

UNIT – 1

Introduction

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Important Repeated Questions:

1. **List/Explain Bresenham's line generation algorithm.** (S23 - Q2c, 07 marks) (S24 - Q1c, N/A marks) (W23 - Q1c, N/A marks) (S22 - Q2c, 07 marks) (W25 - Q1c, 07 marks) (W24 - Q1c, 07 marks)
2. **Differentiate between Raster Scan and Vector Scan Displays.** (S24 - Q2b, N/A marks) (S22 - Q1b-i, 04 marks)
3. **Differentiate between Analytic curves and Synthetic curves.** (S24 - Q2b, N/A marks) (S22 - Q1b-ii, 04 marks)
4. **What is scan conversion? Explain Bresenham's line/circle drawing algorithm.** (W22 - Q1c, 07 marks) (W23 - Q1c, N/A marks)
5. **List graphics standards used for graphics data exchange in CAD / State the role of graphics standards in CAD. List various graphics standards.** (W23 - Q1a, N/A marks) (S22 - Q2a, 03 marks) (W24 - Q2a, 03 marks)
6. **What is CAD? Explain its capabilities/reasons for implementing CAD.** (W22 - Q1b, 04 marks) (S22 - Q1a, 03 marks) (W25 - Q1a, 03 marks)
7. **Differentiate between Conventional design and Computer Aided Design.** (W23 - Q1b, N/A marks) (W24 - Q1a, 03 marks)
8. **List the steps/procedure of Finite Element Analysis.** (S23 - Q1a, 03 marks) (W22 - Q4a, 03 marks) (W24 - Q4a, 03 marks)

Legends: W- Winter, S- Summer, Q- Question and 03/04/07- Marks of Question

1.1 Introduction

In engineering practice, CAD/CAM has been utilized in different ways by different people. Some utilize it to produce drawings and document designs. Others may employ it as a visual tool by generating shaded images and animated displays. A third group may perform engineering analysis of some sort on geometric models such as finite element analysis.

A fourth group may use it to perform process planning and generate NC part programs. In order to establish the scope and definition of CAD/CAM in an engineering environment and identify existing and future related tools, a study of a typical product cycle is necessary. *Fig. 1.1* shows a flowchart of such a cycle.

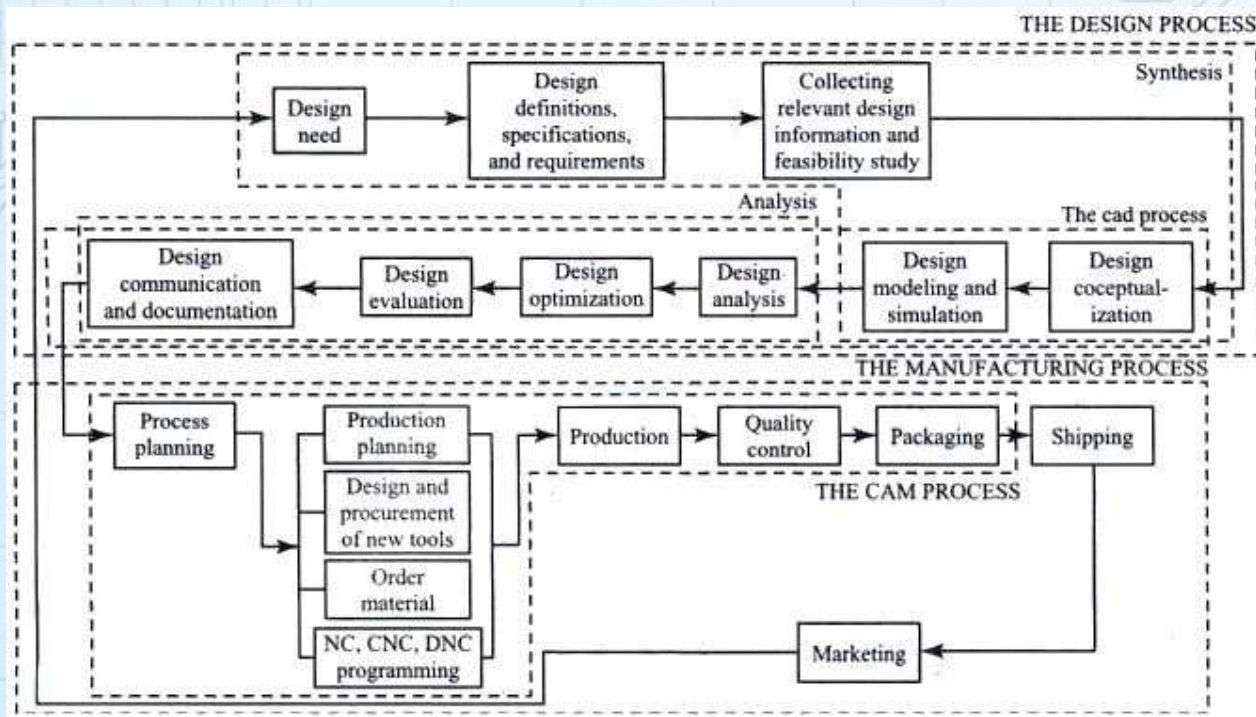


Fig. 1.1 – Typical product cycle

CAD tools can be defined as the intersection of three sets: geometrical modeling, computer graphics and the design tools. *Fig. 1.2* shows such definition. As can be perceived from this figure, the abstracted concepts of geometric modeling and computer graphics must be applied innovatively to serve the design process.

Based on implementation in a design environment, CAD tools can be defined as the design tools (analysis codes, heuristic procedures, design practices, etc.) being improved by computer hardware and software throughout its various phases to achieve the design goal efficiently and competitively as shown in *Fig. 1.2*.

The level of improvement determines the design capabilities of the various CAD/CAM systems and the effectiveness of the CAD tools they provide. Designers will always require tools that provide them with fast and reliable solutions to design situations that involve iterations and testings of more than one alternative.

CAD tools can vary from geometric tools, such as manipulations of graphics entities and interference checking, on one extreme, to customized applications programs, such as developing analysis and optimization routines, on the other extreme. In between these two extremes, typical tools currently available include tolerance analysis, mass property calculations and finite element modeling and analysis.

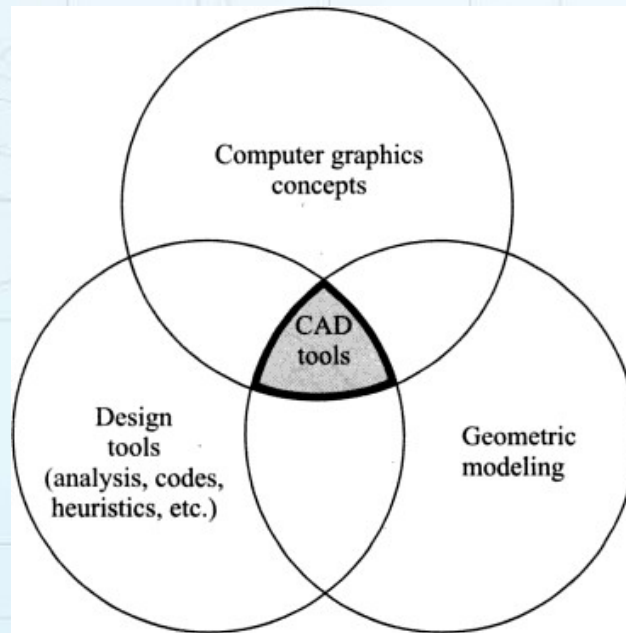


Fig.1.2 – Definition of CAD tools based on their constituents

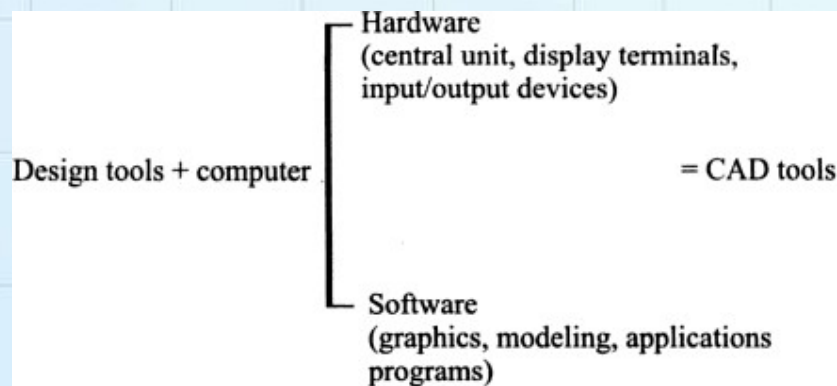


Fig.1.3 – Definition of CAD tools based on their implementation in a design environment

- CAD tools, as defined above, resemble guidance to the user of CAD technology.
- The definition should not and is not intended to, represent a restriction on utilizing it in engineering design and applications. The principal purposes of this definition are the following:
 1. To extend the utilization of current CAD/CAM systems beyond just drafting and visualization.
 2. To customize current CAD/CAM systems to meet special design and analysis needs.
 3. To influence the development of the next generation of CAD/CAM systems to better serve the design and manufacturing processes.

1.2 Reason for Implementing a CAD System

1. To increase in the productivity of the designer
 - The CAD improves the productivity of the designer to visualize the product and its components, parts and reduces time required in synthesizing, analyzing and documenting the design.

2. To improve the quality of design
 - CAD system permits a more detailed engineering analysis and a large no. of design alternatives can be investigated.
 - The design errors are also reduced because of the greater accuracy provided by system.
3. To improve communication in design
 - The use of a CAD system provides better engineering drawings, more standardization in drawing, better documentation of design, few drawing errors.
4. To create a data base for manufacturing
 - In the process of creating the documentation for the product design, much of the required data base to manufacture the product can be created.
5. Improves the efficiency of design
 - It improves the efficiency of design process and the wastages at the design stage can be reduced.

1.3 Conventional Design Process

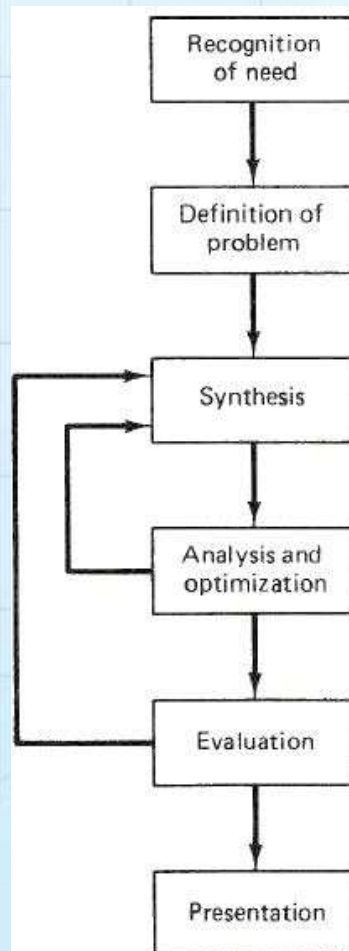


Fig.1.4 – Conventional Design Process

There are six steps involved in the conventional design process as discussed below:

1. Recognition of need

- First step in the designing process is to recognize necessity of that particular design.
- The condition under which the part is going to operate and the operation of part in that particular environment.
- The real problem is identified by knowing the history and difficulties faced in system.

2. Definition of problem

- The design involves type of shape of part, its space requirement, the material restrictions and the condition under which the part has to operate.
- The basic purpose of design process has to be known before starting the design.
- A problem may be design of a simple part or complex part.
- It may be problem on optimizing certain parameters.

3. Synthesis of design

- In this, it may be necessary to prepare a rough drawing of design part.
- The type of loading conditions imposed on the parts.
- The type of shapes which the part section can require and approximate dimension at which the different forces are located has to be provided on the sketch of part.
- The stresses to which the part is likely to be subjected must be analyzed and relevant formulas should be prepared.
- A mathematical model of design may be prepared to synthesize the parts of design.

4. Analysis and optimization

- The design can be analyzed for the type of loading condition as well as the geometric shape of the part.
- In the first stage it will be necessary to check the design of the part for safe stresses.
- If it is not satisfactory, then the dimensions of the part can be recalculated.
- The part can further be optimized for acquiring minimum dimensions, weight, volume, efficiency of the material and cost.
- The optimization depends on definition of problem and importance of a parameter.
- It may be sometimes necessary to optimize the parts for certain operating parameters like efficiency, torque, etc.

5. Evaluation

- It is concerned with measuring the design against the specifications established in the problem definition phase.
- The evaluation often requires the fabrication and testing of model to assess operating performance, quality and reliability.

6. Presentation

- The design of component must be presented along with necessary drawings in an attractive format.
- The presentation of the design can be made by use of colors and attractive presentation.

1.4 Conventional Design vs CAD

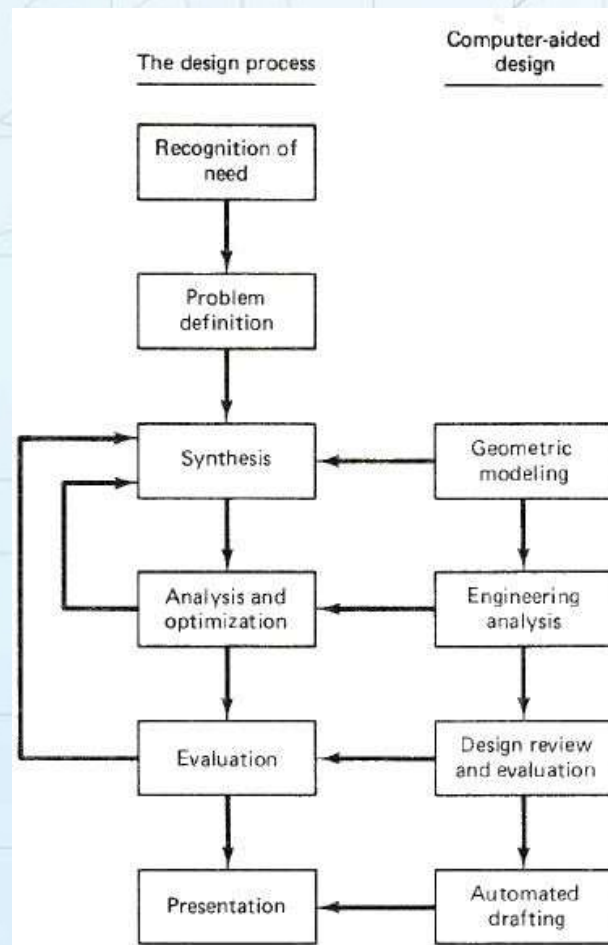


Fig.1.5 – Conventional design vs Computer Aided Design

1. Geometric modeling

- Geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object.
- The mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal through signals from the CPU of CAD system.
- The software that provides geometric modeling capabilities must be designed for efficient use both by the computer and human designer.
- The basic form uses wire frames to represent the object.
- The most advanced method of geometric modeling is solid modeling in three dimensions.

2. Engineering Analysis

- The analysis may involve stress-strain calculations, heat transfer computation etc.
- The analysis of mass properties is the analysis feature of CAD system that has probably the widest application.
- It provides properties of solid object being analyzed, such as surface area, weight, volume, center of gravity and moment of inertia.
- The most powerful analysis feature of CAD system is the finite element method.

3. Design Review & Analysis

- A procedure for design review is interference checking.
- This involves the analysis of an assembled structure in which there is a risk that the components of the assembly may occupy same space.
- Most interesting evaluation features available on some CAD systems is kinematics.
- The available kinematics packages provide the capabilities to animate the motion of simple designed mechanisms such as hinged components and linkages.

4. Automated Drafting

- This feature includes automatic dimensioning, generation of cross-hatched areas, scaling of the drawing and the capability to develop sectional views and enlarged views of particular part details.

1.5 Benefits of CAD

- Improved engineering productivity
- Reduced manpower required
- More efficient operation
- Customer modification are easier to make
- Low wastages
- Improved accuracy of design
- Better design can be evolved
- Saving of materials and machining time by optimization
- Colors can be used to customize the product

1.6 Limitations of CAD

- The system requires large memory and speed.
- The size of the software package is large.
- It requires highly skilled personal to perform the work.
- It has huge investment.

1.7 CAD/CAM Systems Evaluation Criteria

The various types of CAD/CAM systems are Mainframe-Based Systems, Minicomputer-Based Systems, Microcomputer-Based Systems and Workstation-Based Systems. The implementation of these types by various vendors, software developers and hardware manufacturers result in a wide variety of systems, thus making the selection process of one rather difficult. CAD/CAM selection committees find themselves developing long lists of guidelines to screen available choices.

These lists typically begin with cost criteria and end with sample models or benchmarks chosen to test system performance and capabilities. In between comes other factors such as compatibility requirements with in-house existing computers, prospective departments that plan to use the systems and credibility of CAD/CAM systems' suppliers. In contrast to many selection guidelines that may vary sharply from one

organization to another, the technical evaluation criteria are largely the same. They are usually based on and are limited by the existing CAD/CAM theory and technology. These criteria can be listed as follows.

1.7.1 System Considerations

(i) Hardware

- Each workstation is connected to a central computer, called the server, which has enough large disk and memory to store users' files and applications programs as well as executing these programs.

(ii) Software

- Three major contributing factors are the type of operating system the software runs under, the type of user interface (syntax) and the quality of documentation.

(iii) Maintenance

- Repair of hardware components and software updates comprise the majority of typical maintenance contracts. The annual cost of these contracts is substantial (about 5 to 10 percent of the initial system cost) and should be considered in deciding on the cost of a system in addition to the initial capital investment.

(iv) Vendor Support and Service

- Vendor support typically includes training, field services and technical support. Most vendors provide training courses, sometimes on-site if necessary.

1.7.2 Geometric Modeling Capabilities

a) Representation Techniques

- The geometric modeling module of a CAD/CAM system is its heart. The applications module of the system is directly related to and limited by the various representations it supports. Wireframes, surfaces and solids are the three types of modeling available.

b) Coordinate Systems and Inputs

- In order to provide the designer with the proper flexibility to generate geometric models, various types of coordinate systems and coordinate inputs ought to be provided. Coordinate inputs can take the form of cartesian (x, y, z), cylindrical (r, θ, z) and spherical (θ, ϕ, z).

c) Modeling Entities

- The fact that a system supports a representation scheme is not enough. It is important to know the specific entities provided by the scheme. The ease to generate, verify and edit these entities should be considered during evaluation.

d) Geometric Editing and Manipulation

- It is essential to ensure that these geometric functions exist for the three types of representations. Editing functions include intersection, trimming and projection and manipulations include translation, rotation, copy, mirror, offset, scaling and changing attributes.

e) Graphics Standards Support

- If geometric models' databases are to be transferred from one system to another, both systems must support exchange standards.

1.7.3 Design Documentation

(i) Generation of Engineering Drawings

- After a geometric model is created, standard drafting practices are usually applied to it to generate the engineering drawings or the blueprints. Various views (usually top, front and right side) are generated in the proper drawing layout. Then dimensions are added, hidden lines are eliminated and/or dashed, tolerances are specified, general notes and labels are added, etc.

1.7.4 Applications

(i) Assemblies or Model Merging

- Generating assemblies and assembly drawings from individual parts is an essential process.

(ii) Design Applications

- There are design packages available to perform applications such as mass property calculations, tolerance analysis, finite element modeling and analysis, injection modeling analysis and mechanism analysis and simulation.

(iii) Manufacturing Applications

- The common packages available are tool path generation and verification, NC part programming, postprocessing, computer aided process planning, group technology, CIM applications and robot simulation.

(iv) Programming Languages Supported

- It is vital to look into the various levels of programming languages a system supports. Attention should be paid to the syntax of graphics commands when they are used inside and outside the programming languages. If this syntax changes significantly between the two cases, user confusion and panic should be expected.

1.8 CAD Hardware

The hardware of CAD system consists of following:

- CPU
- Secondary memory
- Workstation
- Input unit
- Output unit
- Graphics display terminal

1. Central Processing Unit (CPU) The

CPU is the brain of the entire system.

Functions of CPU

- To receive information from the work station and display the output on the CRT screen.
- To read the data stored in the secondary memory storage unit.

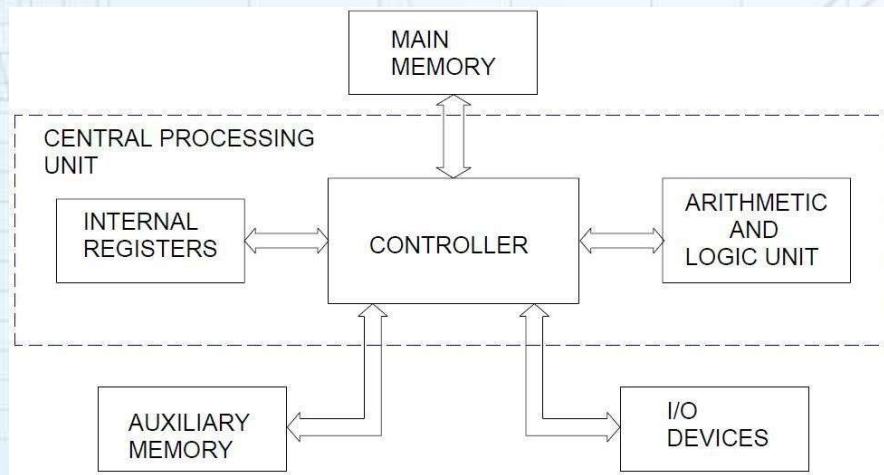


Fig.1.6 – Components of CPU

Functions of secondary memory

- To store files related to engineering drawing
- To store programs required to give instruction to output devices like plotters.
- To store CAD software
- The secondary storage unit consists of magnetic tapes and discs.

2. Work Station

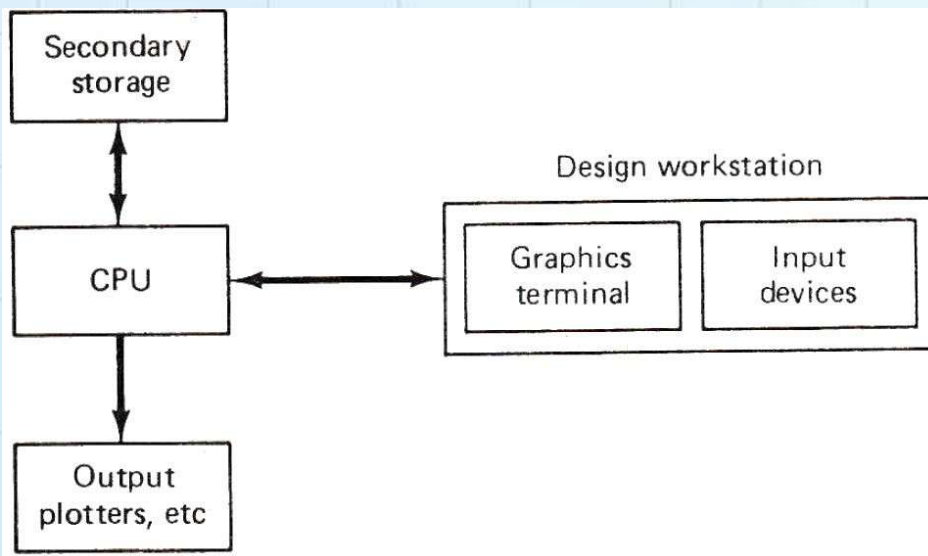


Fig.1.7 – Design workstation

- The work station is a visible part of the CAD system which provides interaction between the operator and the system.
- Among these advantages offered by work station are their availability, portability, the availability to dedicate them to a single task without affecting other users and their consistency of time response.
- A work station can be defined as a station of work with its own computing power to support major software packages, multitasking capabilities demanded by increased usage, complex tasks and networking potential with other computing environments.

Technical specifications of CAD workstation

CAD applications require workstations with reasonably enhanced processing speed, graphic capability, and storage capacity. Typical workstation specifications of some of the currently available models are given below.

Processor:	Intel Pentium 4 at 2.4 GHz
RAM:	2 GB to 16 GB
PCI bus width:	64 – bit
Hard drive:	500 GB to 1 TB
CD-ROM:	CD-RW/DVD Combo
Standard I/O ports:	1 Serial port, 1 Parallel port, 4 USB ports
Graphics:	NVIDIA 512 MB
Graphics resolution:	2018 x 1536 (Max)
Operating system:	Windows XP, Windows 7
Monitor:	21” Flat Panel TFT display
Keyboard:	Enhanced Multimedia USB
Mouse:	Optical Mouse Two-button Scroll Mouse

3. Input devices

- A no. of input devices is available. These devices are used to input two possible types of information: text and graphics.
- Text-input devices and the alphanumeric keyboards.
- There are two classes of graphics input devices: Locating devices and image-input devices.
- Locating devices, or locators, provide a position or location on the screen.
- These include lightpens, mouse, digitizing tablets, joysticks, trackballs, thumbwheels, touchscreen and touchpads.
- Locating devices typically operate by controlling the position of a cursor on screen. Thus, they are also referred to as cursor-control devices.

I. Scanners

- Scanners comprise other class of graphics-input device.
- There are four relevant parameters to measure the performance of graphics input devices. These are resolution, accuracy, repeatability and linearity.
- Some may be more significant to some devices than others.

II. Keyboards

- Keyboards are typically employed to create/edit programs or to perform word processing functions.
- CAD/CAM systems, information entered through keyboards should be displayed back to the user on a screen for verification.

III. Digitizing tablets

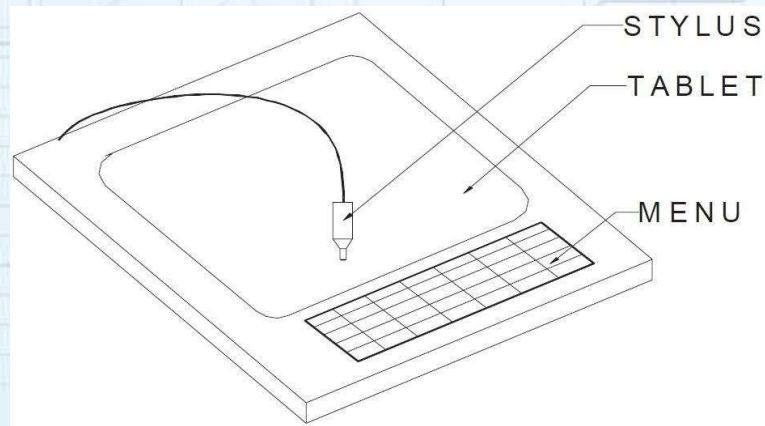


Fig.1.8 – Digitizer

- A digitizing tablet is considered to be a locating as well as pointing device. It is a small, low-resolution digitizing board often used in conjunction with a graphics display.
- The tablet is a flat surface over which a stylus can be moved by the user.
- A tablet's typical resolution is 200 dots per inch
- The tablet operation is based on sensitizing its surface area to be able to track the pointing element motion on the surface.
- Several sensing methods and technologies are used in tablets. The most common sensing technology is electromagnetic, where the pointing element generates an out of phase magnetic field sensed by wire grid in tablet surface.

IV. Mouse

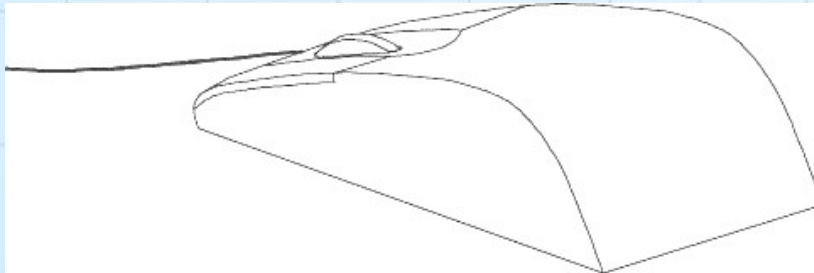


Fig.1.9 – Mouse

- There are two basic types of mouse available mechanical and optical.
- The mechanical mouse has roller in order to record the mouse motion in X and Y directions.
- In optical mouse, movements over the surface are measured by a light beam modulation techniques.
- The light source is located at the bottom and the mouse must be in contact with the surface for screen cursor to follow its movement.

V. Joy sticks & Trackballs

- The joystick works by pushing its stick backwards or forward or to left or right. The extreme positions of these directions correspond to the four corner of the screen.

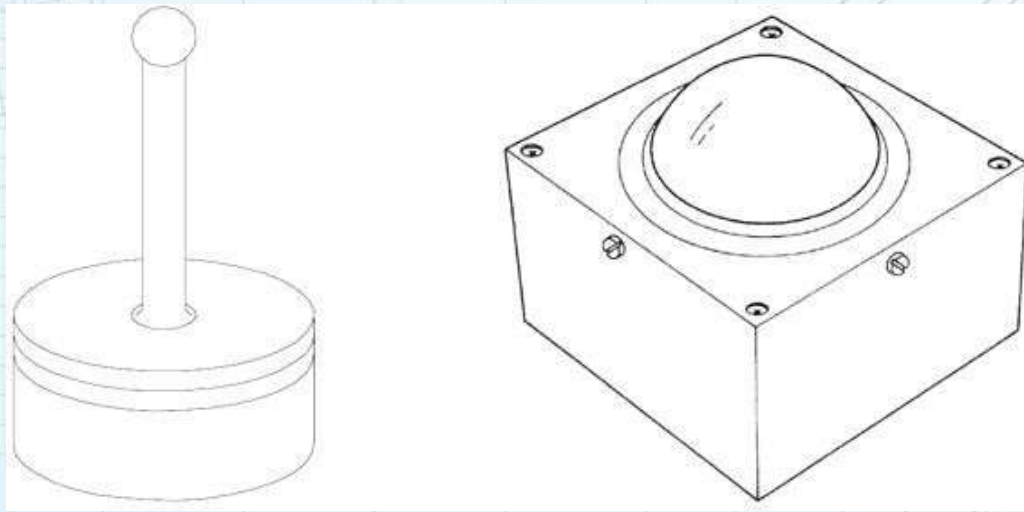


Fig.1.10 – Joy Stick and Track ball

- A trackball is similar in principal to a joystick but allows more precise fingertip control. The ball rotates freely within its mount.
- Both the joystick and trackball are used to navigate the screen display cursor. The user of a trackball can learn quickly how to adjust to any nonlinearity in its performance.

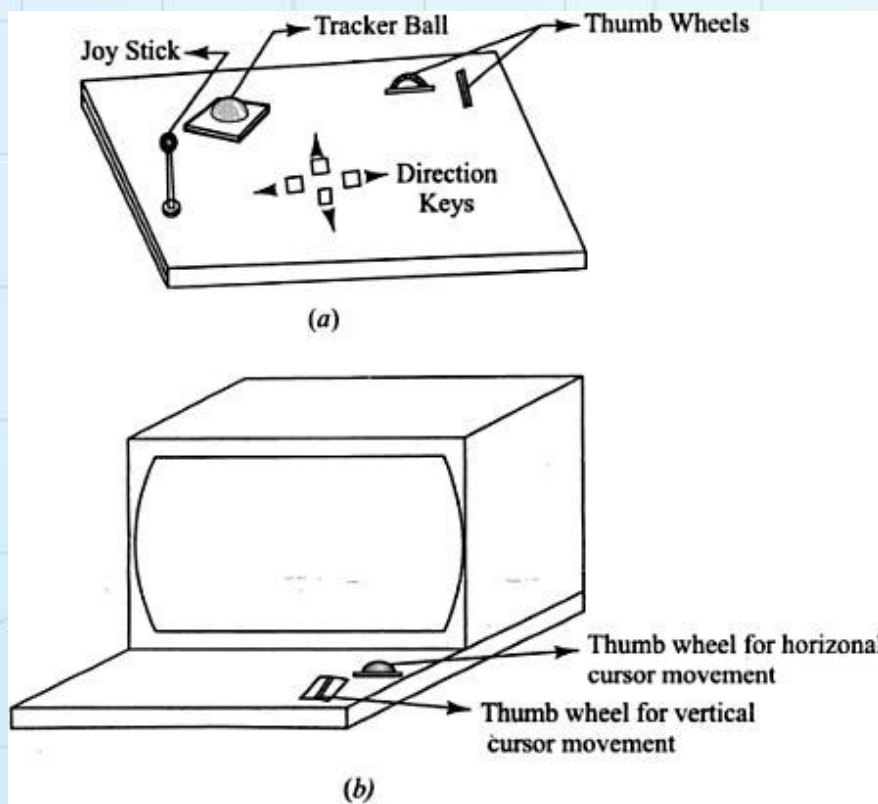


Fig.1.11 – (a) Cursor Control Devices (b) Thumbwheels as input device with a work station

VI. Thumbwheels

- Two thumbwheels are usually required to control the screen cursor, one for its horizontal position and other for its vertical position. Each position is indicated on screen by cross- hair.

4. Output devices

CAD/CAM applications require output devices such as displays and hardcopy printers.

I. Graphics displays

- The operation of CRT is based on concept of energizing an electron beam that strikes the phosphor coating at very high speed.
- The energy transfer from the electron to the phosphor due to the impact causes it to illuminate and glow.
- The electrons are generated via the electron gun that contains the cathode and are focused into a beam via the focusing unit shown in *Fig. 1.12*.
- By controlling the beam direction and intensity in a way related to the graphics information generated in the computer, meaningful and desired graphics can be displayed on the screen.

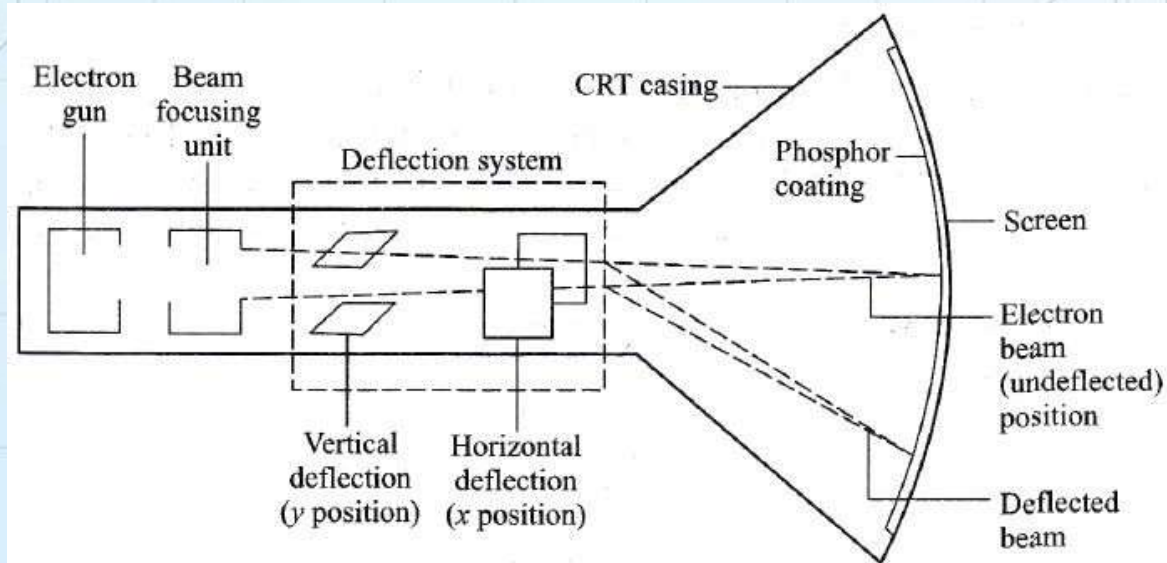


Fig.1.12 – Principle of CRT

- The deflection system of the CRT controls the x and y, or the horizontal and vertical, positions of the beam which in turn are related to the graphics information through the display controller, which typically sits between the computer and the CRT. The controller receives the information from the computer and converts it into signals acceptable to the CRT.

Refresh vector display

- Early displays in 1960s were refresh vector displays.
- The refresh buffer stores the display file or program, which contains points, lines, characters and other attributes of picture to be drawn.
- These commands are interpreted & processed by display processor.
- The electron beam accordingly excites the phosphor, which glows for a short period.
- To maintain a steady flicker-free image, the screen must be refreshed or redrawn at least 30 to 60 times per second, that is at a rate of 30 to 60 Hz.
- The principal advantages of refresh display is its high resolution (4096 x 4096) and thus its generation of high quality picture.

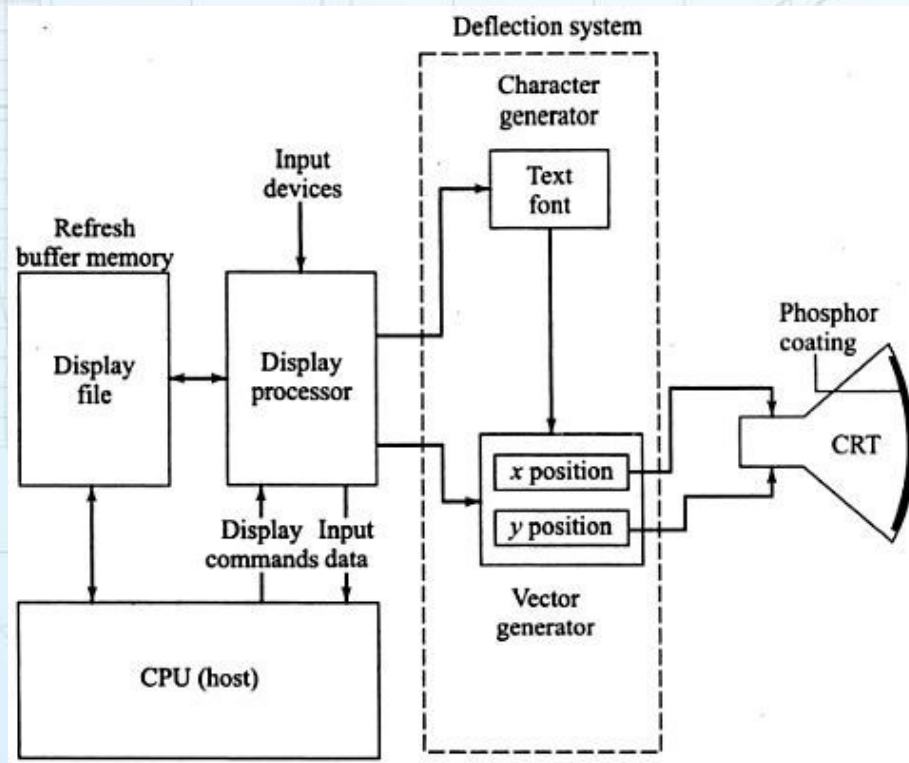


Fig.1.13 – Refresh display

Direct View Storage Tube (DVST)

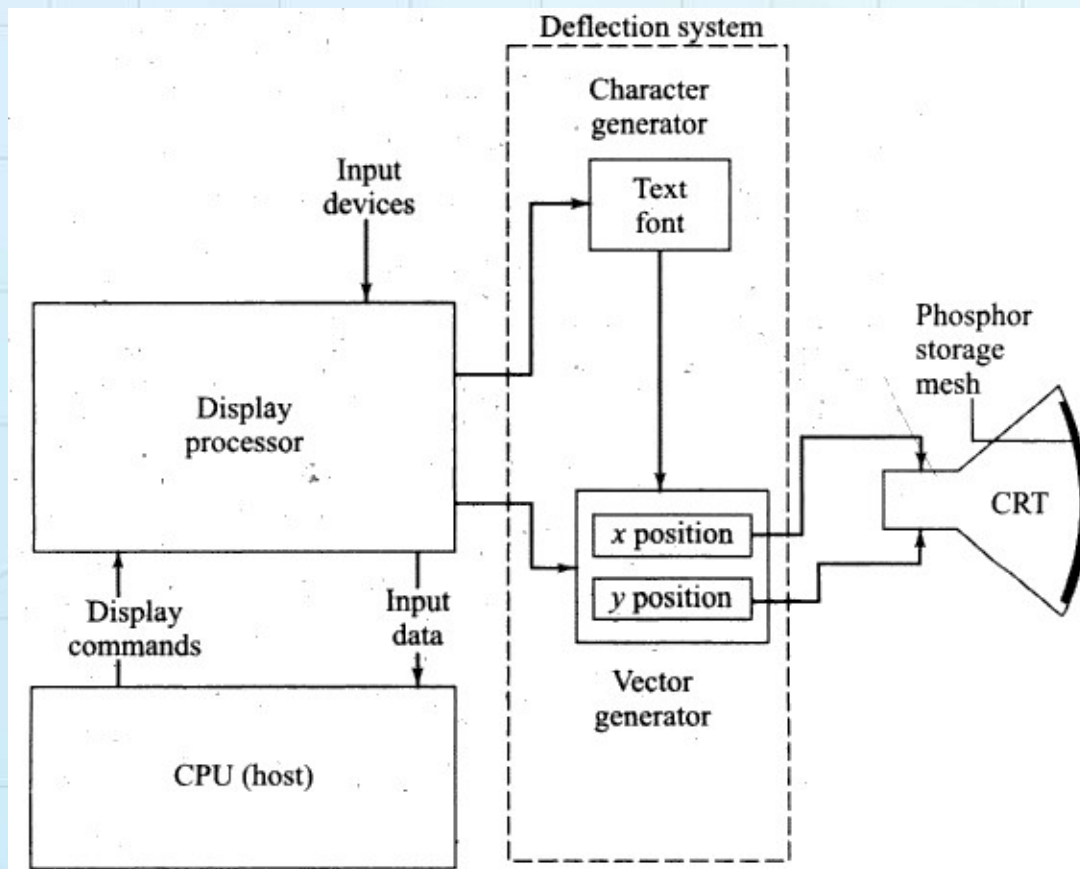


Fig.1.14 – Direct view storage tube

- Refresh displays were very expensive in the 1960s, due to the required refresh buffer memory and fast display processor.
- At the end of 1960s DVST was introduced by Tektronix as an alternative and inexpensive solution.
- It uses a special type of phosphor that has long-lasting glowing effect.
- In the DVST, the picture is stored as a charge in the phosphor mesh located behind the screen's surface. Therefore, complex pictures could be drawn without flicker at high resolution.
- Once displayed, the picture remains on the screen until it is erased. New picture items can be added & displayed rapidly.
- However, if a displayed item is erased, the entire screen must be cleared and new picture displayed to reflect removal of item.

Raster display

- The inability of the DVST to meet the increasing demands by various CAD/CAM applications for colors, shaded images and animation motivated hardware designers to continue searching for solution.
- In raster displays, display screen area is divided horizontally and vertically into a matrix of small element called **pixel**.
- An $N \times M$ resolution defines a screen with N rows and M columns.

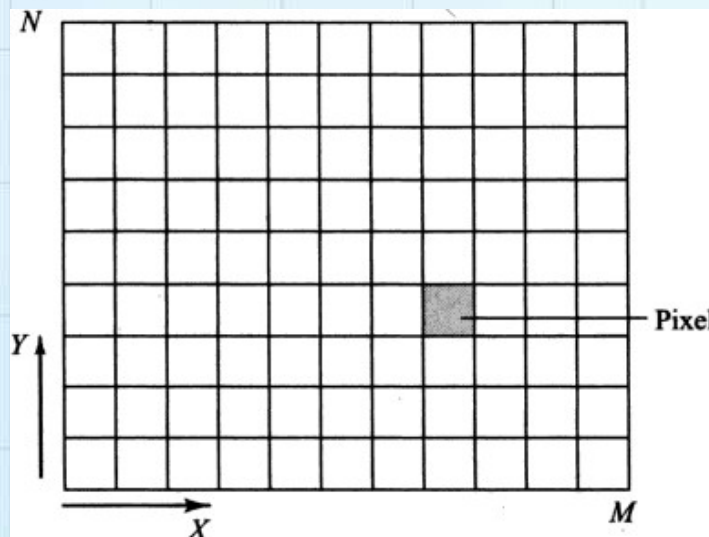


Fig.1.15 – Typical pixel matrix of a raster display

- Images are displayed by converting geometric information into pixel values which are then converted into electron beam deflection through display processors and deflection system.
- The creation of raster-format data from geometric information is known as scan conversion.
- The values of the pixels of a display screen that results from scan-conversion processes are stored in an area or memory called frame buffer or bit map.
- Each pixel value determines its brightness (gray level) or most often its color on the screen.
- 8 bits/pixel are needed to produce satisfactory continuous shades of gray for monochrome display.
- For color displays, 24 bits/pixel would be needed: 8 bits for each primary color red, blue and green.
- This would provide 2^{24} different colors, which are far more than needed in real application.

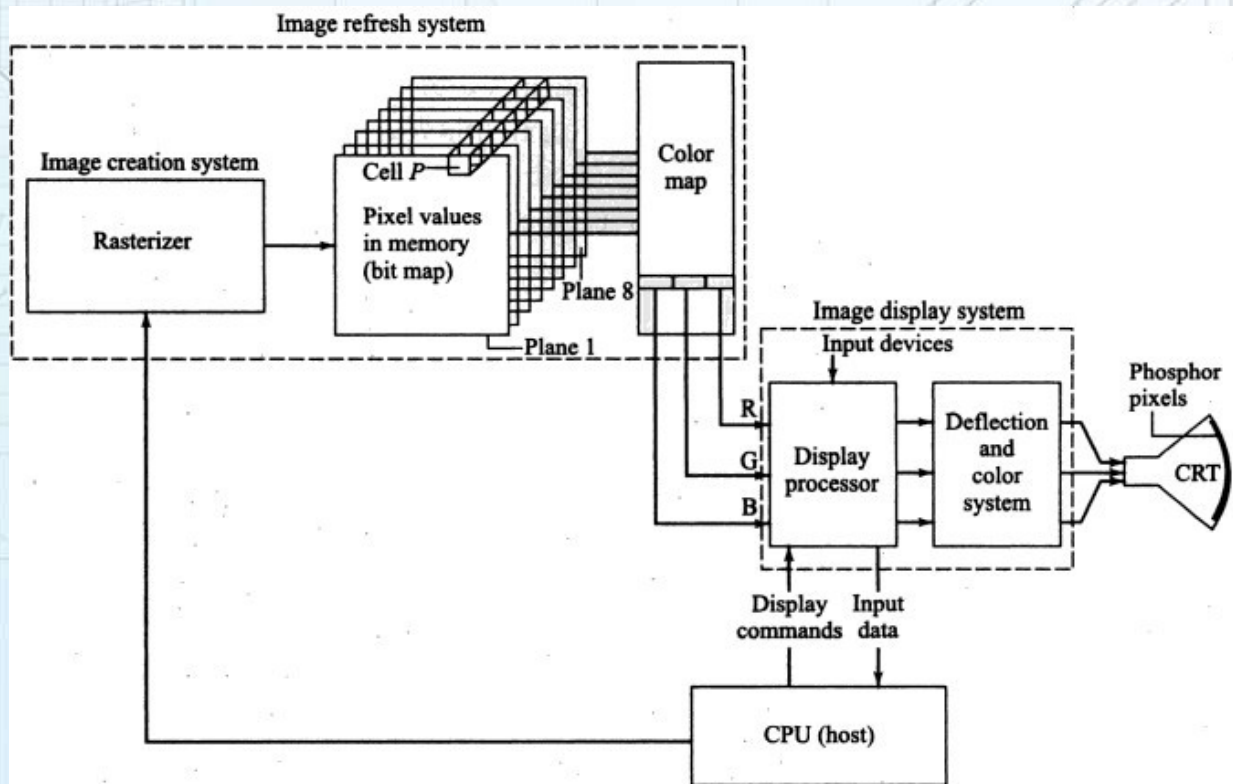


Fig.1.16– Color raster display with eight planes

- The bit map memory is arranged conceptually as a series of planes, one for each bit in the pixel value. Thus an eight-plane memory provides 8 bits/pixel, as shown in Fig.1.16. This provides 2^8 different gray levels or different colors that can be displayed simultaneously in one image. The number of bits per pixel directly affects the quality of its display and consequently its price.
- The value of a pixel in the bit map memory is translated to a gray level or a color through a lookup table (also called a color table or color map for a color display).
- Fig.1.17 shows how the pixel value is related to the lookup table in an eight plane display. If cell P in the bit map corresponds to pixel P at the location P(x, y) on the screen, then the gray level of this pixel is 50 (00110010) or its corresponding color is 50.
- For color displays this may imply that the number of bits per pixel must be increased to increase the number of entries in the color map and therefore increase available number of colors to user.
- This, however, is not true and leads to increasing the size of the bit map memory and the cost of the display. Thus, how can the number of color indexes in the color map increase while keeping the pixel definition (number of bits per pixel) in the bit map to a minimum?
- For example, how can a display have 4 bits/pixel with 24 bits of color output (224 different colors)? This is achieved by designing a color map with 224 (16.7 million) available color indexes. The 4 bits/pixel provides 16 (24 simultaneous colors, in an image, which can be chosen from color map).
- A pixel value (0 to 15) can be used to set the value of the color index which corresponds to the proper color to be displayed. This scheme, in this example, provides 16 simultaneous colors from a palette of 16.7 million.
- To the user, the color map is made available where colors are chosen and the application program relates the chosen color to the proper pixel value. For example, if the user chooses the color purple for an image element, corresponding program sets the corresponding pixels to reflect color purple.

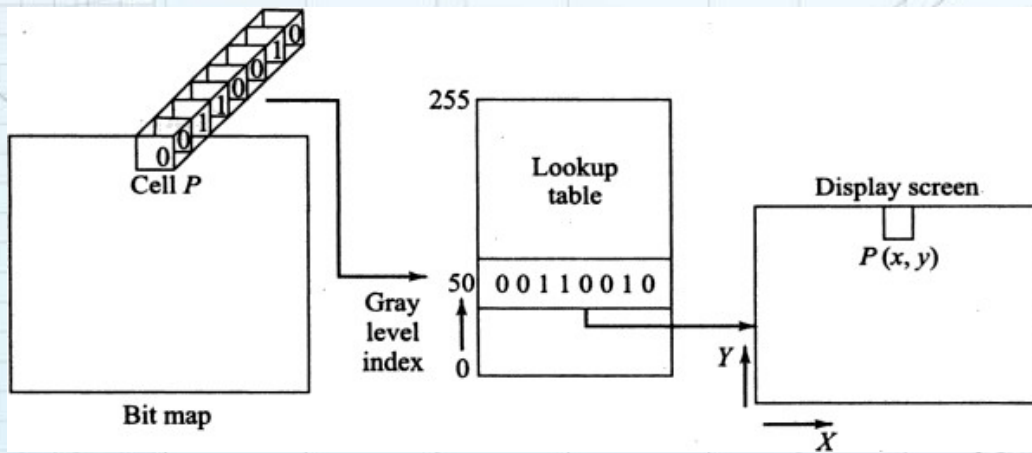


Fig.1.17 – Relationship between pixel value and a lookup table for monochrome display

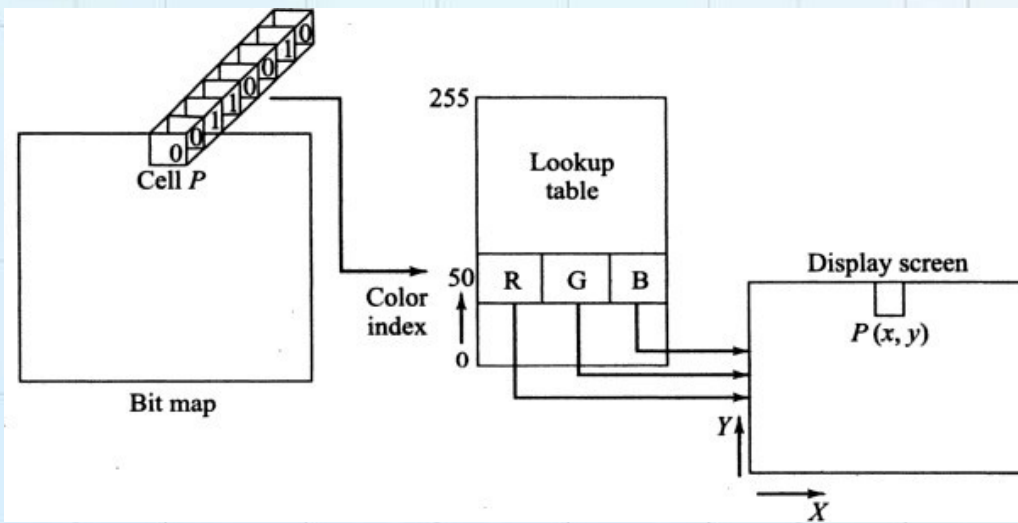


Fig.1.18 – Relationship between pixel value and a lookup table for color display

Light Emitting Diode (LED)

- Light Emitting Diode (LED) is an emissive device. The emissive displays (or emitters) are devices that convert electrical energy into light.
- A matrix of diodes is arranged to form the pixel positions in the display, and picture definition is stored in a refresh buffer.
- As in scan — line refreshing of a CRT, information is read from the refresh buffer and converted to voltage levels that are applied to the diodes to produce the light pattern display.

Liquid Crystal Display (LCD)

- Liquid crystals exist in a state between liquid and solid. The molecules of liquid crystal are all aligned in the same direction, as in a solid, but are free to move around slightly in relation to one another, as in a liquid.
- Liquid crystal is actually closer to a liquid state than a solid state, which is one reason why it is rather sensitive to temperature.
- The array of liquid crystals becomes opaque when the electric field is applied, for displaying the image. Their use as display devices has been made popular by their widespread use in portable calculators and in the laptop or portable computers.

- Their full screen size with reasonably low power consumption has made them suitable for portability. Another advantage is that they occupy very small desktop space while reducing the power consumption.
- The price of these displays is falling rapidly, and are thus becoming popular for desk top applications as well. Also large screen size LCD monitors are available currently at reasonable price.

II. Hardcopy printers and plotters

Output devices of both printers and plotters are available for producing final drawings and documentation on paper.

Pen Plotters

- There are two types of conventional pen plotters flat bed and drum.

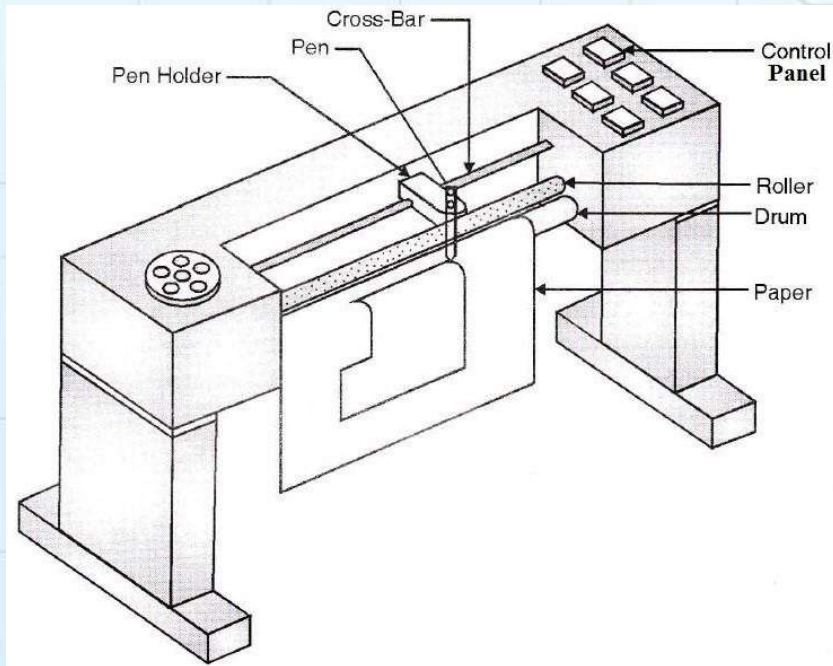


Fig.1.19 – Drum plotter

- In the flat-bed plotter, the paper is stationary and pen holding mechanism can move in two axes.

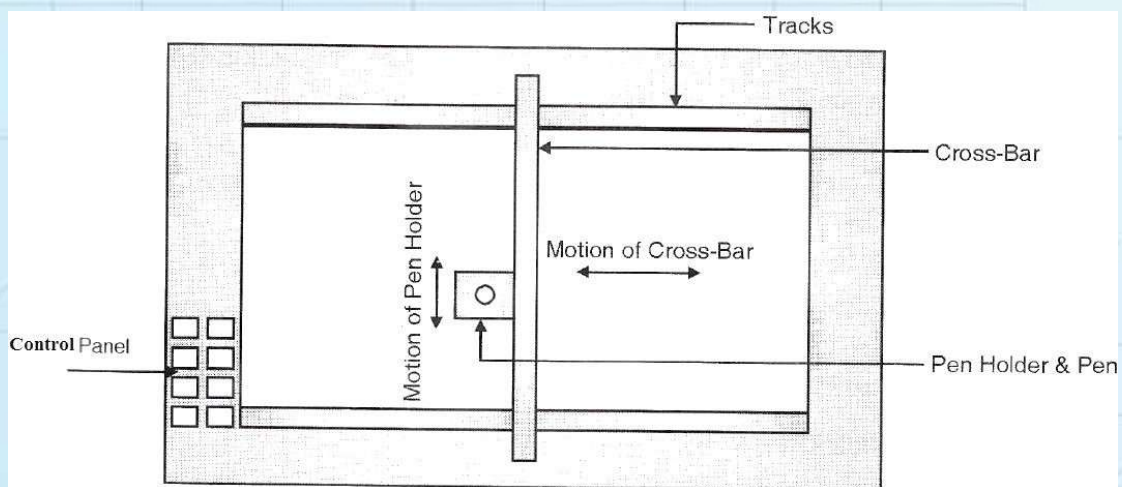


Fig.1.20 – Flat bed plotter

Inkjet plotters

- They utilize dot matrix method of plotting.
- Each dot is, however, created by impelling a tiny jet of ink on the surface of the paper.
- Typical applications include color plots of solid models, shaded images and contour plots.

Black and white printers

- There are major two types of black and white printers are dot matrix and laser printers.
- Dot matrix printers are inexpensive but slow.
- Their resolution is typically 75 dpi.
- Laser printers are more expensive but faster and better than dot matrix printer.
- Their typical resolution is 300 dpi.

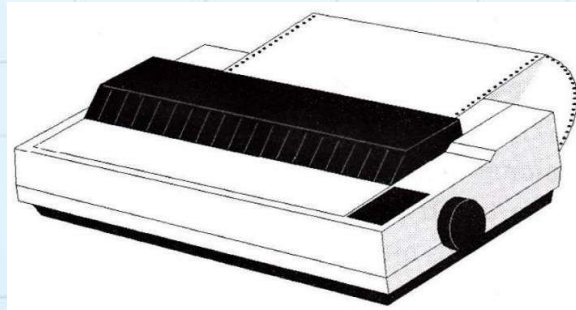


Fig.1.21 – Dot matrix printer

Laser printer

- A semiconductor laser beam scans the electro statically charged drum with a rotating mirror.
- This writes on the drum a no. of points which are similar to pixels.
- When the beam strikes the drum in the wrong way round for printing a positive charge, reversing it, then toner powder is released. The toner powder sticks to the charged positions of the drum, which is then transformed to a sheet of paper.
- Though it is relatively expensive compared to the dot matrix printer, the quality of the output is extremely good and it works very fast.

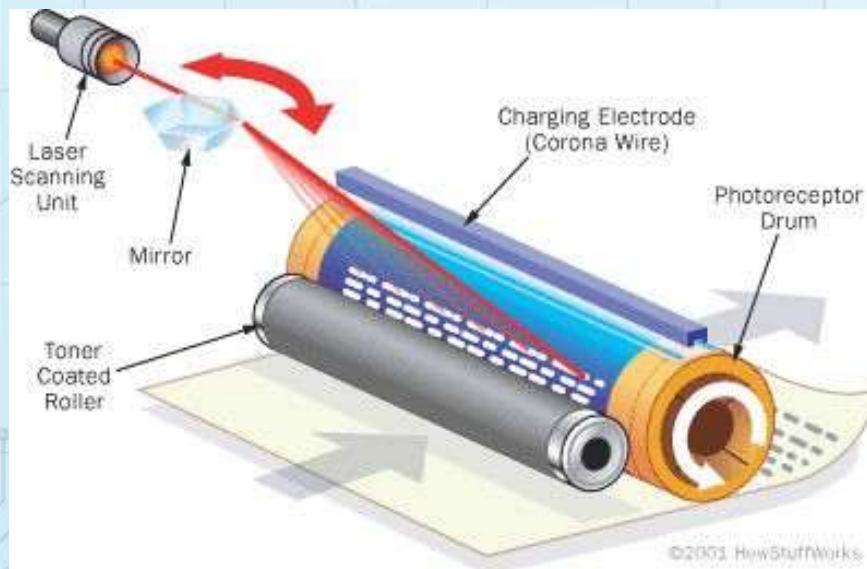


Fig.1.22 – Working of laser printer

1.9 CAD Softwares

- Softwares can be defined as an interpreter or translator which allows the user to perform specific type of application or job related to CAD.
- The user may utilize the software for drafting or designing of machine parts or components subjected to stresses or analysis of any type of system.
- The CAD application software can be prepared in variety of languages such as BASIC (Beginner's All-purpose Symbolic Instruction Code), FORTRAN, Java, PASCAL & C-Language.
- C- Language has been preferred for CAD software development because of no. of advantages as compared to other languages.
- The Java language has the capacity to operate with high level graphics and animation.

1.10 Coordinate Systems

- Three types of coordinate systems are needed to input, store and display model geometry and graphics. They are the world coordinate system (WCS), user coordinate system (UCS) and screen coordinate system (SCS).

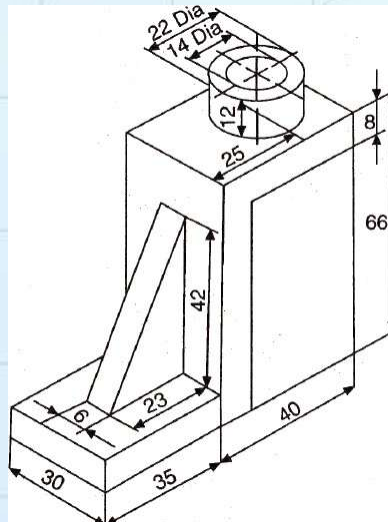


Fig.1.23 – Typical component to model

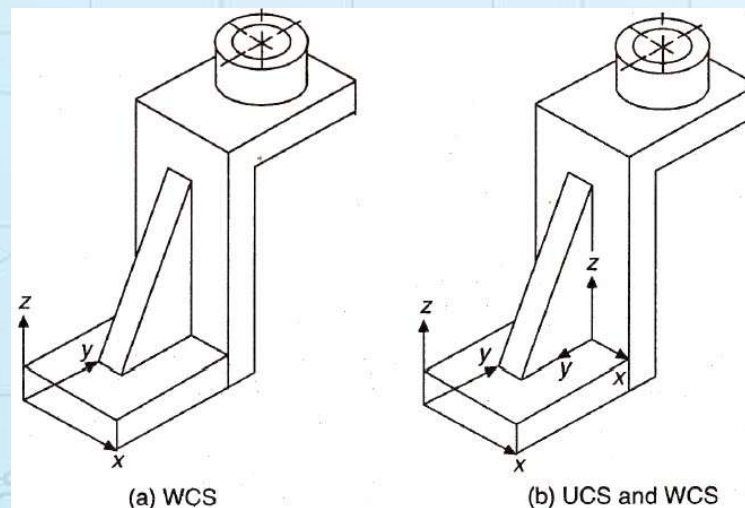


Fig.1.24 – Coordinate systems

(i) World Coordinate System (WCS)

- The world coordinate system is the reference space of the model with respect to which all the model geometrical data is stored. *Fig. 1.23* shows a typical model, which is to be modelled.
- *Fig. 1.24 (a)* illustrates the model with its associated world coordinate system x , y , and z . It is also called the **model coordinate system**. It is the default coordinate system.
- The WCS is the only coordinate system that the software recognises when storing or retrieving geometrical information.

(ii) User Coordinate System (UCS)

- If the model has complex geometry the desired feature of construction can be easily defined with respect to the world coordinate system.
- It is often convenient in the development of geometric models and the input of data with respect to an auxiliary coordinate system instead of WCS.
- The user can define a Cartesian coordinate system whose xy plane is coincident with the desired plane of construction. This coordinate system is called the user coordinate system.
- The UCS can be positioned at any position and orientation in the space that the user desires. The user coordinate system is shown in *Fig. 1.24(b)*.

(iii) Screen Coordinate System (SCS)

- The screen coordinate system is a two-dimensional Cartesian coordinate system whose origin is located at the lower left corner of the graphics display (*Fig. 1.25*). It is a device-dependent coordinate system.
- For raster graphics displays, the pixel grid is the screen coordinate system. A 1024 x 1024 display as a range of (0, 0) to (1024, 1024). The centre of the screen is at (512, 512).
- The SCS is used to display graphics by converting from WCS coordinates to SCS coordinates. The transformation from WCS coordinates to SCS coordinates is performed by the software before displaying the model views and graphics.

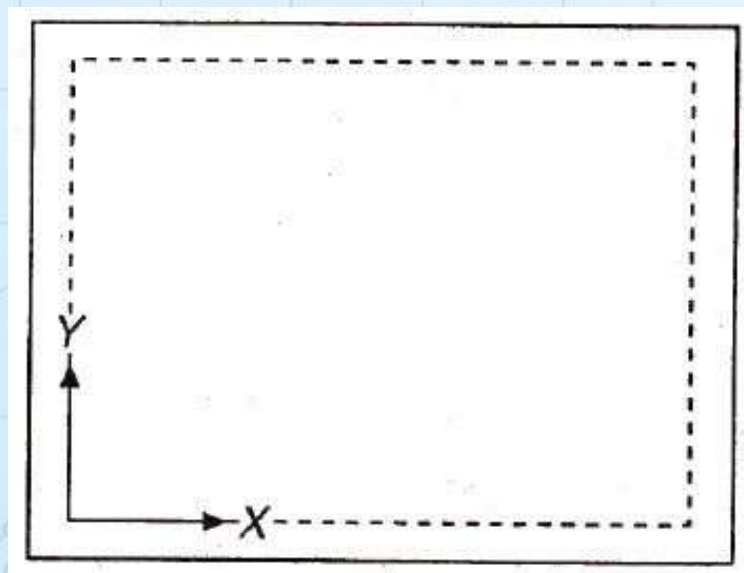


Fig. 1.25 – Screen coordinate system.

1.11 DDA (Digital Differential Analyser) Line Algorithm

- DDA is one of the first algorithms developed for rasterizing the vectorial information. The equation of a straight line is given by Eq. (1.1)

$$Y = mX + C \quad \text{Eq. (1.1)}$$

- Using this equation for direct computing of the pixel positions involves a large amount of computational effort.
- Hence it is necessary to simplify the procedure of calculating the individual pixel positions by a simple algorithm.
- For this purpose consider drawing a line on the screen as shown in Fig.1.26, from (x_1, y_1) to (x_2, y_2) ,

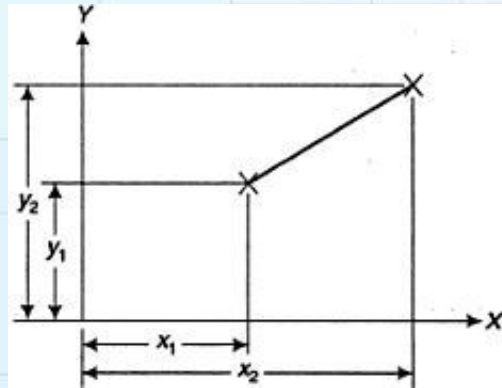


Fig.1.26 – A straight line drawing by DDA algorithm

$$\text{Eq. (1.2)}$$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$C = y_1 - mx_1 \quad \text{Eq. (1.3)}$$

- The line drawing method would have to make use of the above three equations in order to develop a suitable algorithm.

- Eq. (1.1), for small increments can also be written as,

$$\Delta Y = m\Delta X \quad \text{Eq. (1.4)}$$

- By taking a small step for ΔX , ΔY can be computed using Eq. (1.4). However, the computations become unnecessarily long for arbitrary values of ΔX . Let us now work out a procedure to simplify the calculation method.

- Let us consider a case of line drawing where $m \leq 1$. Choose an increment for ΔX as unit pixel. Hence $\Delta X = 1$.

- Then from Eq. (1.4),

$$y_{i+1} = y_i + m \quad \text{Eq. (1.5)}$$

- The subscript i takes the values starting from 1 for the starting point till the end point is reached.
- Hence it is possible to calculate the total pixel positions for completely drawing the line on the display screen. This is called DDA (Digital Differential Analyser) algorithm.
- If $m > 1$, then the roles of x and y would have to be reversed.
- Choose $\Delta Y = 1$

Then from Eq. (1.4), we get

$$x_{i+1} = x_i + \frac{1}{m} \quad \text{Eq. (1.6)}$$

- The following is the flow chart showing the complete process for the implementation of the above procedure.

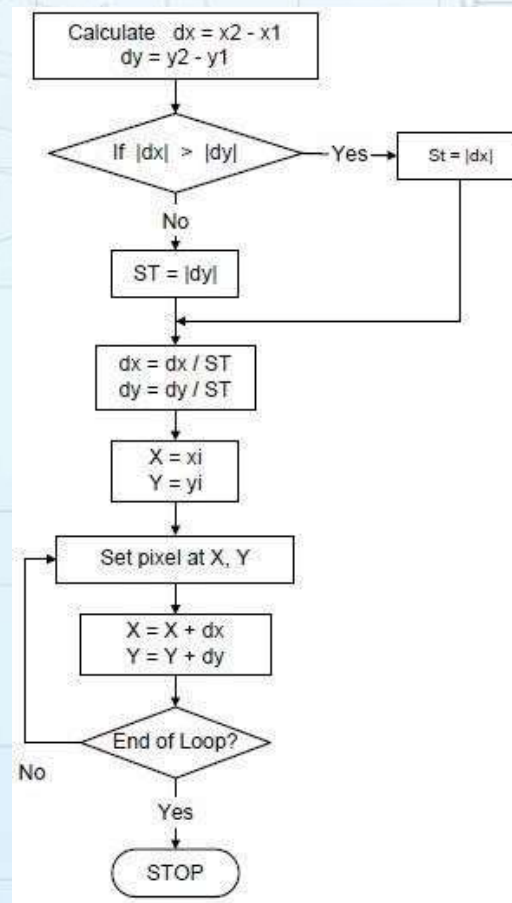


Fig.1.27 – Flow chart for line calculation procedure by DDA algorithm

Solution:

$$\begin{aligned}
 m &= \frac{\Delta Y}{\Delta X} \\
 &= \frac{y_2 - y_1}{x_2 - x_1} \\
 &= \frac{52 - 38}{38 - 19} \\
 &= \frac{14}{19} \\
 &= 0.737
 \end{aligned}$$

So, $m \leq 1$

$$\Delta x = 1 \quad \text{and} \quad y_{i+1} = y_i + m$$

Table 1.1 - Calculation of pixel positions by DDA algorithm

X	Y Calculated	Y Rounded
19	38	38
20	38.737	39
21	39.474	39
22	40.211	40
23	40.948	41
24	41.685	42
25	42.422	42
26	43.159	43
27	43.896	44
28	44.633	45
29	45.370	45
30	46.107	46
31	46.844	47
32	47.581	48
33	48.318	48
34	49.055	49
35	49.792	50
36	50.529	51
37	51.266	51
38	52.003	52

1.12 Bresenham's Line Algorithm

- The above DDA algorithm is certainly an improvement over the direct use of the line equation since it eliminates many of the complicated calculations.
- However, still it requires some amount of floating point arithmetic for each of the pixel positions.
- This is still more expensive in terms of the total computation time since a large number of points need to be calculated for each of the line segments as shown in Example 1.1.

- Bresenham's method is an improvement over DDA since it completely eliminates the floating point arithmetic except for the initial computations. All other computations are fully integer arithmetic and hence it is more efficient for raster conversion.
- As for the DDA algorithm, start from the same line equation and the same parameters. The basic argument for positioning the pixel here is the amount of deviation by which the calculated position is from the actual position obtained by the line equation in terms of d_1 and d_2 as shown in Fig.1.28.
- Let the current position be (X_i, Y_i) at the i^{th} position as shown in Fig.1.28. Each of the circles in Fig.1.28 represents the pixels in the successive positions.

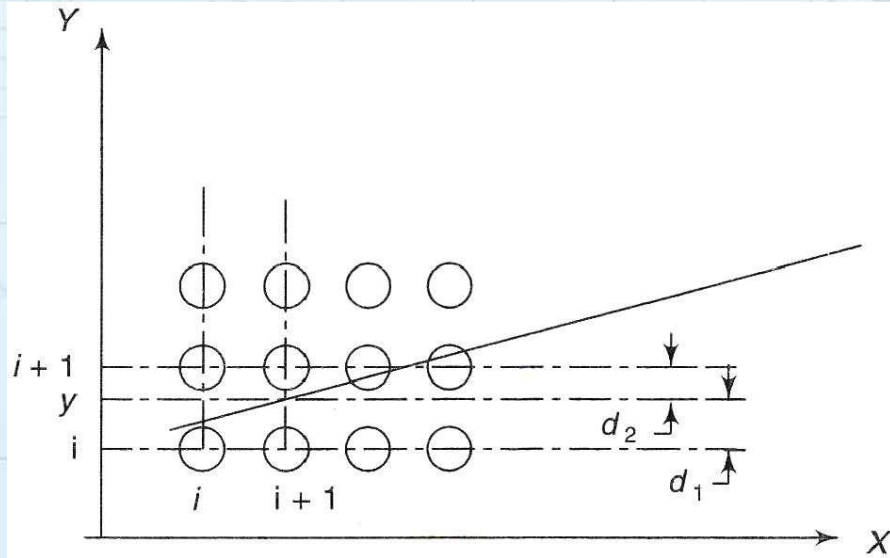


Fig.1.28 – Position of individual pixels for calculation using Bresenham procedure

Then

$$x_{i+1} = x_i + 1 \quad \text{Eq. (1.7)}$$

$$y_i = mx_i + C \quad \text{Eq. (1.8)}$$

$$y = m(x_i + 1) + C \quad \text{Eq. (1.9)}$$

- These are shown in Fig.1.28. Let d_1 and d_2 be two parameters, which indicate where the next pixel is to be located. If d_1 is greater than d_2 , then the y pixel is to be located at the +1 position else, it remains at the same position as previous location.

$$d_1 = y - y_i = m(x_i + 1) + C - y_i \quad \text{Eq. (1.10)}$$

$$d_2 = y_{i+1} - y = y_{i+1} - m(x_i + 1) - C \quad \text{Eq. (1.11)}$$

From Eq. (1.10) and Eq. (1.11)

$$d_1 - d_2 = m(x_i + 1) + C - y_i - y_{i+1} + m(x_i + 1) + C \quad \text{Eq. (1.12)}$$

$$d_1 - d_2 = 2m(x_i + 1) + 2C - 2y_i - 1 \quad \text{Eq. (1.13)}$$

- Eq. (1.13) still contains more computations and hence we would now define another parameter P which would define the relative position in terms of $d_1 - d_2$.

$$P_i = (d_1 - d_2)\Delta x \quad \text{Eq. (1.14)}$$

$$= \{2m(x_i + 1) + 2C - 2y_i - 1\}\Delta x$$

$$= 2mx_i\Delta x + 2m\Delta x + 2C\Delta x - 2y_i\Delta x - \Delta x$$

$$= 2 \frac{\Delta y}{\Delta x} x_i \Delta x + 2 \frac{\Delta y}{\Delta x} \Delta x + 2C \Delta x - 2y_i \Delta x - \Delta x \quad (\because m = \frac{\Delta y}{\Delta x})$$

$$P_i = 2x_i \Delta y + 2\Delta y + 2C \Delta x - 2y_i \Delta x - \Delta x \quad \text{Eq. (1.15)}$$

$$P_i = 2x_i \Delta y - 2y_i \Delta x + b \quad \text{Eq. (1.16)}$$

Where, $b = 2\Delta y + 2C \Delta x - \Delta x$

- Similarly, we can write,

$$P_{i+1} = 2\Delta y(x_i + 1) - 2\Delta x y_{i+1} + b \quad \text{Eq. (1.17)}$$

- Taking the difference of two successive parameters, we can eliminate the constant terms from Eq. (1.17).

$$P_{i+1} - P_i = 2\Delta y x_i + 2\Delta y - 2\Delta x y_{i+1} - 2\Delta y x_i - 2\Delta x y_i$$

$$P_{i+1} - P_i = 2\Delta y - 2\Delta x(y_{i+1} - y_i) \quad \text{Eq. (1.18)}$$

- The same can also be written as

$$P_{i+1} = P_i + 2\Delta y - 2\Delta x(y_{i+1} - y_i) \quad \text{Eq. (1.19)}$$

- The same can also be written as

$$P_{i+1} = P_i + 2\Delta y \quad \text{when } y_{i+1} = y_i \quad \text{Eq. (1.20)}$$

$$P_{i+1} = P_i + 2\Delta y - 2\Delta x \quad \text{when } y_{i+1} = y_i + 1 \quad \text{Eq. (1.21)}$$

- From the start point (x_1, y_1)

$$y_1 = mx_1 + C$$

$$C = y_1 - \frac{\Delta y}{\Delta x} x_1$$

- Substituting this in Eq. (1.15) and simplifying, we get

$$P_1 = 2x_1 \Delta y + 2\Delta y + 2 \left(y_1 - \frac{\Delta y}{\Delta x} x_1 \right) \Delta x - 2y_1 \Delta x - \Delta x$$

$$P_1 = 2x_1 \Delta y + 2\Delta y + 2y_1 \Delta x - 2x_1 \Delta y - 2y_1 \Delta x - \Delta x$$

$$P_1 = 2\Delta y - \Delta x \quad \text{Eq. (1.22)}$$

- Hence from Eq. (1.18), when P_i is negative, then the next pixel location remains the same as previous one and Eq. (1.20) becomes valid. Otherwise, Eq. (1.21) becomes valid.
- Using these equations it is now possible to develop the algorithm for drawing the line on the screen as shown in the flowchart (Fig. 1.29). The procedure just described is for the case when $m \leq 1$.
- The procedure can be repeated for the case when $m > 1$ by interchanging X and Y similar to the DDA algorithm.

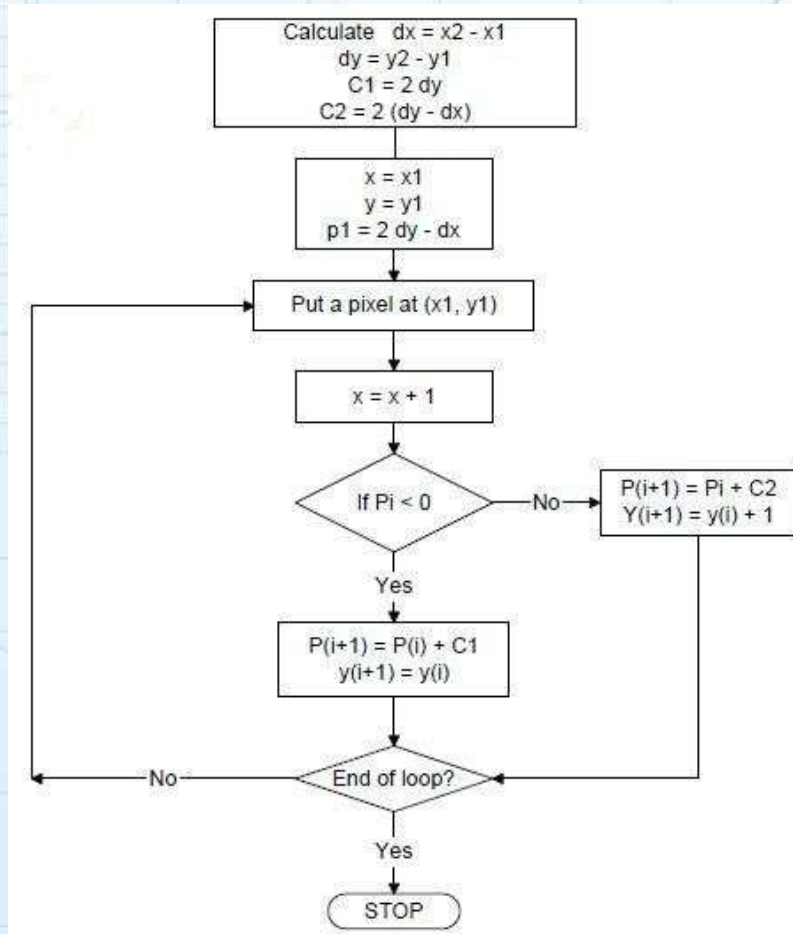


Fig.1.29 – Flow chart for line calculation procedure by Bresenham algorithm

Solution:

$$\begin{aligned}
 m &= \frac{\Delta Y}{\Delta X} \\
 &= \frac{y_2 - y_1}{x_2 - x_1} \\
 &= \frac{52 - 38}{38 - 19} \\
 &= \frac{14}{19} \\
 &= 0.737
 \end{aligned}$$

Table 1.2 - Calculation of pixel positions by Bresenham's procedure

X	P	Y
19	$P_1 = 2\Delta y - \Delta x = 28 - 19 = 9$	38
20	$P_2 = P_1 + 2\Delta y - 2\Delta x = 9 + 28 - 38 = -1$	39
21	$P_3 = P_2 + 2\Delta y = -1 + 28 = 27$	39
22	$P_4 = P_3 + 2\Delta y - 2\Delta x = 27 + 28 - 38 = 17$	40
23	$P_5 = P_4 + 2\Delta y - 2\Delta x = 17 + 28 - 38 = 7$	41
24	$P_6 = P_5 + 2\Delta y - 2\Delta x = 7 + 28 - 38 = -3$	42
25	$P_7 = P_6 + 2\Delta y = -3 + 28 = 25$	42
26	$P_8 = P_7 + 2\Delta y - 2\Delta x = 25 + 28 - 38 = 15$	43
27	$P_9 = P_8 + 2\Delta y - 2\Delta x = 15 + 28 - 38 = 5$	44
28	$P_{10} = P_9 + 2\Delta y - 2\Delta x = 5 + 28 - 38 = -5$	45
29	$P_{11} = P_{10} + 2\Delta y = -5 + 28 = 23$	45
30	$P_{12} = P_{10} + 2\Delta y - 2\Delta x = 23 + 28 - 38 = 13$	46
31	$P_{13} = P_{12} + 2\Delta y - 2\Delta x = 13 + 28 - 38 = 3$	47
32	$P_{14} = P_{13} + 2\Delta y - 2\Delta x = 3 + 28 - 38 = -7$	48
33	$P_{15} = P_{14} + 2\Delta y = -7 + 28 = 21$	48
34	$P_{16} = P_{15} + 2\Delta y - 2\Delta x = 21 + 28 - 38 = 11$	49
35	$P_{17} = P_{16} + 2\Delta y - 2\Delta x = 11 + 28 - 38 = 1$	50
36	$P_{18} = P_{17} + 2\Delta y - 2\Delta x = 1 + 28 - 38 = -9$	51
37	$P_{19} = P_{18} + 2\Delta y = -9 + 28 = 19$	51
38	$P_{20} = P_{19} + 2\Delta y - 2\Delta x = 19 + 28 - 38 = 9$	52

1.13 Database Management System (DBMS)

A DBMS is defined as the software that allows access to use and/or modify data stored in a database. The DBMS forms a layer of software between the physical database itself (i.e., stored data) and the users of this database as shown in *Fig.1.30(a)*.

DBMS shields users from having to deal with hardware-level details by interpreting their input commands and requests from the database. For example, a command such as retrieve a line could involve few lower-level steps to execute.

In general, a DBMS is responsible for all database-related activities such as creating files, checking for illegal users of the database and synchronizing user access to the database.

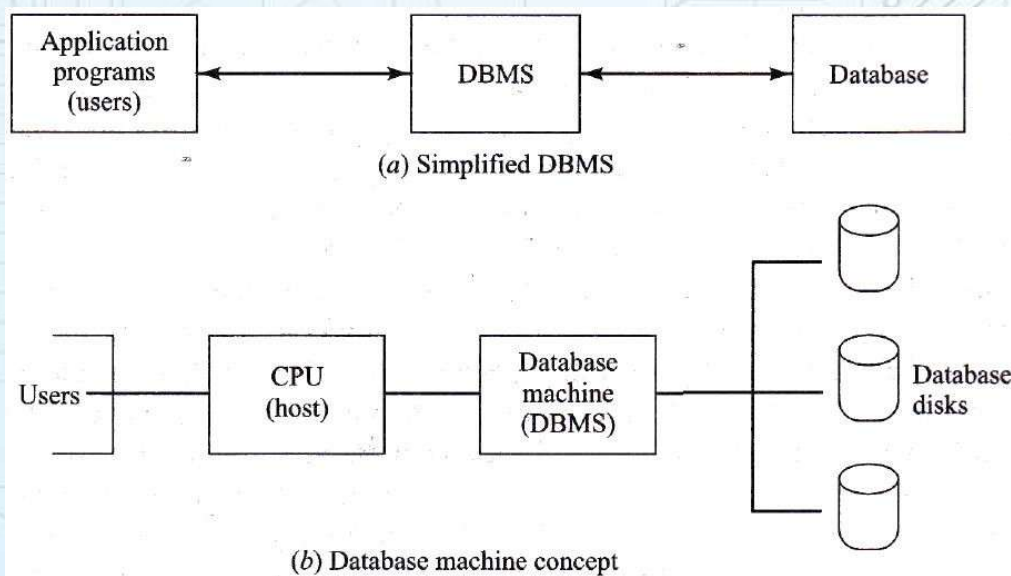


Fig.1.30 – A typical DBMS

DBMSs designed for commercial business systems are too slow for CAD/ CAM. The handling of graphics data is an area where the conventional DBMSs tend to break down under the shear volume of data and the demand for quick display.

By contrast, data handled in the commercial realm is mostly alphanumeric and the objects described are usually not very complex. A DBMS is directly related to the database model it is supposed to manage. For example, relational DBMSs require relatively large amounts of CPU time for searching and sorting data stored in the relations or tables.

Therefore, the concept of database machines exists where a DBMS is implemented into hardware that can lie between the CPU of a computer and its database disks, as shown in Fig.1.30(b).

1.14 Graphics Exchange Standards

- With the proliferation of computers and software in the market, it became necessary to standardize certain elements at each stage, so that investment made by companies in certain hardware or software was not totally lost and could be used without much modification on the newer and different systems.
- Standardization in engineering hardware is well known. Further, it is possible to obtain hardware and software from a number of vendors and then be integrated into a single system.
- This means that there should be compatibility between various software elements as also between the hardware and software. This is achieved by maintaining proper interface standards at various levels.

Both CAD/CAM vendors as well as users identified some needs to have some graphics standards. The needs are as follows:

- Software portability:** This avoids hardware dependence of the software. If the program is written originally for random scan display, when the display device is changed to raster scan display the program should work with minimum effort.

- ii. **Image data portability:** Information and storage of images should be independent of different graphics devices.
- iii. **Text data portability:** The text associated with graphics should be independent of different input/output devices.
- iv. **Model database portability:** Transporting of design and manufacturing data from one application software to another should be simple and economical.

The search for standards began in 1974 to fulfill the above needs both at the USA and International levels. As a result of worldwide efforts, various standards at different levels of the graphics systems were developed. The standards are as follows:

1. **GKS (Graphics kernel system):** It is an ANSI (American National Standards Institute) and ISO (International Standards Organization) standard. It interfaces the application program with graphics support package.
2. **IGES (Initial graphics exchange specification):** It is an ANSI standard. It enables an exchange of model database among CAD/CAM software.
3. **PHIGS (Programmer's hierarchical interactive graphics system):** It supports workstations and their related CAD/CAM applications. It supports 3-dimensional modeling of geometry segmentation and dynamic display.
4. **CGM (Computer graphics metafile):** It defines functions needed to describe an image. Such description can be stored or transported from one graphics device to another.
5. **CGII (Computer graphics interface):** It is designed to interface plotters to GKS or PHIGS. It is the lowest device independent interface in a graphics system.
6. **Drawing Exchange Format (DXF):** The DXF format has been developed and supported by Autodesk for use with the AutoCAD drawing files. It is not an industry standard developed by any standards organisation, but in view of the widespread use of AutoCAD made it a default standard for use of a variety of CAD/CAM vendors. A Drawing Interchange File is simply an ASCII text file with a file extension of .DXF and specially formatted text.
7. **Standard for the Exchange of Product Model Data (STEP),** officially the ISO standard 10303, Product Data Representation and Exchange, is a series of International Standards with the goal of defining data across the full engineering and manufacturing life cycle. The ability to share data across applications, across vendor platforms and between contractors, suppliers and customers, is the main goal of this standard.
8. **Parasolid:** It is a portable "kernel" that can be used in multiple systems - both high-end and mid-range. By adopting Parasolid, start-up software companies have eliminated a major barrier to application development - a high initial investment. This enabled them to effectively market softwares with strong solid modeling functionality at lower-cost.
9. **PDES (Product Data Exchange Specification)** is an exchange for product data in support of industrial automation. "Product data" encompasses data relevant to the entire life cycle of a product such as design, manufacturing, quality assurance, testing and support. In order to support industrial automation, PDES files are fully interpretable by computer. For example, tolerance information would be carried in a form directly interpretable by a computer rather than a computerized text form which requires human intervention to interpret.

1.14.1 Initial Graphics Exchange Specification (IGES) Graphics Standard

The IGES committee was established in the year 1979. The CAD/CAM Integrated Information Network (CIIN) of Boeing served as the preliminary basis of IGES. IGES version 1.0 was released in 1980, version 2.0 in 1983 and version 3.0 in 1986. IGES continues to undergo revisions and a brief revision history is given in *Table 1.3*.

Table 1.3 - Revision history of IGES

Version	Year	Features
1.0	1980	Mechanical 2-D and 3-D drawings
2.0	1983	Sculpture surfaces, Rational B-splines Finite elements
3.0	1986	AEC, Piping etc
4.0	1988	Constructive solid geometry
3.0	1990	Rationalization of existing formats
6.0	1991	B-REP solids

A number of vendors have implemented IGES. They include Applicon, Autotrol, CADAM, Calcomp, Calma, Computervision, Control Data, Gerber, IBM, Intergraph, McAuto, Prime, Summagraphics, Tektronix and T & W systems.

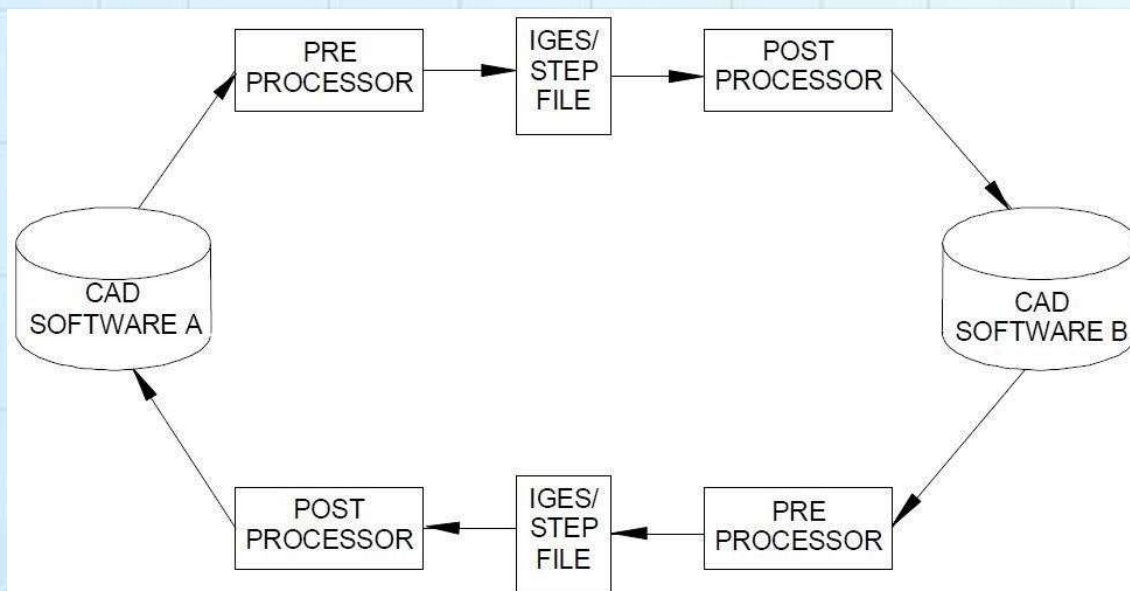


Fig.1.31 – CAD data transfer using IGES

As mentioned earlier, IGES enables data transfer from one CAD system to another. This is shown in *Fig.1.31*. Software which translates data from CAD system to IGES is called pre-processor. Software which translates IGES data to a CAD system is called postprocessor.

Like most CAD systems IGES is based on the concept of entities which range from simple geometric objects such, as points, lines and circles, to more sophisticated items like dimensions and sculptured surfaces.

Entities in IGES are divided into three categories:

(a). Geometry - lines, circles, surfaces etc. that define an object (b).

Annotation - dimension, notes, title block

(c). Structure - Ways in which CAD systems combine other entities to make Description of object is easier (BLOCK, CELL or DITTO in CAD systems).

IGES files are divided into six sections:

- 1. Flag section:** This is the optional section. It is not output by the postprocessor and is found only in compressed ASCII files, never in fixed length ASCII files. It is identified by a "C" in column 73, indicating that the file is in compressed ASCII format. This section contains information that will be required, by a postprocessor. A postprocessor is a program such as IGESIN. It translates a file from IGES format to the database form of a specific CAD.
- 2. Start section:** An "S" in column 73 identifies this section. It contains comments that you can use to describe the drawing, identify its source, comment on its format, and so forth.
- 3. Global section:** A "G" in column 73 identifies this section. It contains a series of values that describe global characteristics of the IGES file, such as the name of the file, the system that created the file, the parameter and record delimiters, units of measure and precision.
- 4. Directory Entry section:** A "D" in column 73 identifies this section. It describes all the entities in the drawing. There is one entry for each entity in the file; each entry consists of two lines organized into 20 eight-character fixed-format fields. This section contains attributes such as color, view, line style, pointers to transformation matrices, pointers to parameter data for the entities, and so on. This section also provides an index to the entities in the file. IGES entities are identified by their type number (fields 1 and 11) and a form number (Field 15).
- 5. Parameter Data section:** A "P" in column 73 identifies this section. It contains the data to describe each entity, such as point coordinates, coefficients of curve and surface equations, pointers to other entities, text characters, and other attributes. The kind of data found in the PD section is different for each entity type. This section contains at least one record for each entity in the file. It contains a combination of real numbers, integers, and text.
- 6. Terminate section:** A "T" in column 73 identifies this section. This section is a single record organized into ten 8-character fields. The first four fields contain the sequence number of the last line from each of the four preceding sections. The next five fields are unused, and the last field is the sequence number of the terminate section itself; this record must always have a sequence number of 1.

1.15 References

- 1) CAD/CAM Principles and Applications by P. N. Rao, Tata McGraw-Hill Publication.
- 2) Mastering CAD/CAM by Zeid, Ibrahim, Tata McGraw-Hill Publication.
- 3) CAD/CAM/CIM by Radhakrishnan, P.; Subramanyan, S.; Raju, V, New Age International (P) Limited.
- 4) CAD/CAM: Theory and Practice by Zeid, Ibrahim, Subramanian, R, Tata McGraw-Hill Publication.