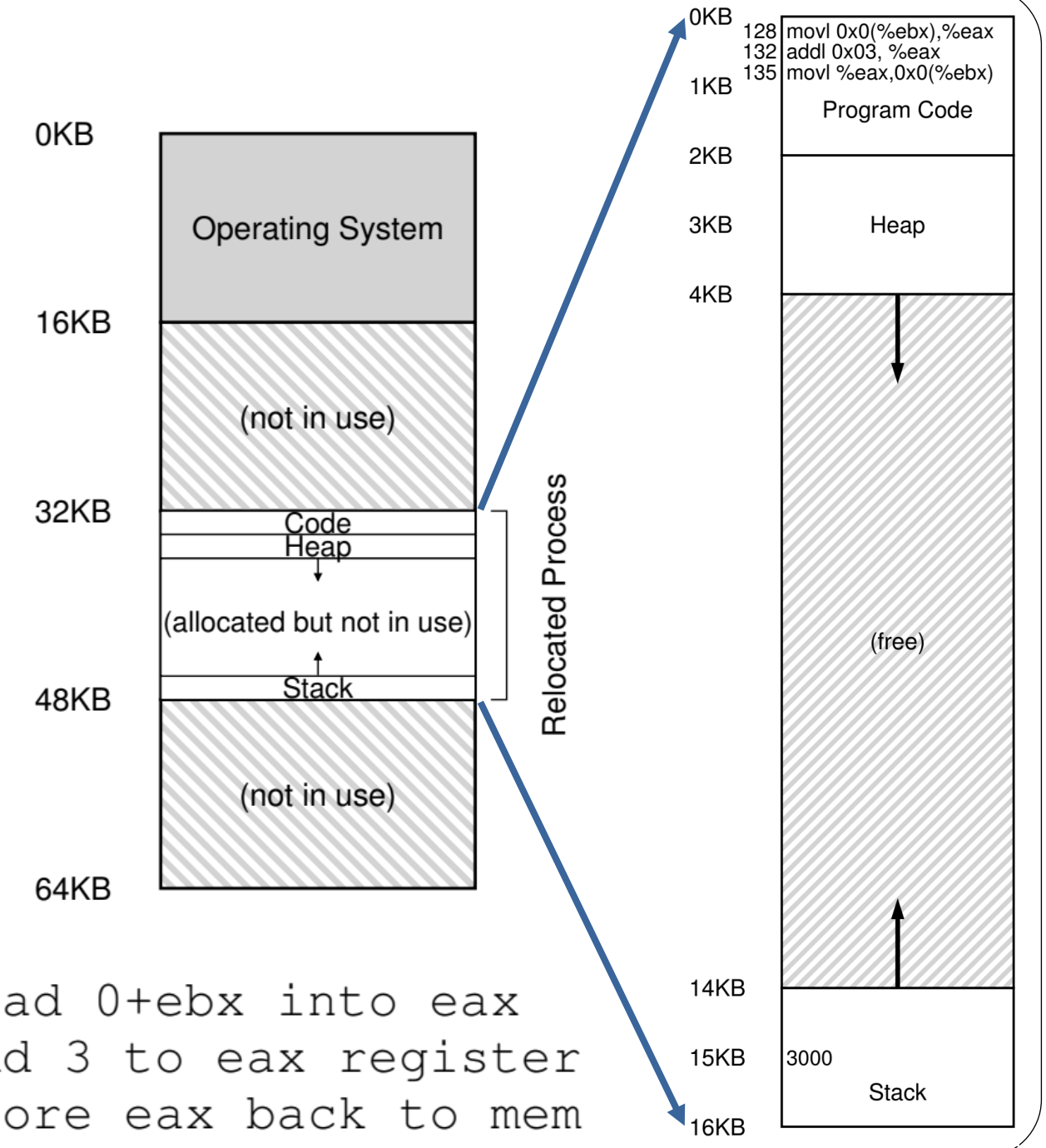
```
#include <stdio.h>
#include <stdlib.h>

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



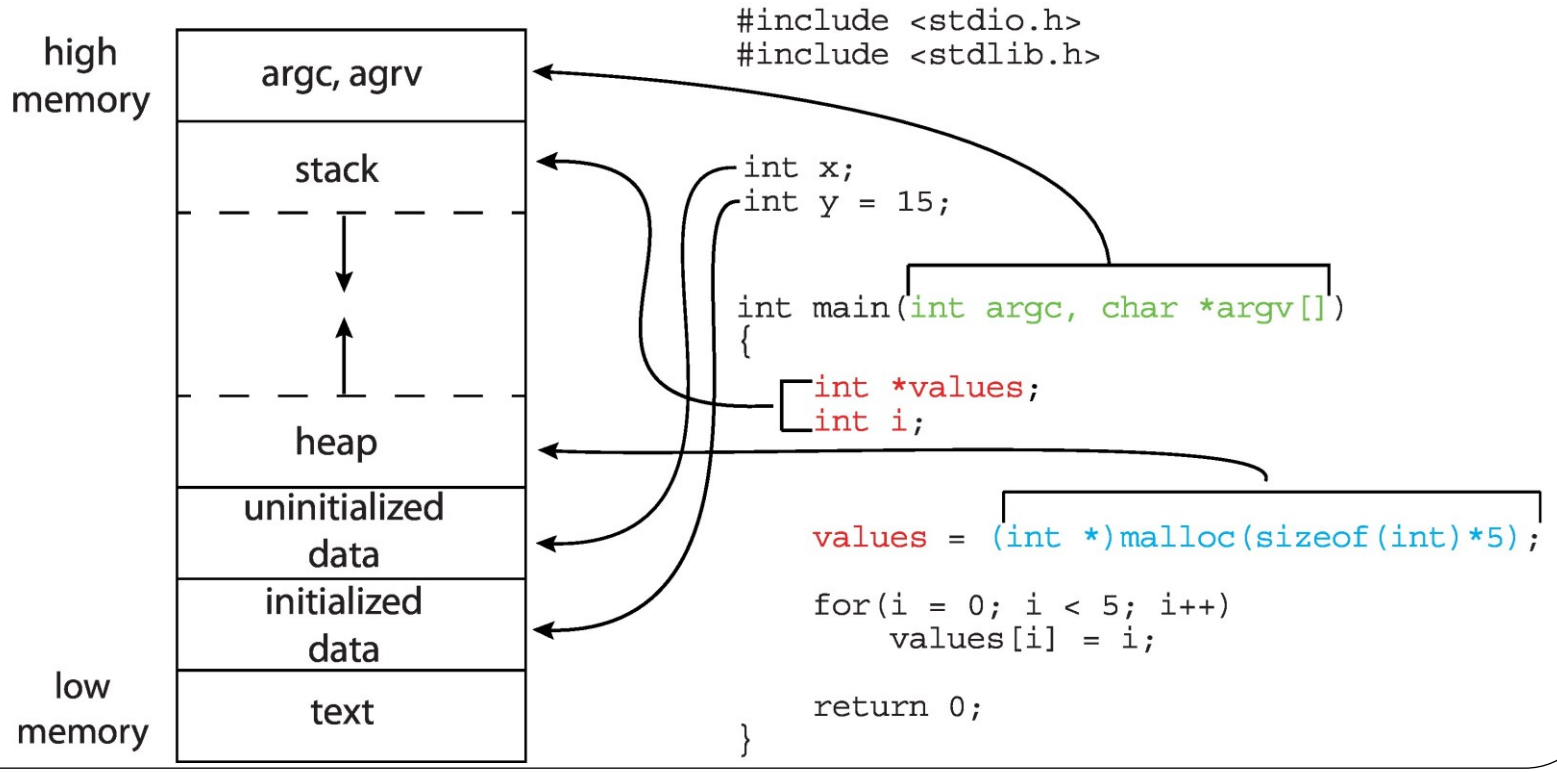

```
void func() {
    int x = 3000;
    x = x + 3;
    ...
```

Compiler

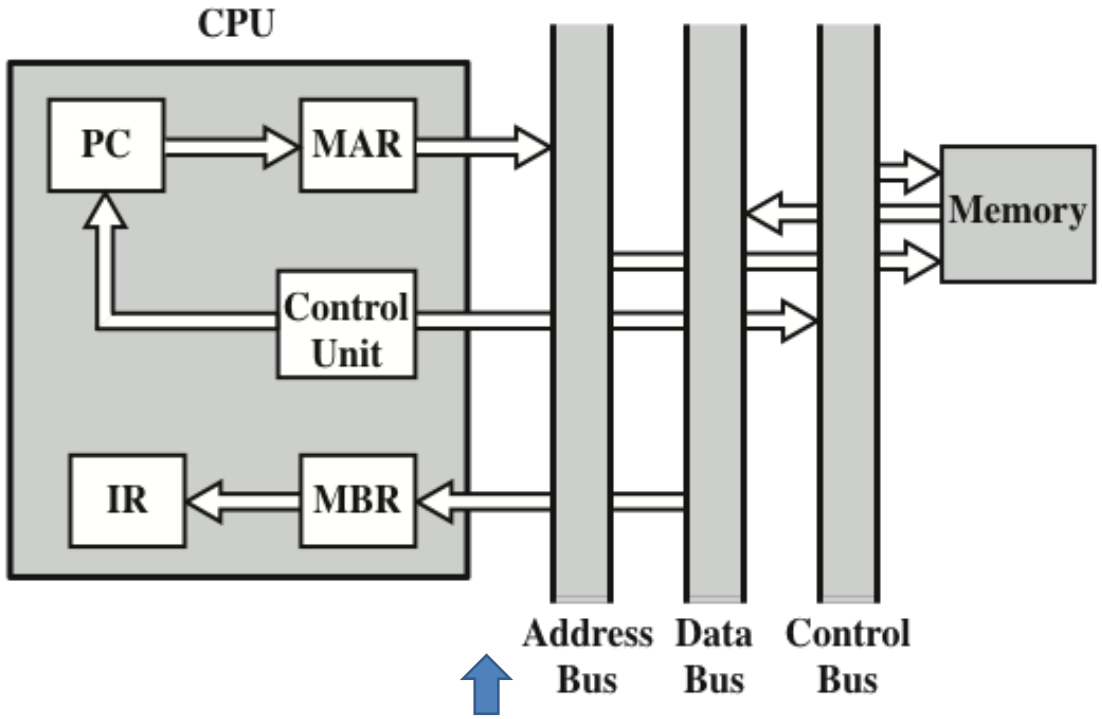
```
128: movl 0x0(%ebx), %eax     ;load 0+ebx into eax
132: addl $0x03, %eax         ;add 3 to eax register
135: movl %eax, 0x0(%ebx)     ;store eax back to mem
```

Program and Process

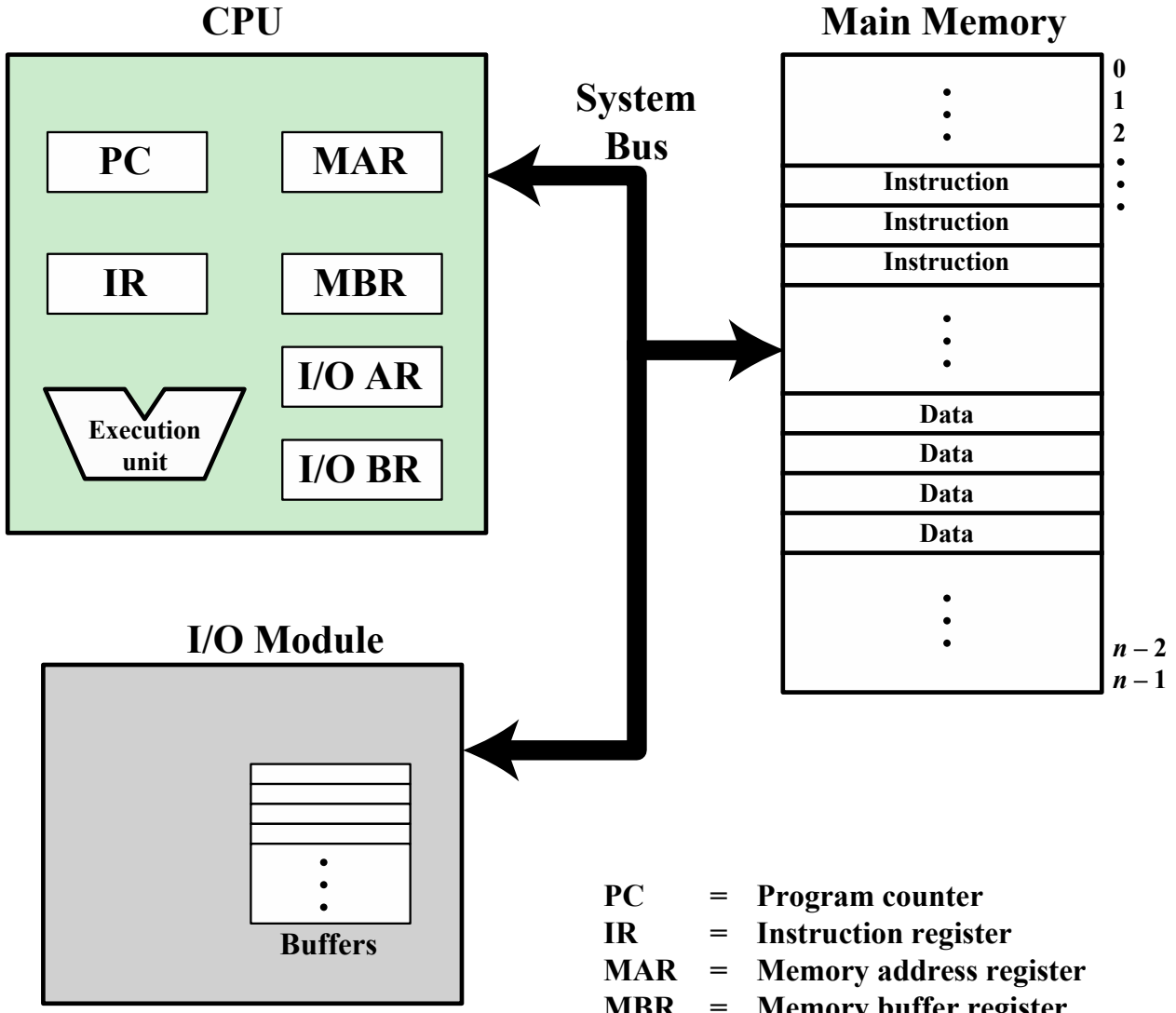
- A unique identifier
- Points CPU program counter to current instruction – Other registers may store operands, return values etc.
- CPU context: registers
  - Program counter
  - Current operands
  - Stack pointer



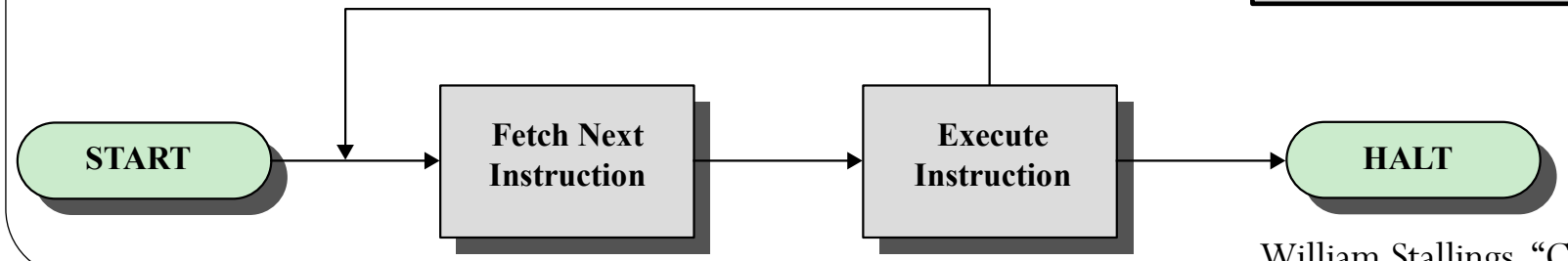
CPU and Memory



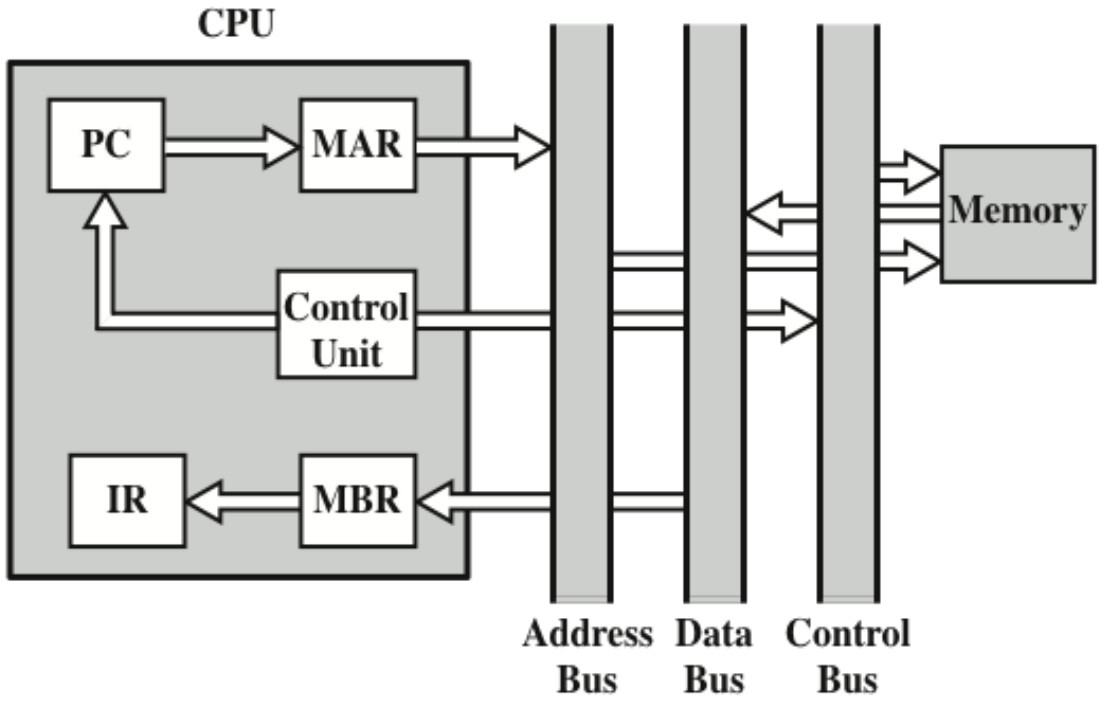
Fetch Cycle Execute Cycle



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



CPU and Memory

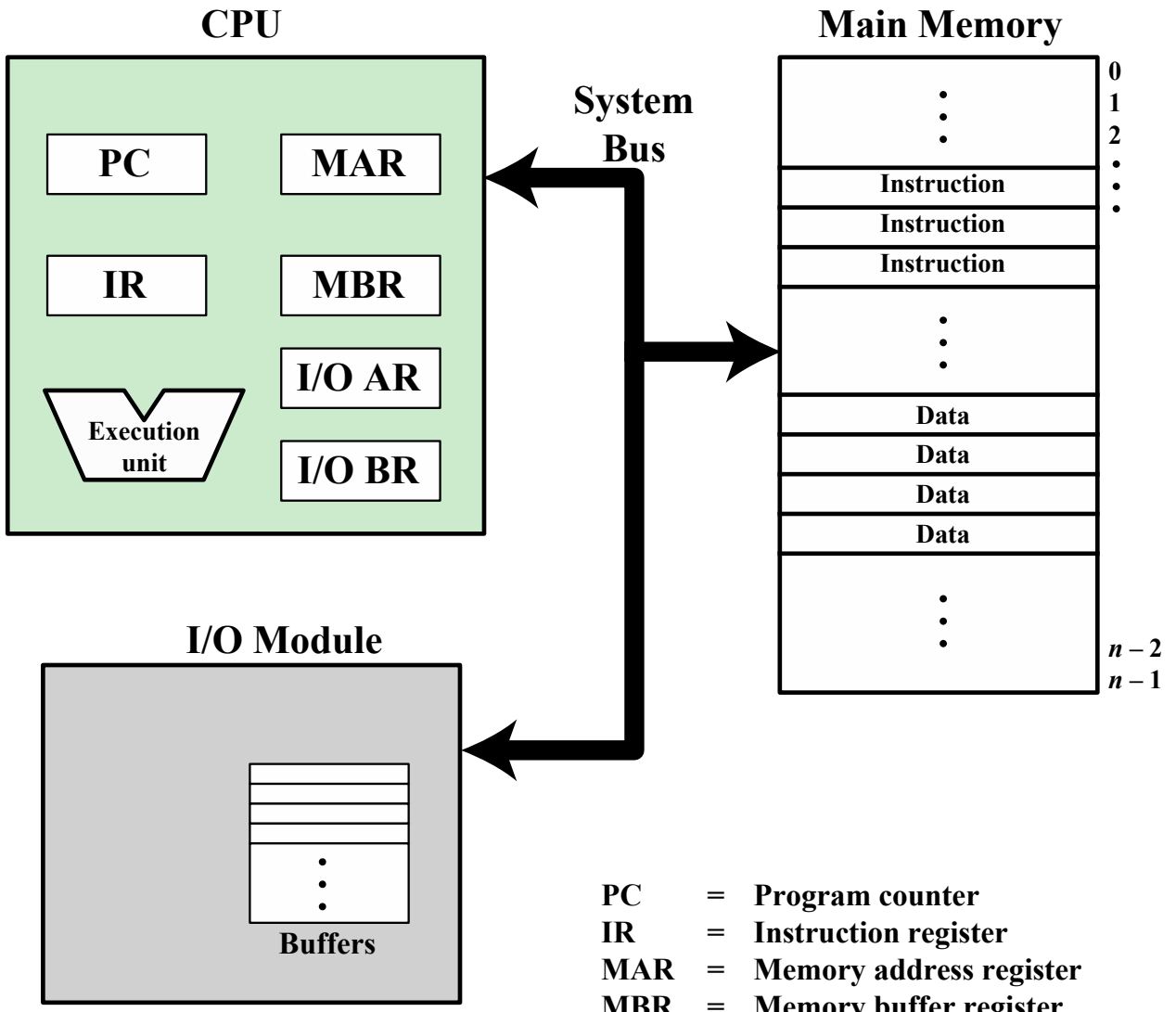


t1 : MAR ← PC

t2 : MBR ← MEMORY

PC ← (PC) + I

t3 : IR ← (MBR)



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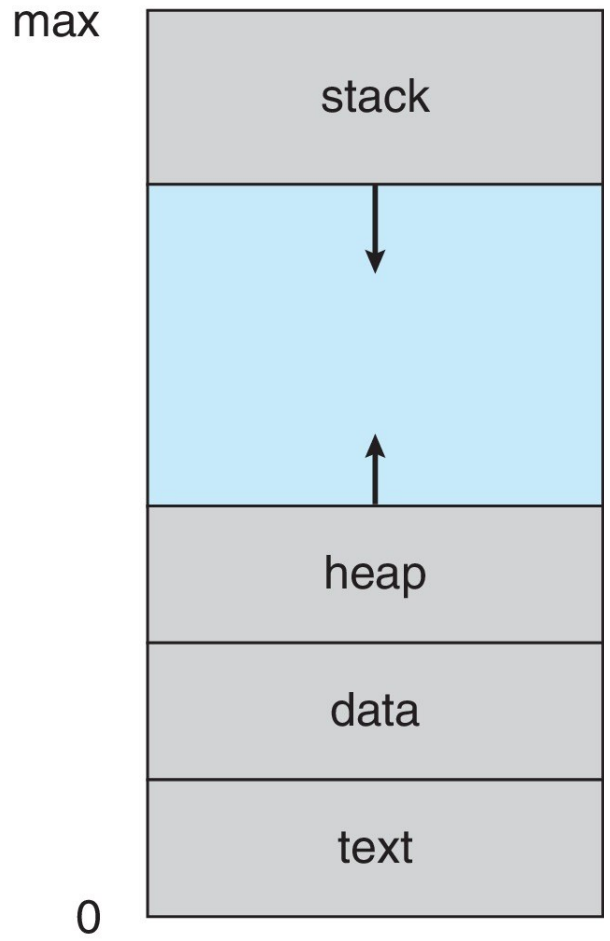
Program and Process

- 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)

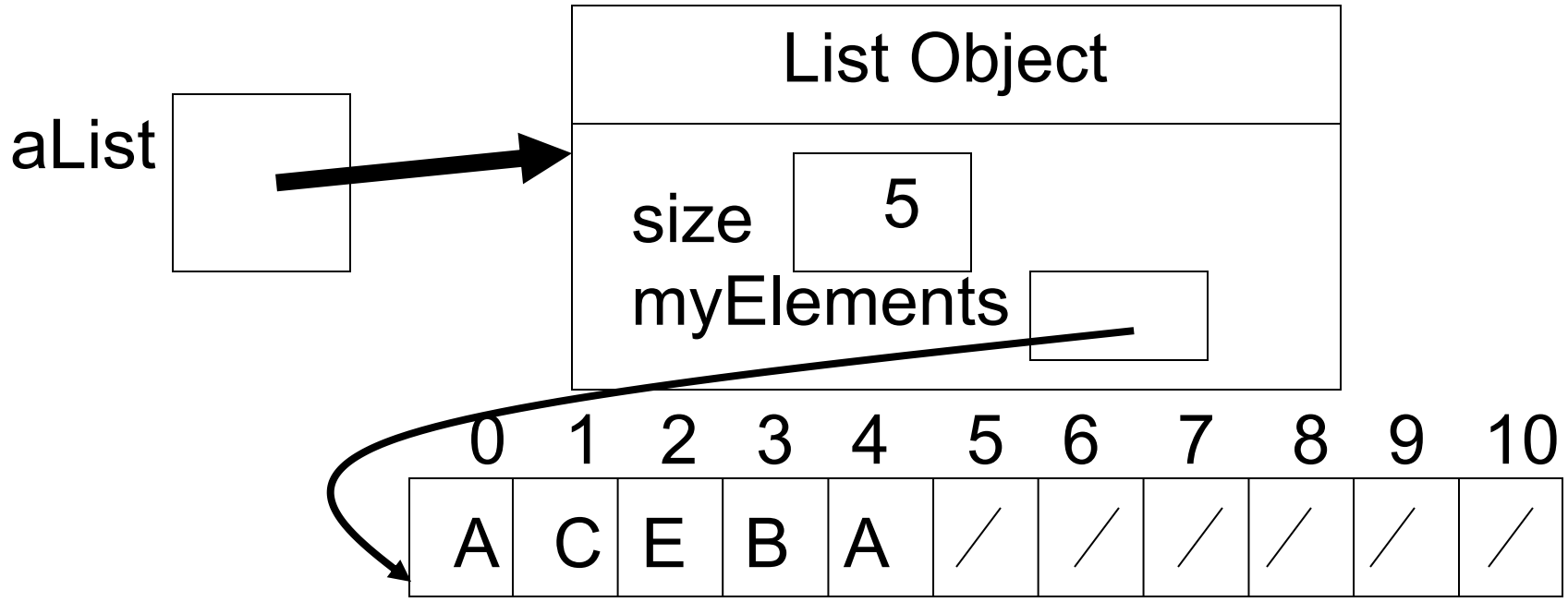
- All programs (or process) has data
  - To *store, display, gather*
  - In the form of *information, numbers, images, sound*
- Programmer decide to structure data
- Several option leads to program development
- Program properties
  - execution speed
  - memory requirements
  - maintenance (debugging,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

- 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 Type

- 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

References

Images and Text from basics of

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