Computer Graphics

Introduction to Computer Graphics -

The term graphics refers to images i.e. – drawing, photograph etc.
Photograph is an image created by collecting and focusing electromagnetic radiations.

The word image is derived from Latin word *imago* or picture is an artefact that reproduces the likeness of some subject. Image may be 2D or 3D.

Types of Image -

1. **Volatile Image** – Image Which exists for a short period of time i.e. – image on mobile or any display screen.
2. **Non-Volatile / Fixed Image** – Those Images that has been recorded on a material object. i.e. image on paper or flex.
3. **Mental Image** – Those images which exists in someone's mind i.e. - something one remembers or imagines.

**Digital photos can be stored in various file formats

- JPEG (Joint Photographic Experts Group)
- TIFF (Tagged image file format)
- PNG (Portable Network Graphics)
- GIF (Graphics Interchanged Formats)

**Till 1960's Mostly photograph are taken in black and white format.

Computer Graphics: Computer graphics is the field of study and practice that involves creating, manipulating, and displaying visual representations of information using computers.

It encompasses the use of algorithms, mathematics, and computer technology to generate, modify, and interact with images, animations, and graphical content in various forms, including 2D and 3D graphics, text, and multimedia.

The primary goal of computer graphics is to accurately and effectively convey information or create aesthetic visual experiences through digital means.

History of Computer Graphics:

- **1950s and 1960s: Early Beginnings**
  - Researchers like Ivan Sutherland create early graphical displays like the "Sketchpad."

  - First graphics software for creating simple drawings and geometric shapes.

- **1970s: Emergence of 2D Graphics**
  - Introduction of cathode-ray tube (CRT) displays enables real-time graphics.
  - Development of BASIC programming language and early graphics libraries.
  - Xerox PARC creates the Alto computer with GUI elements like icons and windows.

- **1980s: Advancements in Hardware and Software**
  - Introduction of bitmap displays and graphics cards.
  - Apple's Macintosh introduces user-friendly GUI and popularizes graphical interfaces.
  - Pixar pioneers computer-generated imagery (CGI) in films with "Luxo Jr."

- **1990s: Rise of 3D Graphics and Video Games**
  - Advancements in 3D rendering techniques and hardware acceleration.
  - Video game industry drives demand for real-time 3D graphics.
  - Virtual Reality Markup Language (VRML) attempts to create 3D web content.

- **2000s: Realism and Interactive Graphics**
  - Graphics hardware becomes more powerful, enabling more realistic rendering.
  - Shaders revolutionize how light and materials are simulated in real-time graphics.
  - Introduction of WebGL brings 3D graphics to web browsers.

- **2010s: VR, AR, and Global Impact**

- ◆ Virtual Reality (VR) and Augmented Reality (AR) gain traction, transforming various industries.
- ◆ Ray tracing technology becomes more accessible for better visual realism.
- ◆ Deep learning and AI techniques contribute to image synthesis and manipulation.

■ **Present and Beyond: Immersive Experiences**

- ◆ Continued advancements in real-time rendering, ray tracing, and AI-driven graphics.
- ◆ Emphasis on creating immersive experiences in entertainment, education, and more.
- ◆ Ongoing integration of computer graphics with other technologies like machine learning.

Broad Classifications of Computer Graphics:

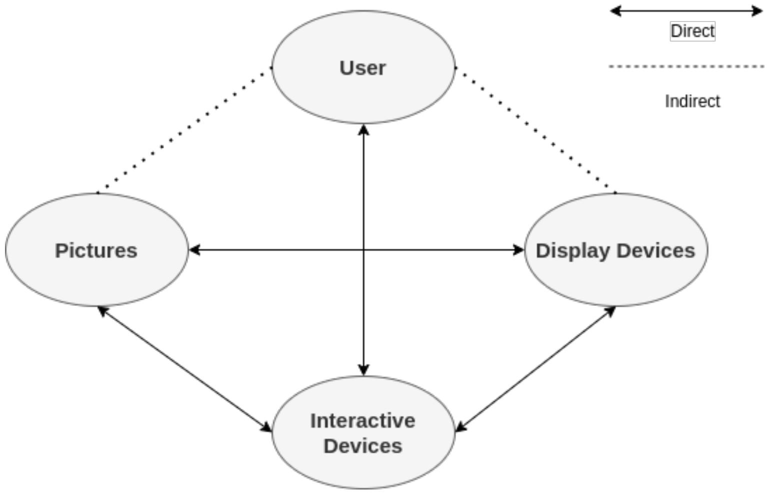
➔ **Non-Interactive (Passive) Computer Graphics**: In non-interactive computer graphics, the picture is produced on the monitor, and the user does not have any controlled over the image, i.e., the user cannot make any change in the rendered image. One example of its Titles shown on T.V.

Non-interactive Graphics involves only one-way communication between the computer and the user, User can see the produced image, and he cannot make any change in the image.

➔ **Interactive (Active) computer graphics:** In interactive Computer Graphics user have some controls over the picture, i.e., the user can make any change in the produced image. One example of it is the ping-pong game.

Interactive Computer Graphics require two-way communication between the computer and the user. A User can see the image and make any change by sending his command with an input device.

Computer Graphics



Advantages:

- Higher Quality.
- More precise results and products.
- Greater productivity.
- Lower analysis and Design cost.
- Significantly enhances our ability to understand data and to perceive trends.

Architecture of Interactive Computer Graphics -

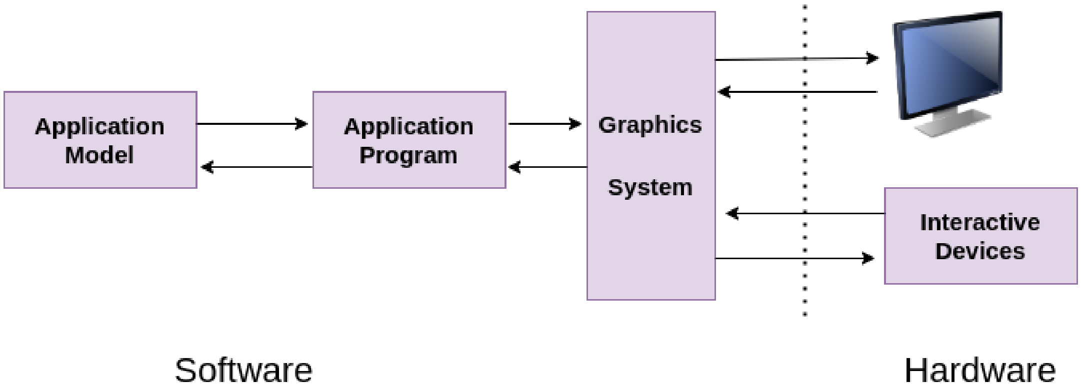
Interactive computer graphics has major two components

a) Software level
   - Application Model
   - Application Program
   - Graphics system

b) Hardware level
   - Interactive Devices
   - Display Devices

Working of Interactive computer Graphics:

Computer Graphics



At hardware level, the computer receives input from interactive devices and show images on display devices.

At software level there are three components – Application program, Application model and Graphic system. Application program creates, stores, retrieves picture from the second component application model. Application model represents the data or object to be pictured on the screen. Graphics system is a series of graphics commands that contain both – who is to be viewed and how is to be viewed?

Computer Graphics encompasses several key areas, that includes:

- **Rendering**: Rendering involves the process of converting 3D models or scenes into 2D images, simulating lighting, shading, and other visual effects to create realistic or stylized representations.
- **Modeling**: Modeling entails the creation of 3D objects or scenes using various techniques, such as polygonal modeling, spline-based modeling, and more recently, procedural and sculpting methods.
- **Animation**: Animation focuses on the creation of movement and motion in visual content. This includes character animation, particle simulations, and physics-based animations.
- **Image Processing**: Image processing involves manipulating and enhancing digital images using algorithms to improve quality, remove noise, apply filters, and perform various transformations.

- **Computer-Aided Design (CAD)**: CAD uses computer graphics to aid in the design and visualization of physical objects, from auto-mobiles to buildings, before they are physically constructed.
- **Virtual Reality (VR) and Augmented Reality (AR)**: VR immerses users in a fully digital environment, while AR overlays digital elements onto the real world. Both rely heavily on computer graphics to create seamless and interactive experiences.
- **Human-Computer Interaction (HCI)**: HCI uses computer graphics to create user interfaces, graphical user interfaces (GUIs), and interactive experiences that allow users to interact with digital systems.
- **Simulation and Visualization**: Computer graphics is crucial in simulating real-world phenomena and visualizing complex data, aiding scientists, engineers, and researchers in understanding and communicating their findings.

Applications of Computer Graphics:

- **Entertainment and Media:**
  - **Video Games:** Computer graphics are the foundation of modern video games, enabling realistic 3D environments, characters, and special effects.
  - **Film and Animation:** CGI (Computer-Generated Imagery) is used extensively in movies and animations to create realistic or fantastical scenes, characters, and visual effects.
  - **Visual Effects (VFX):** Graphics are used to enhance scenes with explosions, morphing, simulation of natural phenomena, and more.
- **Design and Visualization:**

- **Architectural Visualization:** Architects and designers use computer graphics to create photorealistic visualizations of buildings and interiors before construction.
- **Product Design:** Computer-aided design (CAD) tools allow designers to create and modify 3D models of products and prototypes.
- **Fashion Design:** Computer graphics aid in designing and visualizing clothing and accessories.

■ **Education and Training:**

- **Medical Visualization:** Graphics help visualize complex medical data, anatomy, and surgical procedures for training and patient education.
- **Scientific Visualization:** Complex scientific data is presented using graphics to aid researchers in understanding and communicating their findings.
- **Educational Software:** Graphics enhance interactive learning experiences in subjects like maths, science, and geography.

■ **Simulation and Virtual Reality (VR):**

- **Flight Simulators:** Pilots and astronauts use graphics-based simulators to practice and train in virtual environments.
- **Training Simulations:** Industries like military, healthcare, and emergency services use simulations for training in controlled virtual environments.
- **Virtual Reality:** VR relies heavily on computer graphics to create immersive experiences in fields such as gaming, education, and therapy.

■ **Advertising and Marketing:**

- **Digital Marketing:** Graphics are used in online ads, social media content, and website design to engage users and convey messages.

- **Product Visualization:** Graphics create appealing visuals for advertising products, often before they are physically produced.

■ **Art and Creativity:**

- **Digital Art:** Artists use computer graphics software to create digital paintings, illustrations, and digital sculptures.
- **Generative Art:** Algorithms are used to create art, producing unique patterns, images, and animations.

■ **Communication and Interaction:**

- **User Interfaces (UI):** Graphics design is crucial in creating user-friendly interfaces for software, websites, and apps.
- **Graphical Data Representation:** Graphics help communicate complex data and trends through charts, graphs, and infographics.

■ **Gaming and Interactive Experiences:**

- **Serious Games:** Games designed for education, training, or simulation purposes often rely on computer graphics to create realistic scenarios.
- **Interactive Exhibits:** Museums, galleries, and public spaces use computer graphics to create interactive exhibits and installations.

■ **Research and Scientific Visualization:**

- **Astrophysics:** Graphics help visualize complex astronomical data and phenomena.
- **Molecular Modeling:** Graphics are used to simulate and visualize molecular structures for drug discovery and research.

■ **Fashion and Textile Industry:**

- **Textile Design:** Computer graphics are employed to create intricate patterns and designs for textiles and fabrics.

Computer Graphics

Overview of a Graphics System: Graphics system is a combination of hardware and software components that works together to create, manipulate, display visual images and content on a computer screen.

A graphics system includes -

- **Graphics Hardware:**
  - **GPU (Graphics Processing Unit):** The core component responsible for performing complex mathematical and graphical computations quickly and efficiently.
  - **VRAM (Video Random Access Memory):** Dedicated memory on the GPU for storing textures, frame buffers, and other graphical data.
  - **Graphics Card:** The physical card housing the GPU, VRAM, and other hardware components.
- **Graphics Software:**
  - **Device Drivers:** Software that enables communication between the operating system and graphics hardware, allowing the OS to utilize and control the GPU effectively.
  - **Graphics Libraries and APIs:** Standardized interfaces for software developers to interact with the GPU. Examples include OpenGL, DirectX, Vulkan, and Metal.
  - **Shaders:** Small programs executed on the GPU for various tasks like vertex manipulation, pixel color calculation, and lighting effects.
- **Geometric Primitives:**
  - **Points, Lines, Polygons:** Fundamental shapes used to construct 3D models in a virtual environment.
- **Transformation Pipeline:**
  - **Modeling Transformation:** Scaling, rotating, and translating 3D models to position them within the scene.
  - **Viewing Transformation:** Converting the 3D scene into a 2D perspective to prepare for rendering.

   - **Projection Transformation:** Mapping 3D coordinates onto a 2D plane for rendering.
- **Rasterization:**
   - The process of converting 3D objects into 2D pixel data on the screen.
   - Involves determining which pixels are affected by a primitive's presence and interpolating attributes across those pixels.
- **Color and Lighting:**
   - **Shading:** Applying colors and textures to surfaces to create realistic appearances.
   - **Lighting:** Simulating the behavior of light as it interacts with objects, affecting their visual characteristics.
- **Frame Buffer:**
   - A region of memory that holds the final image to be displayed on the screen.
   - After rendering, the frame buffer contains pixel data that defines the image's appearance.
- **Rendering Pipeline:**
   - **Input Assembly:** Gathering vertex and index data.
   - **Vertex Shader:** Manipulating vertex positions and attributes.
   - **Geometry Shader (optional):** Processing primitive shapes.
   - **Rasterization:** Converting primitives into fragments (pixels).
   - **Fragment Shader:** Calculating color and lighting for each pixel.
   - **Pixel Operations:** Additional processing like blending and depth testing.
- **Output:**
   - The processed frame buffer data is sent to the screen, creating a visual representation of the 3D scene.
- **Rendering Techniques:**

   - **Rasterization:** Suitable for real-time graphics, widely used in video games.
   - **Ray Tracing:** Emulates the behaviour of light rays, leading to highly realistic rendering.
- **Textures and Mapping:**
   - Applying images (textures) to surfaces to enhance realism.
- **Antialiasing:**
   - Techniques to reduce visual artifacts like jagged edges, improving image quality.

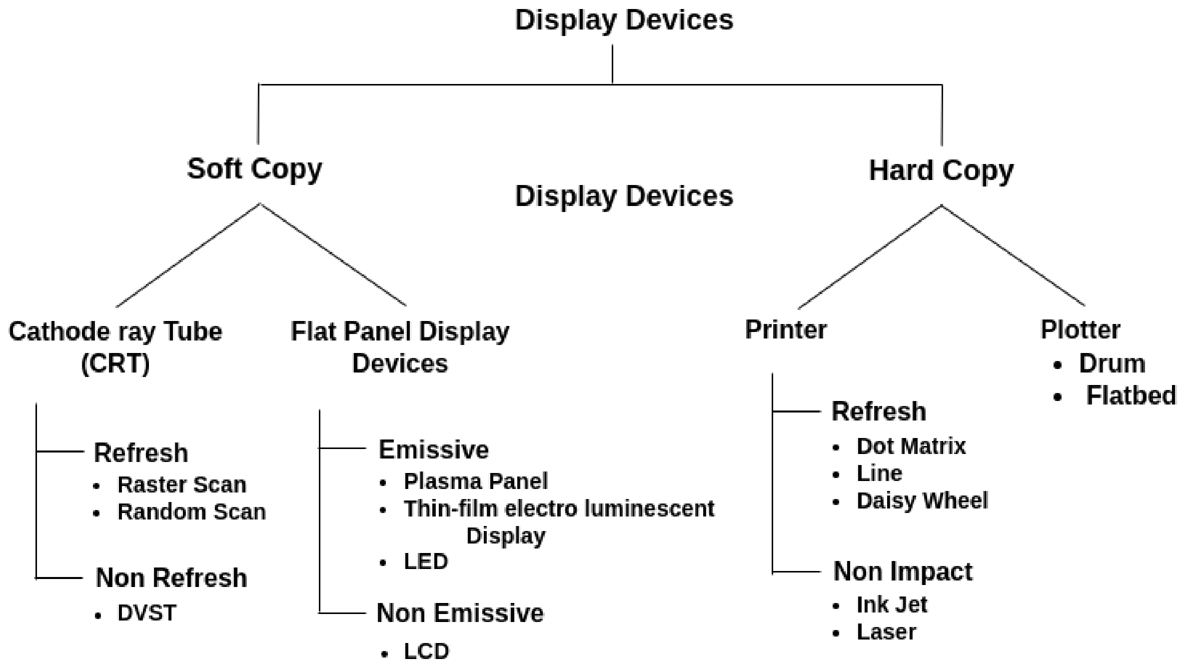
Display Devices: Display devices are used to display the output, graphics without display devices couldn't be interactive; there could be the preview of correctness of the image until it is plotted or printed.

There are mainly two forms of output-

- Soft Copy
- Hard Copy

Soft Copy – The electronic version of an output, which usually resides in a computer memory or on a disk known as s*oft copy.* Soft copy is not a permanent form of output, it is transient and usually displayed on a screen. This kind of output is intangible and can't be touched. It includes audio and visuals forms of output. Soft copy output uses soft copy display devices to display soft copy output such as cathode ray tube, flat panel display etc.

Hard Copy – The physical form of the output is known as Hard Copy. Generally, it refers to the recorded information copied from a computer onto paper or some durable surface, such as microfilm. Hard copy output is permanent and relatively stable form of output. Hard copy output uses hard copy display devices to display hard copy output such as printer, plotter etc.



***In our syllabus there is only video display devices, so we will study only that.*

Video Display Devices: Video display devices in computer graphics are screens that convert digital signals into visual images. They use pixels to create images, and resolution determines image quality. Colors are made by mixing red, green, and blue. Refresh rate affects motion smoothness, and some devices even offer 3D or virtual reality experiences. Video display devices generally consist of *soft copy devices.*

Cathode Ray Tube (CRT):

A Cathode Ray Tube (CRT) is a vacuum tube device that forms images by striking an electron beam onto a phosphor-coated screen. It is a fundamental component of traditional display devices such as oscilloscopes, radar screens, and old CRT monitors/televisions.

It works by **thermionic emission of electrons** from a heated cathode, which are then **accelerated, focused, and deflected** to produce a visible image.

Construction of CRT

The CRT consists of the following major components, shown in the diagram:

(a) Electron Gun Assembly

Purpose: Produces a fine beam of electrons (electron stream) and imparts initial velocity to them.

Components:

- **Heater (Filament):**
  Heats the cathode to emit electrons through **thermionic emission**.
- **Cathode:**
  A negatively charged element coated with oxides (like barium oxide) that emits electrons when heated.
- **Control Grid:**
  A cylindrical electrode with a small hole. It controls the **intensity of the electron beam** by regulating the number of electrons allowed to pass through (negative voltage controls brightness).
- **Pre-accelerating, Accelerating, and Focusing Anodes:**
  - **Pre-accelerating anode:** Gives initial acceleration to the electrons.
  - **Accelerating anode:** Increases the speed of electrons to high velocity.
  - **Focusing anode:** Focuses the electrons into a **narrow fine beam**, ensuring a sharp spot on the screen.

(b) Deflection System

Purpose: Controls the position of the electron beam on the screen.

Components:

- **Vertical Deflection Plates:**
  Control the **vertical position** (Y-axis movement) of the beam by creating an electrostatic field between the plates.
- **Horizontal Deflection Plates:**
  Control the **horizontal position** (X-axis movement) of the beam similarly.

By applying time-varying voltages to these plates, the beam can be made to scan the screen in a controlled manner.

(c) Screen and Coatings

Purpose: Converts electron energy into visible light and collects secondary electrons.

Components:

- **Phosphor Screen:**
  The inside of the screen is coated with **phosphorescent material** (like ZnS) that emits visible light when struck by electrons.
  - The **brightness depends on beam intensity**.
  - The **spot size depends on beam focusing**.
- **Aquadag Coating (Conductive Coating):**
  A **graphite-based conductive coating** applied on the inner surface around the screen.
  - Collects **secondary electrons** emitted from the screen.
  - Maintains the **positive potential of the anode**.

Working Principle

1. The **heater warms the cathode**, causing it to emit electrons by **thermionic emission**.
2. The **grid controls the beam intensity** by controlling the number of electrons allowed through.
3. The **anodes accelerate and focus** the electrons into a sharp, high-velocity beam.
4. The **deflection plates steer the beam** to desired positions on the screen.
5. When the **electron beam strikes the phosphor screen**, it emits **visible light**, creating a bright spot.
6. By **rapidly changing the beam's position using deflection plates**, the CRT can draw complex waveforms or images.

Applications

- Oscilloscopes (CROs) in laboratories

- Older Television and Computer monitors
- Radar display systems
- Cathode ray oscillographs in measurement systems

Advantages

- High resolution and sharp images
- Fast response time
- Can display analog signals directly (ideal for oscilloscopes)

Limitations

- Bulky and heavy
- High power consumption
- Image distortion possible due to magnetic fields
- Obsolete in modern display systems (replaced by LCD, LED, OLED)