ANNAMACHARYA INSTITUTE OF TECHNOLOGY AND SCIENCES:: RAJAMPET
(An Autonomous Institution)

DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTES

CAD/CAM
23A0362T

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Syllabus

Title of the Course: CAD/CAM
Category: Professional Core
Couse Code: 23A0362T
Branch/es: Mechanical Engineering
Year & Semester: III Year II Semester

Unit 1

Introduction To Computer Graphics 08

Overview of CAD/CAM: Product cycle, CAD, CAM and CIM. CAD Tools, CAM Tools, Utilization in an Industrial Environment, Evaluation criteria. CAD data structure, Data base management systems (database structure for graphics modeling).

Computer Graphics: Co-ordinate systems, Graphics package functions, 2D and 3D transformations, clipping, hidden line / surface removal color, shading.

Unit 2

Curve Representation 10

Geometric Modeling: Representation techniques, Parametric and non-parametric representation, various construction methods, wire frame modeling, synthetic curves and their representations, surface modeling, synthetics surfaces and their representations. Solid modeling, solid representation, fundamentals, introduction to boundary representations, constructive solid geometry representations

Unit 3

Numerical Control 10

Numerical Control: NC, NC Modes, NC Elements, NC Machine tools and their structure, Machining center, types (working Principle for 3,4 and 5 Axis) and features. Controls in NC, CNC systems, DNC systems. Adaptive control machining systems, types of adaptive control.

CNC Part Programming: Fundamentals, NC word, NC Nodes, canned cycles, cutter radius compensation, length compensation, computed assisted part programming using APT: Geometry statements, motion statements, post process statements, auxiliary statements, macro statement program for simple components.

Unit 4

Group Technology, Flexible Manufacturing System & CAQC 10

Group Technology & FMS: Part Family, Classification and Coding, advantages & limitations, Group technology machine cells, benefits. FMS: Introduction, components of FMS, material handling systems, Computer control systems, advantages. Computer Aided Quality Control: Terminology in Quality control, Inspection and testing, Contact inspection methods - optical and non-optical, integration of CAQC with CAD and CIM.

Unit 5

Computer Integrated Production Planning 10

Computer Aided Processes Planning: Retrieval type and Generative type, benefits Machinability data systems, Computer generated time standards.

Computer integrated production planning: Capacity planning, shop floor control, MRP-I, MRP- II, CIMS benefits. Trends in manufacturing systems: Concepts of Reconfigurable manufacturing, Sustainable manufacturing and lean manufacturing.

UNIT-1

1.1 INTRODUCTION

CAD/CAM acronym is Computer-aided Design and Computer Aided Manufacturing. It is the technology concentrated with the application of digital computer to perform certain functions in design and manufacturing. This technology is moving in the direction of greater interaction and integration of design and manufacturing. Ultimately, this technology will be direction toward one goal: the fully automated factory of the future.

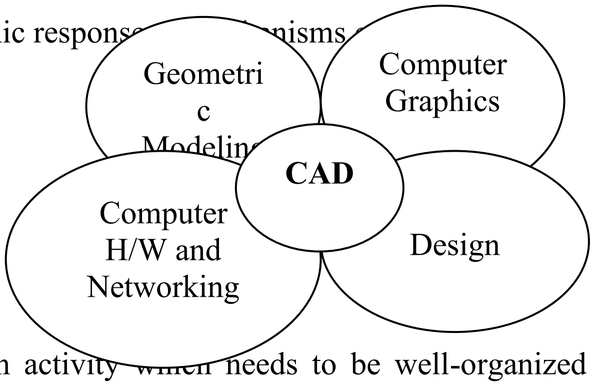
CAD/CAM has been utility in different ways by different people as shown in below figure.

Utilization

Group-1	Group-2	Group-3	Group-4
Utilization to produce drawings and document designs	Employ as a visual tool by generating shaded images and animated displays	Perform engineering analysis on geometric models such as FEA	Perform process planning and generate NC part programs

1.2 COMPUTER AIDED DESIGN (CAD)

Computer-aided design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis or optimization of a design. The computer system consists of the hardware and software to perform the specialized design functions required by the particular user firm. The CAD hardware typically includes the computer, one or more graphics display terminals, keyboards and other peripheral equipment. The CAD software consists of the computer programs to implement computer graphics on the system plus application programs to facilitate engineering functions such as stress-strain analysis of components, dynamic response of mechanisms etc.



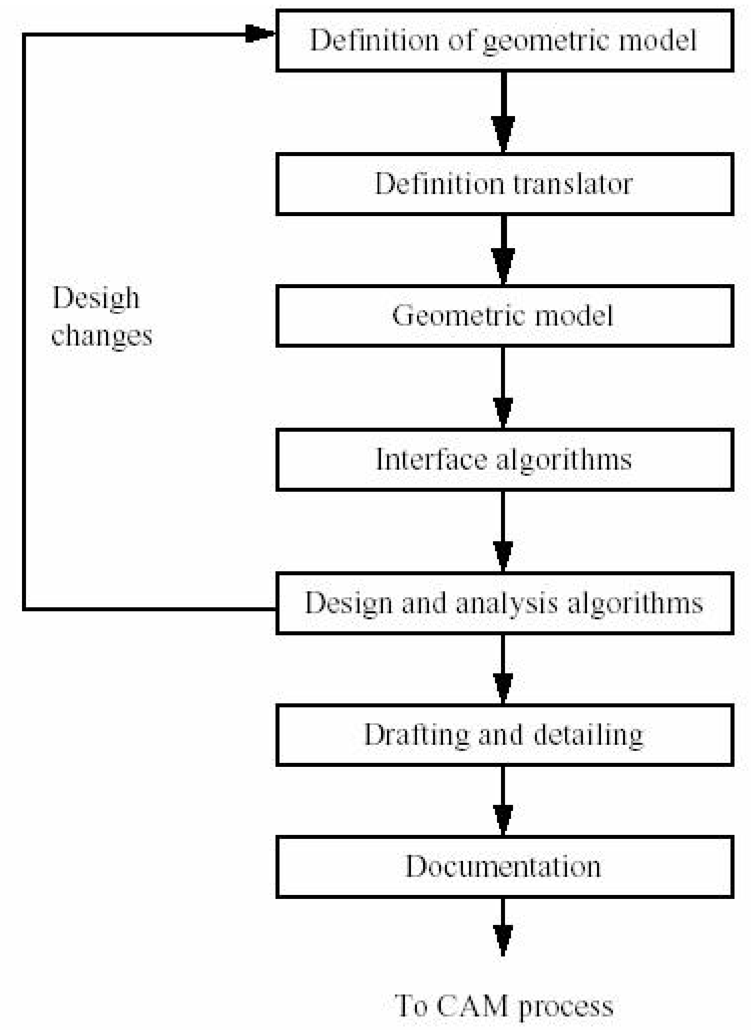
Design is an activity which needs to be well-organized and takes into account all influences that are likely to be responsible for the success of the product under development. A product here means a single component, which is functional in itself like a wrench or an assembly of a large number of components of the design process certainly increases with the number of components present in the final part.

In the case of number of factors, it is impossible to specify a design procedure for each component. To overcome this problem some common guidelines and steps needed to proceed for a successful product design. The various faculties involved in the successful product as follows.

Product Engineering: Product functions, Product specifications, Conceptual design, Ergonomics and Aesthetics, Standards, Detailed design, Prototype development, Testing, Simulation, Analysis, Strength, Kinematics, Dynamics, Heat, Design for Manufacture, Design for Assembly, Drafting

Identically the designers are supposed to consider all these factors while finalizing the design. It is impossible for a single individual to carry out these functions, except in the case simple parts. Or for complex systems the product design function will be carried out by a team of specialists who have specified knowledge and experience in the individual areas as mentioned above.

Once a conceptual design materializes in the designers mind, the definition of geometric models starts via the user interface provided by the relevant software. A valid geometric model is created by the CAD system through its definition translator which converts the designer input into the proper database format. In order to apply engineering analysis to the geometric model, interface algorithms are provided by the system to extract the required data from the model database to perform the analysis. In the case of finite element analysis, these algorithms form and evaluation modeling package of the system. Design testing and evaluation may require changing the geometric model before finalizing it. When the final design is achieved the drafting and detailing model starts following by documentation and packaging final drawings. Implementation of CAD process is shown in below figure.



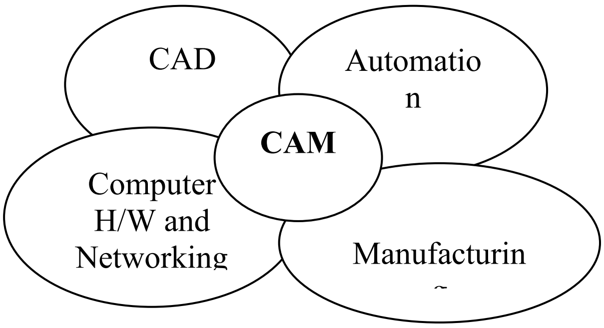
Advantages of CAD

1. Computer aided design (CAD) is faster and more accurate than conventional method.
2. The various construction and associated drafting a very easy task.
3. In contrast with the traditional drawing methods, under CAD it is possible to manipulate various dimensions, attributes and distances of the drawing elements. This quality makes CAD useful for design work.
4. Under CAD no need to repeat the design or drawing of any component. Once a component has made, it can be copied in call further works within seconds, including any geometric transformation needed.
5. Accurate calculation of the various geometric properties including dimensions of various components interactively in CAD, without actually making their models and profiles.
6. Modification of a model is very easy and could the designers task of improving a given product simple to take care of any future requirements.

7. Automation of repeated tasks (Part libraries-Standard components) – most frequently used designs and drawing symbols such as gears, nut-bolts, washers, screws etc. can be stored in the library and can be recalled wherever required.
8. Data exchange format – Now a day's number of software's are available for CAD/CAM applications. Every software has its own standard with the increase in number of CAD/CAM systems there is a desire for increased mobility of data both internally within a company and externally to and from other companies. Thus to integrate various activities in the organization data must be exchange and his can be only possible by introducing translator amongst various CAD/CAM software's. For this we use this standard file format is known as neutral file format. Some of the standard formats are IGES, DXF, STL, STEP etc.
9. Multitask applications – once 3–D model is prepared, it can be used for numerous down streams applications of CAD which includes computer aided manufacturing (CAM), Finite element analysis (FEA), Computer aided process planning (CAPP), computer aided quality control (CAQC), Robot programming, MRP system, Simulations etc.

1.3 COMPUTER AIDED MANUFACTURING (CAM)

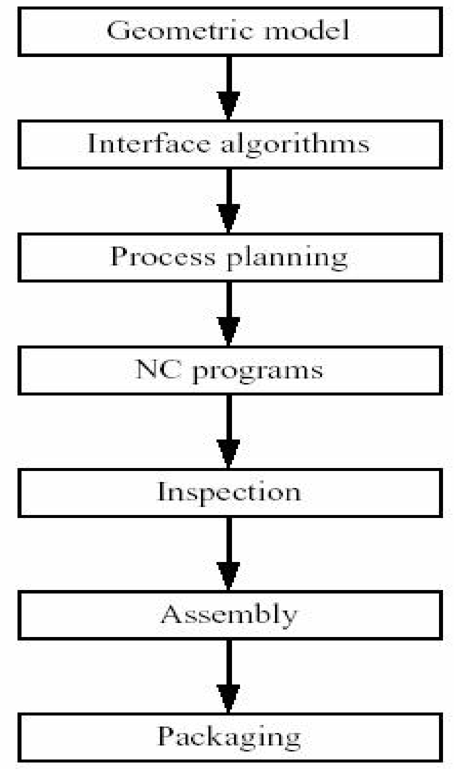
Computer aided manufacturing (CAM) can be defined as the use of computer systems to plan, manage and control the operations of manufacturing plant through either direct or indirect computer interface with the plant's production resources.



CAM refers to computer software used to develop computer numerical control (CNC) part programs for achieving and other processing applications. CAM is subset of manufacturing which is integrated outcome of CAD, CAE, Automation and Manufacturing concepts. The various facilities involved in CAM are as follows.

Manufacturing Engineer: Co-ordinate measuring machine (CMM), Computer aided process planning (CAPP), Process sheets, Route sheets, Tooling, Cutting tools, Jigs and Fixtures, Dies and Moulds, Manufacturing Information Generation, CNC Part programmer, Inspection (CMM) programmer, Production Organization, Material Requirement Planning, Production Planning, Shop Floor Control, Plant Simulation, Marketing and Distribution, Automated Packaging and assembling, Material handling through automated guided vehicle (AGV), Robots, Automated storage and retrieval system (ASRS).

The implementation of the CAM process on the CAD/CAM system is shown in below figure. The geometric model generated during the CAD process forms the basis for the CAM process. Various activities in CAM may require different types of information of the CAD process. Interface algorithms are used to extract such information from the CAD database. NC programme, along with ordering tools and fixtures, result from process planning. Once the parts are manufactured, computer aided quality control software is used to inspect the parts. This is achieved by superposing an image of the real part with a master image stores in its model database. After passing inspection, all the parts are assembled by robots to result in the final production. Implementation of CAM system is shown in below Figure.



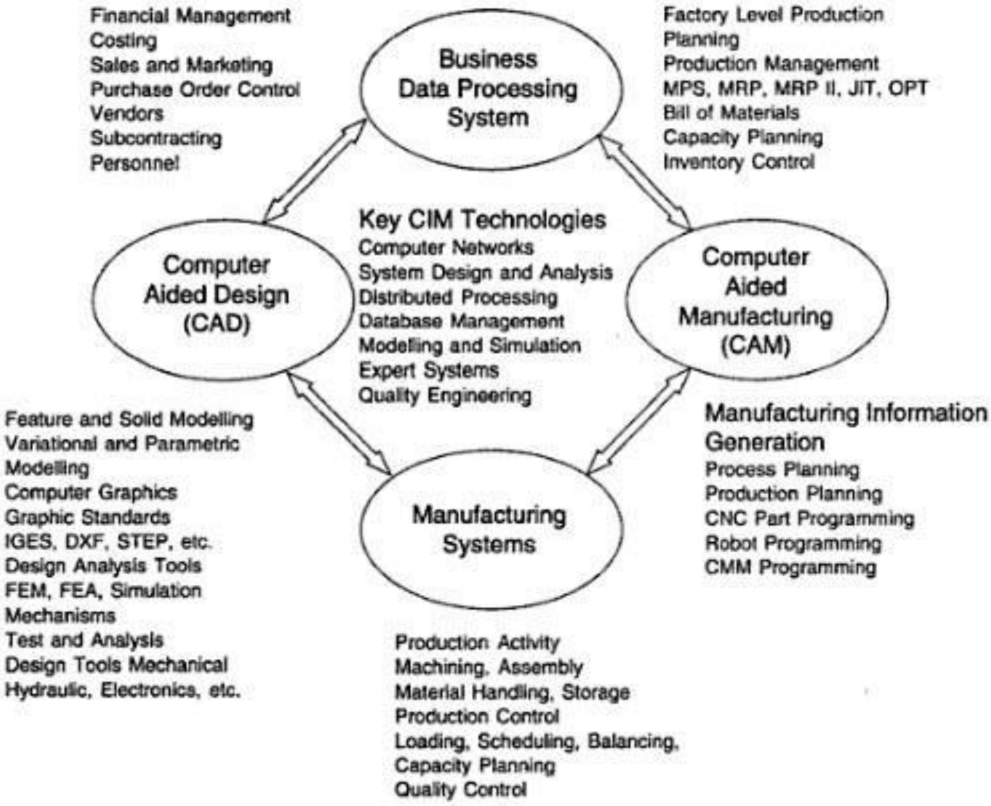
Advantages of CAM

1. *Greater design freedom:* Any changes that are required in design can be incorporated at any design stage without worrying about any delays, since there would hardly be any in an integrated CAM environment.
2. *Increased productivity:* In view of the fact that the total manufacturing activity is completely organized through the computer, it would be possible to increase the productivity of the plant

3. *Greater operating flexibility:* CAM enhances the flexibility in manufacturing methods and changing of product lines.
4. *Shorter lead time:* Lead times in manufacturing would be greatly reduced.
5. *Improved reliability:* In view of the better manufacturing methods and controls at the manufacturing stage, the products thus manufactured as well as of the manufacturing system would be highly reliable.
6. *Reduced maintenance:* Since most of the components of a CAM system would include integrated diagnostics and monitoring facilities, they would require less maintenance compared to the conventional manufacturing methods.
7. *Reduced scrap and rework:* Because of the CNC machines used in production, and the part programs being made by the stored geometry from the design stage, the scrap level would be reduced to the minimum possible and almost no rework would be necessary.
8. *Better management control:* As discussed above, since all the information and controlling functions are attempted with the help of the computer, a better management control on the manufacturing activity is possible.

All the above advantages when properly translated, would mean a lower total cost and consequently, higher final earnings. Therefore, any manufacturing activity can get the benefits of Computer Aided Manufacturing, be it a job shop production or mass scale manufacture. However, better results would be obtained when the design and manufacturing activities are properly integrated. Also, when there is a large variety of products or minor changes required in the existing production programmer, CAM can easily manage the necessary alterations.

1.4 COMPUTERS IN INDUSTRIAL MANUFACTURING



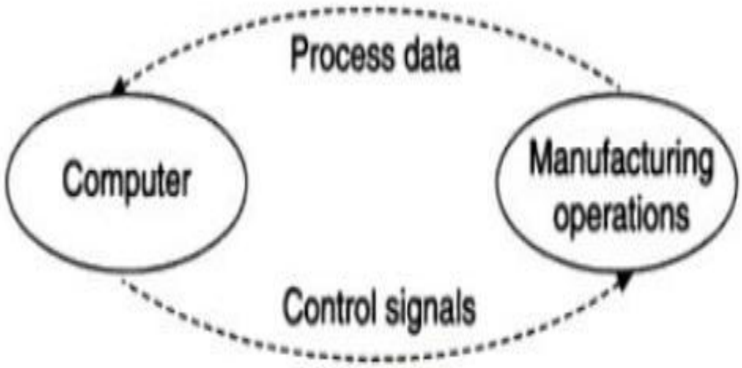
Quality is related to the loss to society caused by a product during its lifecycle. A truly high-quality product will have a minimal loss to society as it goes through its lifecycle. If a product does not perform as expected, the customer senses some loss. After a product is shipped, the manufacturer can do nothing to the product. Before shipment, the manufacturer can use expensive or inexpensive process or materials etc; but once shipped, the commitment is made for a certain product expense during the remainder of its life.

It is becoming increasingly important for manufacturers to initiate steps for manufacturing quality products. There is therefore, a need to optimize the design of a product, the means and techniques to achieve production improvement, cost reduction, fulfillment of scheduled delivery times, and flexibility (to facilitate variety, quality and quantity of product) of the manufacturing system.

It has become imperative for the manufacturer to take advantage of the powerful multifunctional capabilities of computers in industrial manufacturing. Hence, the use of computers in the manufacturing industries has become a reality. The role of computers in industrial manufacturing is broadly classified into the following three groups:

1. Pre-processing support applications of the manufacturing system
2. Monitoring and control of the manufacturing process
3. Post-processing support applications of the manufacturing system

1.4.1 Pre-processing support applications of the manufacturing system



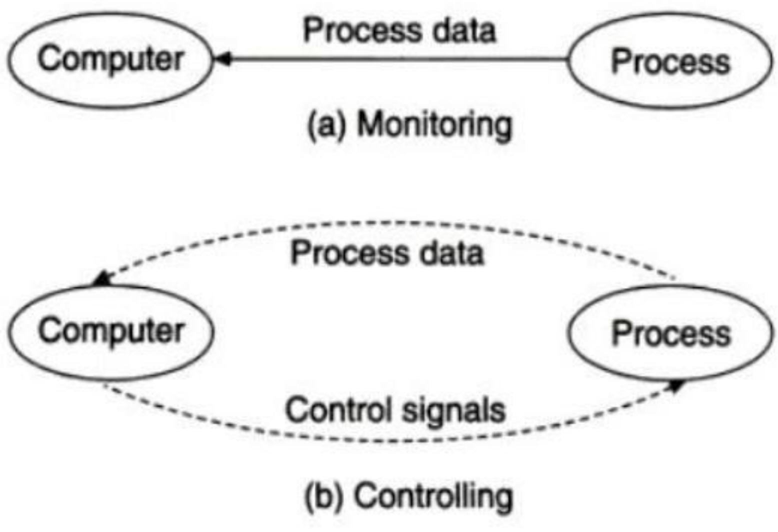
The first category involves all the support functions that computers can provide to facilitate the efficient and economical manufacturing of a product:

1. Computer-aided design and drafting
2. Finite element analysis
3. Computer-aided part programming
4. Computer-aided process planning
5. Computer-aided scheduling
6. Computer-aided tool design
7. Computer-aided material requirement planning

The computer indirectly supports the manufacturing process to provide part programming, process planning, time standards for manufacturing operations, production scheduling, forecasting and inventory, and instructions and information as shown in below Figure. In this system, human beings are required either to enter the input to the computer or to interpret the computer output and implement the required action.

1.4.2 Monitoring and control of the manufacturing process

The second category includes applications wherein computers are directly interfaced with manufacturing. The computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process as shown in below Figure. Monitoring involves a direct interface of the computer with the manufacturing process for the purpose of observing the process and collecting data from the process. The manufacturing process is controlled by the operator but not by the computer. Controlling the computer implies not only monitoring the manufacturing process but also controlling the process based on the observations. The computer issues command signals to the manufacturing process on the basis of control algorithms contained in its software.



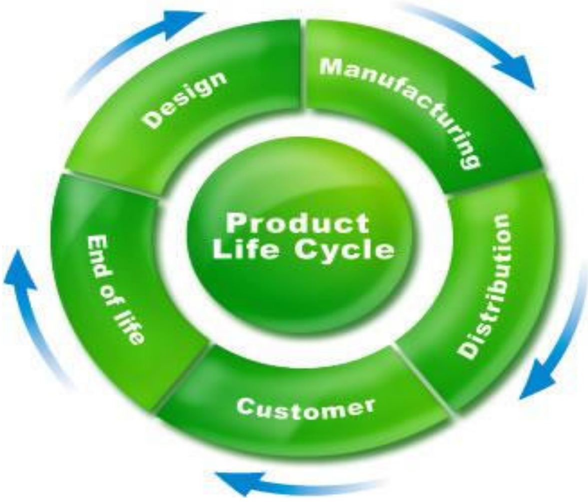
1.4.3 Post-processing support applications of the manufacturing system

The third category consists of all the support functions that enable computers to deliver quality product to the customers. These include:

1. Computer-aided assembly
2. Computer-aided inspection and quality control
3. Computer-aided cost analysis
4. Computer-aided packing and labeling
5. Computer-aided analysis of market feedbacks
6. Computer-aided billing

The use of computers in industrial manufacturing signifies a methodological approach to be implemented in the entire process of product development and manufacture. This requires a whole lot of enabling technologies (CAD, CAM. computer-integrated manufacturing. Business functions, etc.) to be implemented with the aid of computers.

1.5 PRODUCT LIFECYCLE

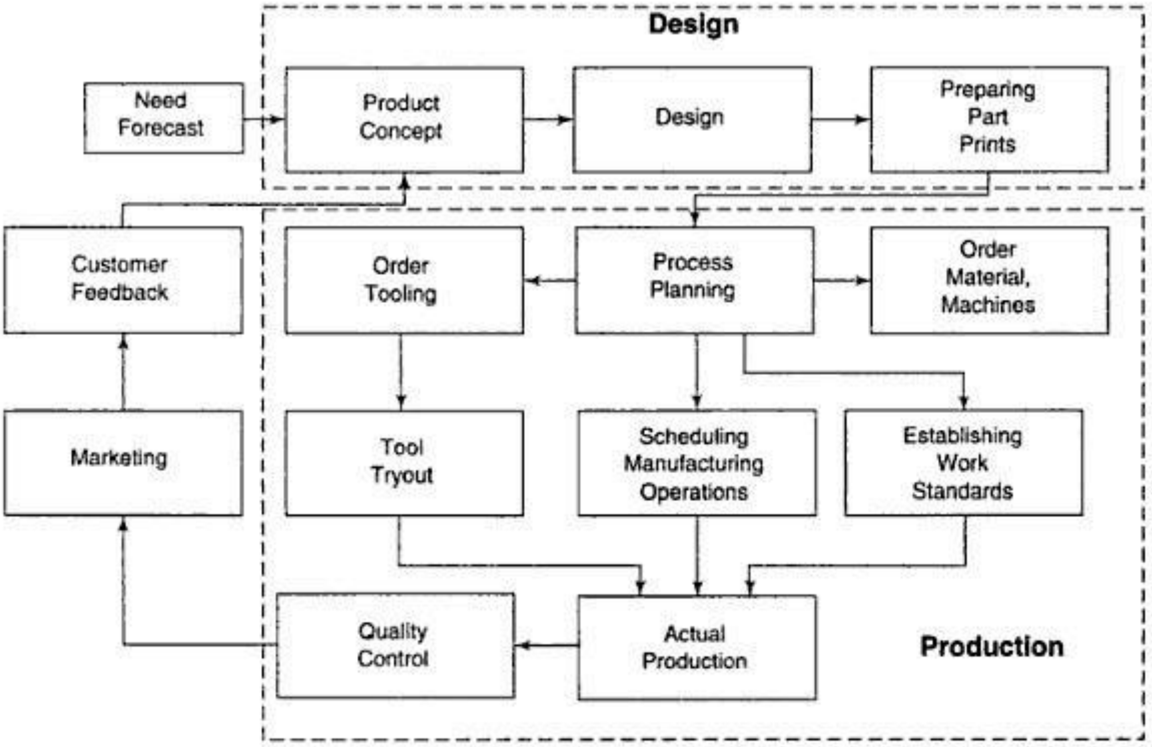


A manufacturing product has a life. The lifecycle is driven by customers and markets, which demand the product. The product cycle begins with a concept and idea for a product. This concept is cultivated, refined, analyzed, improved upon and translated into a plan for the product through the design engineering process. The details of such a design and the subsequent manufacturing process are explained in two ways

1. Traditional product cycle
2. CAD CAM product cycle

1.5.1 Traditional product cycle

Traditional product cycle is show in below figure. In a traditional product cycle all manufacturing activities are done manually. In this customer is start and end state of the product cycle and the main objective of the cycle is to satisfy three quality objectives – best quality, economic and make available in time.



Following are the various stages through which raw material is converted into finished product

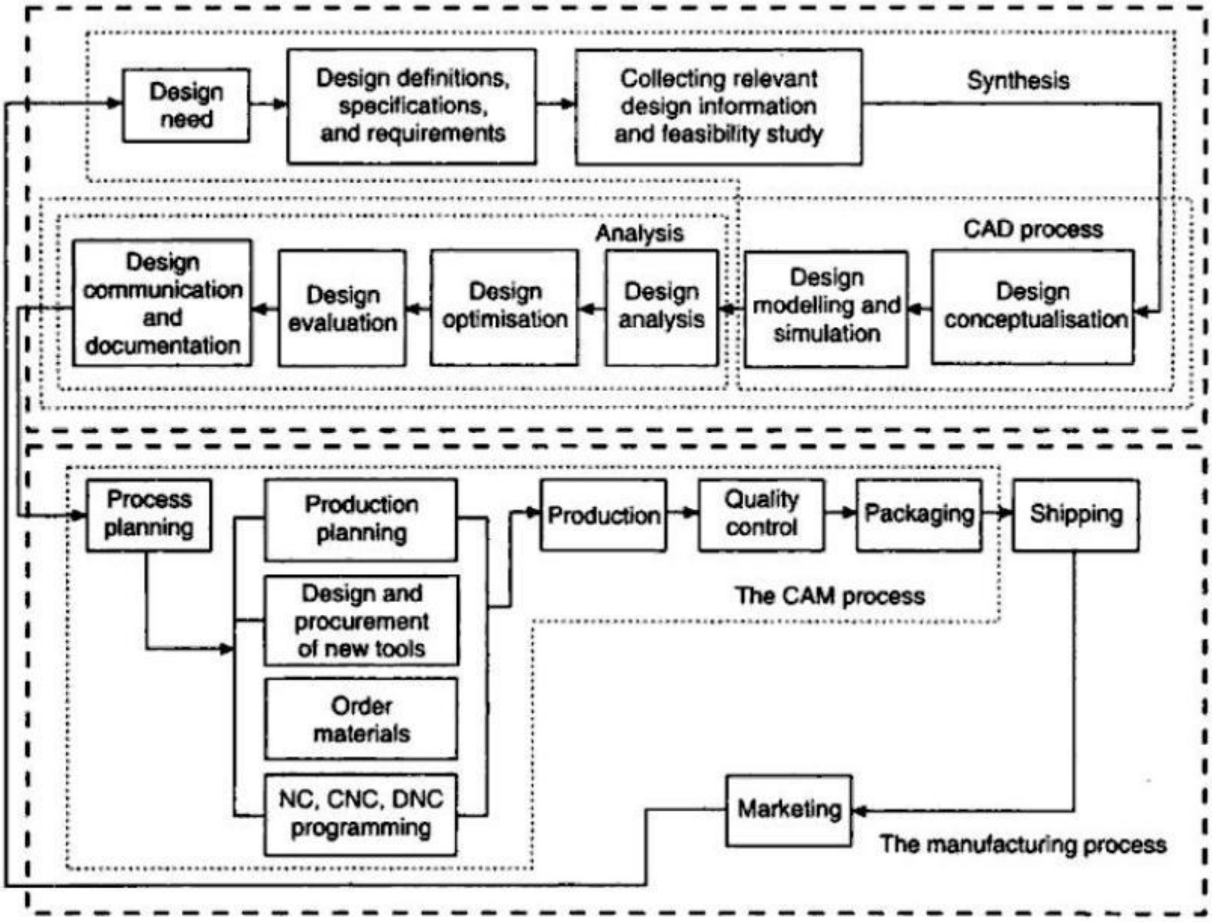
1. Initially customers needs are arises which are captured by market department
2. Product concept department will create the concept of entire product and overall outline of product preparation
3. Based on above information design department design each and every component subassembly and assembly. Any redesign that is needed for improving the producibility of the product without comprising on its functionality would have to be done at this stage
4. After design process various reports such as assembly drawings, detail drawings, manufacturing drawings etc are generated which are forwarded to the manufacturing
5. Production of design component will starts from this stage. Under product concept stage, depending upon the resource available in the organization make or buy decision is taken.
6. Purchase department procures products from concerned vendors
7. Jig fixture design is done in consolation with tool room department
8. Based on the component and process plans establishing work standards will takes place

9. In actual production department manufacturing all the components as per the design specifications and production scheduling
10. Quality control department check the quality of produced components
11. Finally end product are packed properly and dispatched to the customer
12. Customer tests the product and gives the valuable feedback to the organization. Which will be very helpful for further product quality enhancement

The various functions of each department are summarized below

1. Design – Design (modeling, assembly, drafting, analysis)
   Optimization, sensitive analysis
   New product development
   Product specification and manual preparation
2. Production – Prepare production plan day wise, weekly wise, monthly wise
   Assignment – man, machine – shift wise
   In process inspection
   Involve In new design process – Design for manufacturing
3. Manufacturing services – Process design
   Design tools, jig and fixtures
   Capacity planning
   Make or buy decision
   New resource procurement – man, machine
   Time study, method study
4. Quality control - Calibration of gauges
   Measuring tools
   Material testing and machine alignment study
5. Purchase - Procurement, vendor selection etc
6. Sales - Sales analysis – product wise, period, region, customer type
   Sales comparison with competitors
7. Tool room - Tool preparation, tool procurement
8. Marketing - Market survey
   Reorganization customer needs
   Customer order information

1.5.2 CAD CAM product cycle



CAD CAM based product cycle is shown in above figure. The product begins with a need which is identified based on customers and markets demands. The product goes through two main processes from inception to a finished product: the design process and the manufacturing process. Synthesis and analysis are the two main sub processes of the design process. The philosophy, functionality and uniqueness of the product are all determined during synthesis. During synthesis, a design takes the form of sketches and layout drawings that show the relationship among the various product parts. These sketches and drawings can be created using a CAD/CAM system.

The analysis sub process deigns with an attempt to put the conceptual design into the context of engineering sciences to evaluate the performance of the expected product. This requires design modeling and simulation. An important aspect of analysis is the "what if" questions that help us to eliminate multiple design choices and find the best solution to each design problem. The outcome of analysis is the design documentation in the form of engineering drawings (also known as blueprints).

The manufacturing process begins with the process planning and ends with the actual product- Process planning is considered the backbone of the manufacturing process since it attempts to determine the most efficient sequence in which to produce the product. A process planner must be aware of the various aspects of manufacturing to plan properly. The planner typically works with the blueprints and may communicate with the design team to clarify or request changes in the design to fit manufacturing requirements. The outcome of the process planning is a production plan, tools procurement, material order, and machine programming. Other special manufacturing needs such as design of jigs and fixtures or inspection gages are planned.

Once the process planning phase is completed, the actual production of the product begins. The manufacturing parts are inspected and usually must pass certain standard quality control (assurance) requirements. Parts that survive inspection are assembled, packaged, labeled and shipped to customers. Market feedback is usually incorporated into design process. With this feedback, a closed-loop product cycle results as shown in figure.

1.6 TYPES OF PRODUCTION

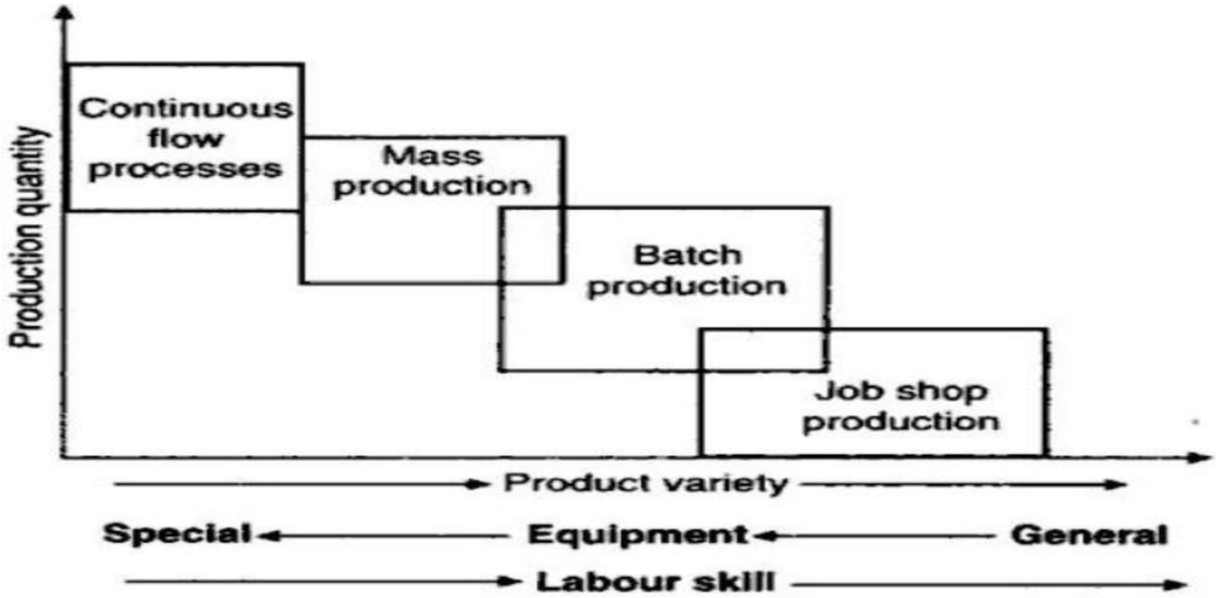
Production activities can be classified according to the quantity of the product made. In this classification there are four types of production: job shop production, batch production, mass production of discrete products, and continuous flow process. These are explained below

1.6.1 Job Shop Production

This category involves a low volume of production. The manufacturing lot sizes in this case are very small, preferably one of a kind. There is a great variety in the type of work. The manufacturing equipment must be flexible and general purpose to facilitate this variety of work. Examples of products manufactured in a job shop are machine tools, space vehicles, aircraft, and prototypes of future products.

1.6.2 Batch Production

Batch production refers to the manufacturing of products in medium lots. The lots may be produced only once and may be manufactured at regular intervals. The purpose of batch production is often to satisfy continuous customer demand for an item. The production equipment must be general purpose but designed for higher rates of production. Batch production industries include machine shops, casting foundries, plastic moulding factories and press working shops.



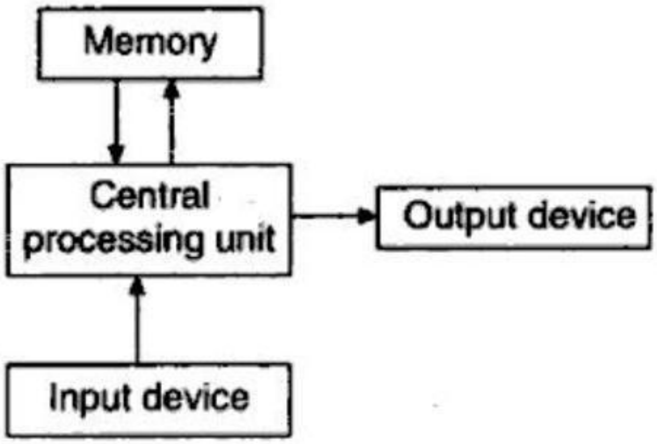
1.6.3 Mass Production

This category involves a very high volume of production. The equipment in this case is completely dedicated to the manufacture of a particular product, and there are very high demand rates for the product. Examples of this production include automobiles, household appliances, etc.

1.6.4 Continuous Flow Production

This category involves continuous dedicated bulk manufacturing of large amounts of a product. Examples of these products include continuous chemical plants and oil refineries.

1.7 BASIC COMPUTER ARCHITECTURE



The basic computer architecture of a typical computing system is shown in above figure. The modern digital computer is an electronic machine that can perform mathematical, logical computational and data processing instructions in accordance with a pre-determined programmer of instructions. There are four basic components of simple digital computer, they are

1. CPU
2. Memory
3. Input devices
4. Output devices

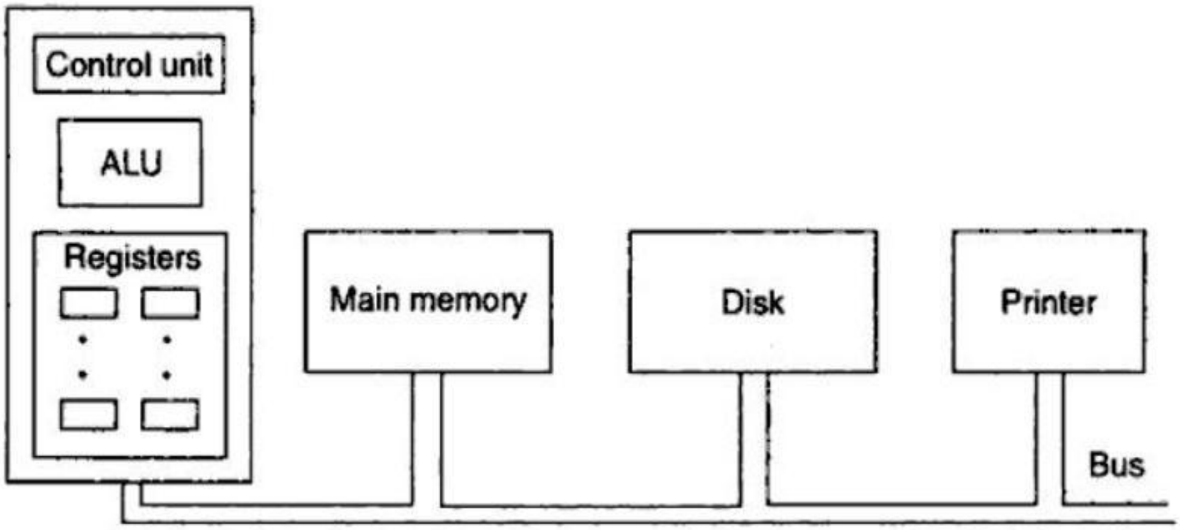
The central processing unit (CPU) is the brain of the computer. Its function is to execute programs stored in the main memory by fetching their instructions, examining them and then executing them one after another. The CPU is composed of two sub-sections: a control unit and an arithmetic and logical unit. The control unit is responsible for fetching instructions from the main memory and determining their type. The control unit also coordinates the operations of other components. It controls the input and output of information between the computer and the outside world thorough the input and output devices. These are also collectively called peripheral units. Through an input device the user would be able to communicate with CPU, either to give certain data or to control the operation of the CPU. The output device is a means through which the CPU gives the results of the computations.

The arithmetic and logical unit performs operations such as addition and Boolean needed to carry out the instruction. The present day computers work on the principle called stored program concept. It means that the sequence of operations to be carried out by the

CPU is stored in the memory of the computer. The CPU reads an instruction and executes it and continues doing so until it reaches the end of the program. This stored program is called software in computer technology. Since it is the software, which runs any computer, the computer is as good as the program that is running at any given time.

1.8 CONTROL PROCESSING UNIT (CPU)

The central processing unit (CPU) regulates the operation of all system components and performs the arithmetic and logical operations on the data. The CPU consists of several distinct parts. The organization of a simple computer with CPU, output and input devices is shown in below figure.



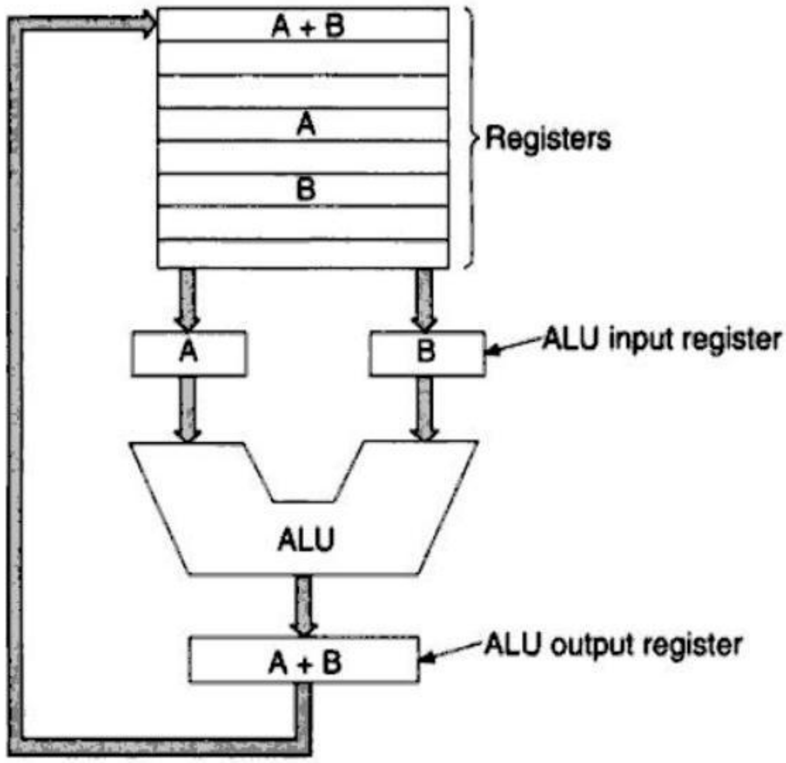
The control unit coordinates the various operations specified by program instructions. The CPU also contains a small, high – speed memory used to store temporary results and certain control information. This memory consists of a number of registers, each of which has a certain function. The most important register is the program counter (PC), which points to the next instruction to be executed. Also important is the instruction register (IR), which holds the instruction currently being executed. Accumulator is a temporary storage register used during an arithmetic or logical operation. For example, while adding two numbers, the accumulator is used to store the first number while the second number is fetched. Status register is used to indicate the internal condition of the CPU. The arithmetic and logical unit (ALU) provides the circuitry required to perform the various calculations and manipulations of data.

The CPU executes each instruction in a series of small steps

1. Fetch the next instruction from memory into the instruction register
2. Change the program counter to point to the following instruction
3. Determine the type of instruction just fetched

4. If the instruction used data in memory, determine where they are
5. Fetch the data, if any, into internal CPU registers
6. Execute the results in the proper place
7. Store the results in the proper place
8. Go to step 1 to begin executing the following instruction

The organization of CPU is shown in below Figure. The registers feed into two ALU input registers, labeled A and B. These registers hold the ALU input while the ALU is computing. The ALU itself performs addition, subtraction, and other simple operations on its inputs, yielding a result in the output register. This output register can be stored back into a register, and from there, back into memory, if desired. In the example, addition is illustrated.



Instructions can be divided into three categories:

1. Register – Memory

   Register – Memory instructions allow memory words to be fetched into register

2. Register – Register

   Register – Register instruction fetches two operations from the registers, brings them to the ALU input registers, performs some operation in them and stores the result back in a register

3. Memory – Memory

   Memory – Memory instruction fetches its operands from memory into the ALU input registers, performs its operation, and then the result back into memory.

The operation of the data path is the heart of most CPUs. To a considerable extent, it defines what the machine can do.

1.9 MEMORY TYPES

Memory is an integral part of a computer storing data and programs often called as main memory. Traditionally, this used to be called *core memory* in the main frame computer parlance. The name *core memory* is because the individual memory cells are formed by making a small magnetic core about 1.5 mm in size wound around a thin material of wires. These cells would be magnetized or not depending upon the data to be written. By magnetizing, they obtain a specific orientation, which would not be erased even when the electric supply is put off.

Increase in the capability of holding a number of memory units in a single chip greatly decreases the complexity of the circuitry involved in the computer mother board.

The various types of semiconductor memory units available are:

- ROM-Read only memory,
- PROM-Programmable ROM.
- RAM-Random access memory in its various forms
- EPROM-Erasable programmable ROM. and
- EEPROM-Electrically erasable and programmable ROM.
- Flash memory

Read only memory (ROM), as the name implies, can only be read but cannot be written upon. Thus, the ROM when prepared can hold information, which need not be updated during the useful life of that information. Most of the system software is normally provided in the form of ROM.

Programmable ROM (PROM) used for small volume applications. Here, a general purpose ROM from the semiconductor factory is specifically programmed by suitable means and then used as ROM. The PROM can be programmed only once. A ROM, which can be erased fully, by means of ultraviolet light and then reprogrammed using a high voltage (32 V) signal, is called EPROM. These can be programmed in part or in full a number of times, but the erasure when done would necessarily be full. EEPROM is an alternative to the EPROM in which information can be written and erased using the normal voltage signal (5 V) available for operating all the circuits.

Random access memory for RAM is not apt, since all semiconductor memories can be accessed randomly. It is essentially a read and write memory. The information can be read as well as written into the memory. However, the information stored can only be retained till the power supply stays on. Since most of the memory of a computing system is contained in the RAM, it is necessary to maintain the power supply throughout without even a momentary interruption, otherwise the data stored or computations carried out partially would all be lost.

Some RAM chips are coming up with a lithium battery embedded permanently in the casing of the RAM chip so that information present in the RAM is retained even when the external power supply is cut off. RAM chips come in two varieties, static and dynamic. In static RAM, the information is to be written only once whereas in dynamic RAM, the information after having been written would have to be continuously refreshed for merely being retained, even though there may be no change in it. Static RAM is more expensive compared to the dynamic RAM or DRAM.

There are currently five types of DRAM technology used in computers: Fast Page Mode (FPM), Extended Data out (EDO) and synchronous DRAM (SDRAM). Also the RAM can be fixed as parity, non-parity, Error-Checking-and-Correcting (ECC) or ECC-on-SIMM (EOS).

FPM DRAM Fast-Page Mode memory is a type of DRAM that allows for replicated memory access with minimum waiting for the next instruction.

EDO RAM EDO (Extended Data Out) is a memory technology that can provide approximately a 5-30% boost in the memory subsystem speed versus Fast-Page Mode. Also known as Hyper-page mode DRAM, EDO provides increased performance by outputting data at the same time it is searching for new information. Fast-page memory has to wait between such operations, thus causing delays. EDO reduces the bottlenecking in data transfers between high-speed processors that need to get data quickly. Of critical importance, a high-performance computer system must be designed to take advantage of EDO memory to realize the benefits. The increase in system-level performance gained by EDO DRAMs is quite good considering that the performance benefit carries no increased cost.

SDRAM or synchronous DRAM is a fast, high-bandwidth memory designed to work best with systems employing high-performance PC chipsets and processors. This technology synchronizes itself with the system clock that controls the CPU. Eliminating time delays and improving processor efficiency. Offering bandwidths of up to 100MHz—twice the bandwidth of EDO—SDRAM is a result of a major shift from EDO and Fast Page Mode DRAMs. As bus speeds increase, the performance difference increases. To use SDRAM, a computer system must be designed to support that kind of memory, and as most new chipsets support SDRAM technology, it has become the new RAM standard.

RDRAM Rambus Direct RAM is another technology, which is slowly gaining ground in the high end workstations. It utilizes a narrow, uniform-impedance transmission line, the Rambus Channel, to connect the memory controller to a set of RIMMs. This single channel is capable of supplying 1.6 GB/sec of bandwidth. However it is possible to use multiple channels thereby increasing the bandwidth. This suits well with the new processors most of which are operating at or above 1 GHz. However, the RDRAM is still very expensive compared to the SDRAM, partly because it is new technology. With more people start using in the future most of the workstations should probably be using RDRAM.

DDR-SDRAM DDR-SDRAM (double data rate) is another variation of SDRAM that is faster compared to normal SDRAM and is gaining ground and is replacing the SDRAM in most of the workstations. The basic principle of DDR-SDRAM is very simple. It is able to transport double the amount of data by using the rising as well as falling edge of the clock signal for data transfers. Plans are in pipeline for quadrupling the transfer rate to 4 times using the quad-pumped technology known as DDR II. DDR-SDRAM has another important improvement over PC133 SDRAM. Its voltage supply is using only 2.5 V. instead of 3.3 V. This and the lower capacities inside the memory chips lead to a significantly reduced power consumption.

Parity and Non-parity

Parity checking circuitry adds an extra bit to each 8 bits of memory data. The benefit of incorporating parity memory in a system is the ability to detect single-bit errors and send an error message before halting the system. After reading 8 bits of data, the memory controller can examine the parity bit to detect any single-bit errors. If an error occurs, the system notifies the user and usually shuts down immediately. With many business users dependent upon the accuracy of the data being processed, requiring parity memory is an important consideration. Non-parity memory is less expensive than parity memory. Parity checking is also limited to detecting only odd numbers of bit errors. Even though they are extremely rare, even numbers of bit errors are possible.

Error Checking and Correcting (ECC)

ECC memory provides a vast improvement in memory integrity management over parity checking. ECC circuitry automatically detects and corrects single-bit errors and can detect highly unlikely multiple-bit errors. As with parity checking, ECC requires one extra memory bit for each byte of data. ECC memory requires more overhead than parity memory for storing data and causes approximately a 3% performance degradation in the memory subsystem and is also expensive. However, the resulting error detection and correction can make the trade-off well worth it. Many new high-end computers include ECC circuitry in the memory controller. This allows the use of low-cost parity memory modules to provide advanced ECC functionality.

ECC-on-SIMM

EOS or ECC-on-SIMM is a special type of ECC memory that performs error checking and correcting within the memory SIMM. Performance is not affected (over standard ECC) but provides ECC function to systems without an ECC memory controller.

Flash Memory

It is a type of non-volatile memory that can be erased and reprogrammed in units of memory called blocks and not single byte. Otherwise the writing process is similar to EEPROM. It is also called "flash RAM". With the cost of production of flash memory becoming small, it is extensively used presently in the form of separate drive that can be attached to USB port, generally called jump drive. It can be used for transferring data similar to a floppy drive, but with much larger capacity and speed. Currently these drives are available from 32 MB to 512 MB with reasonable cost.

1.10 STORAGE DEVICES

Since every word in the main memory must be directly accessible in a very short time, the main memory is relatively expensive. Consequently, most computers have slower, cheaper and usually much larger secondary memories as well. Secondary memories are used to hold sets of data far larger than what the main memory can hold. The storage devices can be classified as follows:

1. Magnetic tapes
2. Magnetic disks
3. Winchester disks
4. Floppy disks
5. CD ROM
6. DVD

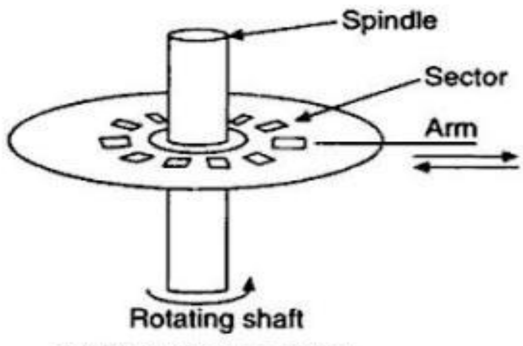
1.10.1 Magnetic Tapes

Historically a magnetic tape was the first kind of storage device. A computer tape drive is analogous to a home tape recorder: a 2400-fl long tape is wound from the feed reel past a recording head to the take-up reel. By varying the current in the recording head, the computer can write information on the tape in the form of little magnetized spots.

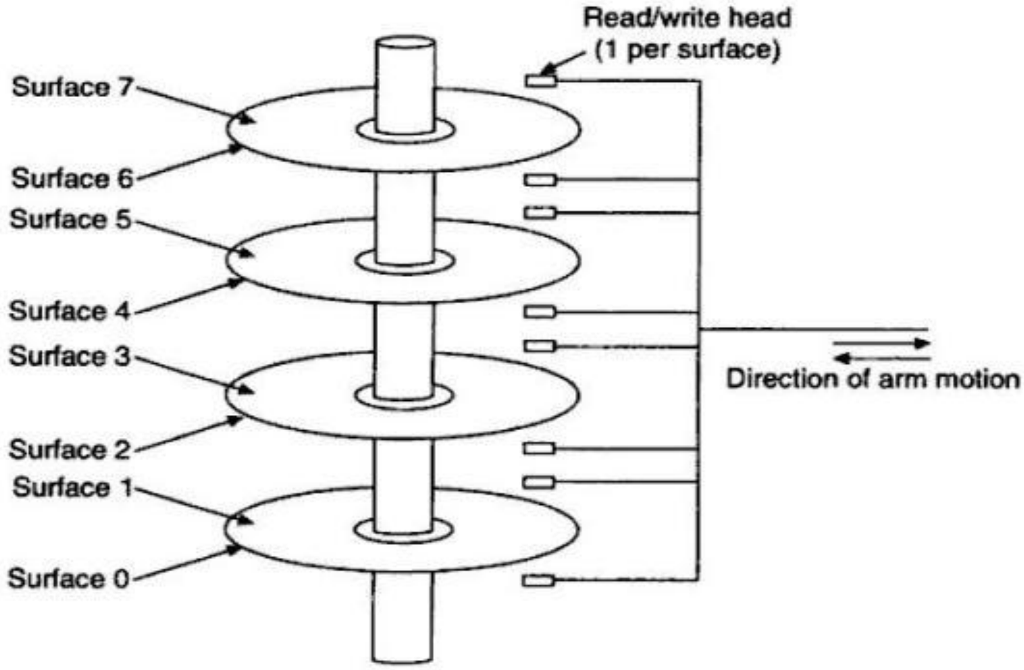
Magnetic tapes are sequential access devices. If the tape is positioned at the beginning, to read physical record *n,* it is first necessary to read the physical records I through (n-1), one at a time. If the information desired is near the end of the tape, the program will have to read almost the entire tape, which may take several minutes, forcing a CPU that can execute millions of instructions per second to wait 200 seconds while a tape is advanced is wasteful. Tapes are most appropriate when the data must be accessed sequentially.

1.10.2 Magnetic Disks

A disk is a piece of metal, ranging from about 5 to 10 inches in diameter, to which a magnetisable coating has been applied at the factor)', generally on both sides. Information is recorded on a number of concentric circles, called 'tracks'. Disks are typically between 40 and a few hundred tracks per surface. Each disk drive has a movable head that can be moved closer to. or farther from, the centre. The head is wide enough to read or write information from exactly one track. A disk drive often has several disks stacked vertically about an inch apart. In such a configuration, the arm will have one head next to each surface, all of which move in and out together. The radial position of the heads (distance from the spindle) is called the cylinder. A disk drive with *n* platters will have *2n* heads and, hence *2n* tracks per cylinder.



(a) Disk with one platter



(b) Disk with four platters

Tracks are divided into sectors, normally between 10 and 100 sectors per track. A sector consists of a certain number of bytes, usually 512.

In order to specify a transfer, the program must provide the following information: the cylinder and head, which together specify a unique track, the sector number where the information starts, the number of words to be transmitted, the main memory address where the information comes from or goes to, and whether information is to be read from the disk into memory or written from memory to the disk.

Disk transfers always start at the beginning of a sector, never in the middle. If a multi-sector transfer crosses a track boundary within a cylinder (e.g., from surface 0 to surface 1 at the same arm position), no time is lost because switching from one head to another is done electronically. However, if the transfer crosses a cylinder boundary, one rotation time may be lost while repositioning the heads to the next cylinder and waiting for sector 0 to come around.

If the head happens to be positioned over the wrong cylinder, it must first be moved. This motion is called seek. A seek typically takes 3 msec between adjacent tracks and 20 to 100 msec to go from the innermost cylinder to the outermost cylinder. Once the head is positioned properly, the controller must wait until the first sector has rotated under the head before beginning the transfer. The time wasted in waiting for the right sector varies from 0, if the program is lucky, to the complete rotation time if it is just missed. This waiting time is called the 'rotational latency'. Most disks rotate at 3600 rotations/min, giving a maximum latency of 16.67 msec. The total access time is the seek time plus the rotational latency plus the transfer time. The information is transferred at a rate of one track per rotation period.

1.10.3 Winchester disks

Nearly all computers use multi-platter disks as described above for their main data storage. These are often called ***hard disks.*** The most common type is the ***Winchester disk,*** which is a sealed unit (to avoid contamination from dust). The heads on a Winchester drive are aerodynamically shaped and float on a cushion of air generated by the spinning platters. Their capacities range from about 20 megabytes on low-end personal computers to around 10 gigabytes on large mainframes.

1.10.4 Floppy Disks

With the advent of the personal computer, it became necessary to find a way to distribute software. The solution was found in the diskette or floppy disk, a small, removable medium so-called because the early floppies were physically flexible. The floppy disk was actually invented by IBM for recording maintenance information about its mainframes for the service staff, but was quickly seized on by personal computer manufacturers as a convenient way to distribute software for sale.

Unlike Winchester disks, where the heads float a few microns above the surface, floppy disk heads actually touch the diskettes. As a result, both the media and the heads wear out comparatively quickly. In order to reduce wear and tear, personal computers retract the heads and stop the rotation when a drive is not reading or writing. Consequently, when the next read or write command is given, there is a delay of about half a second while the motor acquires speed.

1.10.5 CD ROM

In recent years, Optical disks were originally developed for recording television programs, but they can be put to more aesthetic use as computer storage devices. Television has a bandwidth of 6 MHz. so a one-hour disk has a theoretical capacity of about 10 gigabits. Practical systems achieve about half of that. (Bandwidth is an electrical engineering term and refers to the information-carrying capacity of a wire or other channel. A bandwidth of 1 Hertz (Hz) is typically, but not always, good for transmitting one bit per second).

Due to their potentially enormous capacity, optical disks have been the subject of a great deal of research and have gone through an incredibly rapid evolution. The first generation was invented by the Dutch electronics conglomerate. Philips, and further developed in collaboration with Sony. These disks are based on the same technology used in Compact Disc audio players and arc called *CD ROMs (Compact Disc Read Only Memory).*

A CD ROM is prepared by using a high-power laser to burn one-micron (10-6 of a meter) holes in a master disk. From this master, a mould is made. This mould is used to stamp out copies on plastic disks in the same way that phonograph records are made. A thin layer of aluminum is then deposited on the surface, followed by a transparent plastic layer for protection. CD ROMs are read by devices similar to CD audio players, by having a detector measure the energy reflected off the surface when a low-power laser is aimed at the surface. The holes, called *pits,* and the unburned areas between the pits, called *lands* have different reflectivity, making it possible to distinguish between pits and lands.

1.10.6 DVD

Another storage medium which is becoming increasingly popular is the DVD originally named "Digital Video Disk,'* then "Digital Versatile Disk," and now simply "DVD". There is no official three-word equivalent to DVD. Like CD-ROM, the DVD is read by an infrared laser focused through a protective plastic layer onto the disc's reflective layer. The transparent layer is 1.2 mm thick on a CD-ROM, but only 0.6 mm on a DVD-ROM. The beam reflects off pits burned into the reflective layer by the recording laser and is passed through optics to the pickup. The laser beam used on a CD-ROM player has a wavelength of 780 nanometers. DVD players employ a laser with a wavelength of 635 and 650 nanometers, designed to read through the thinner 0.6 mm transparent layer. This makes it possible to focus on smaller pits of digital data, about half the physical size of pits on a CD-ROM—effectively doubling the density of pits on a DVD-ROM. More data is squeezed onto the disc by recording tracks closer together and closer to the centre hole, as well as improving the error-correcting decoding algorithms.

DVD discs come in capacities of 4.7, 8.5, 9.4 and 17GB. Some of the early discs are single-sided, but the specification includes dual-layered and double-side versions that define the four levels of storage capacity. DVD data is read by a variable-focus laser; on dual-layered discs, a lens shifts the beam's focus from the pits on the outer layer to the pits on the inner layer. Currently there are three different types of DVD drives that have been defined:

DVD-ROM These are the drives with only the reading capability. They are used basically for removable mass storage for large volumes of data such as encyclopedia, and are currently available.

DVD-R These are drives with write-once capability. DVD-R drives are also called "write once, read many" (WORM) drives and are currently available. These are similar to the CD-R drives with WORM capability. This category, as a result there are a number of different formats that are being pushed by the various groups in the DVD forum. What was approved by the forum is a phase-change design that can hold 2.6GB of data per side on single or double-sided disks. The single-sided disks will come in removable cartridges, but to protect the sensitive recording layer, double-sided disks will be permanently mounted in cartridges. Currently, there is no standardization in the DVD formats. Both the +R and -R are currently available, and there is not much of difference between the two formats. Many drives are available that can write in both the formats, so that the user has little to worry about in terms of the format and usability.

DVD+RW This is supported by Hewlett-Packard, Philips and Sony. DVD+RW*s single-layer phase-change disks have more capacity than DVD-RAM disks—4.7 GB per side, and use a higher-density recording process. The DVD+RW format does not rely on cartridges to hold the disks.

DVD-RAV This is put forward by Pioneer and the first one to be available commercially. It will use random-access media that hold up to 4.7 GB. One of this technology's key characteristics is that its phase-change media have a higher reflectivity, and as a result, can be read in existing DVD-ROM drives and DVD players without modification.

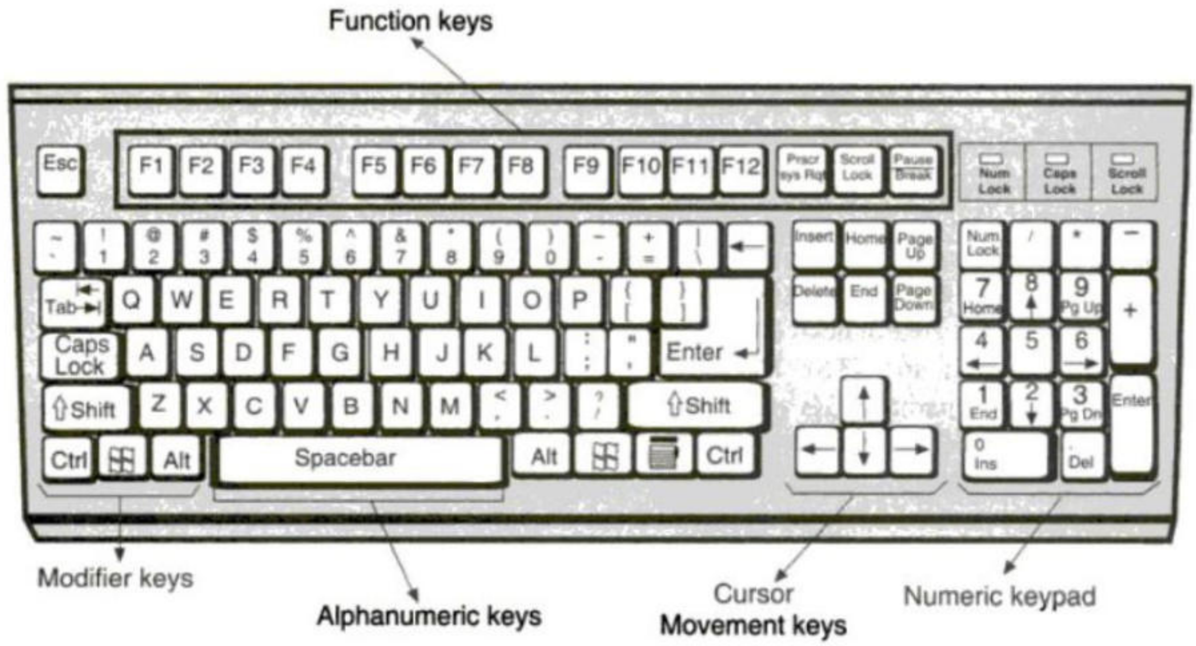
1.11 INPUT DEVICES

These are the devices through which the user/ operator communicates with the computer for feeding it with the necessary information, both graphical and alphanumerical as required. The various devices used arc:

- Keyboard
- Mouse
- Light pen
- Joystick
- Digitizer
- Trackball

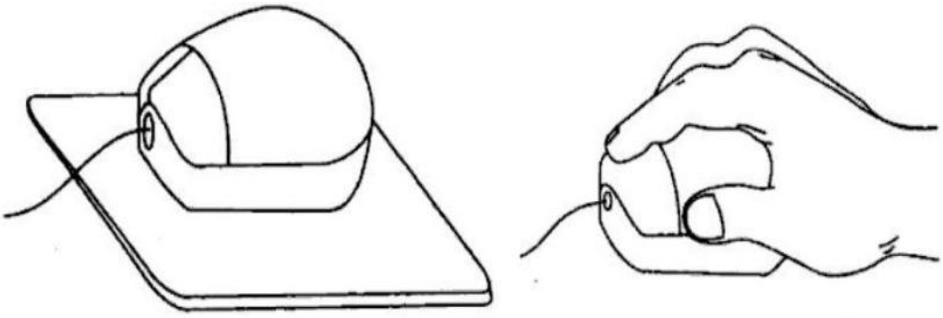
1.11.1 keyboard

The keyboard is the most basic input medium for all computers. The layout of keys on a keyboard generally consists of the traditional typewriter keys together with some special keys, which are used for controlling the execution of the program or the screen display. The presence of a higher number of keys would facilitate the interaction. How does the keyboard communicate with the CAD/CAM software or the main application program? How is the software interrupted to receive the keyboard input? The keyboard is connected to the computer by means of registers whose contents can be read by the computer. A keyboard typically has two registers, one to set a status bit when a key has been struck, and the other to identify the key by its character code.



The value of the status bit is monitored in a continuous repetitive manner by the software via a programming technique known as 'polling'. When the user hits a key, the status bit is set and the application program is consequently interrupted to clear the status bit followed by reading the corresponding code of the key character. The loop is repeated every time the user strikes a key. Keyboard characters are identified by their ASCII (American Standard Code for Information Interchange) codes. The ASCII codes for alphanumeric characters are 7-bit codes. The character code for a capital letter, say A, is different from that for a small letter, say a. EBCDIC (Extended Binary Coded Decimal Interchange Codes) for alphanumeric characters are 8-bit codes and do not have this distinction, that is. Capital letters are always used.

1.11.2 Mouse

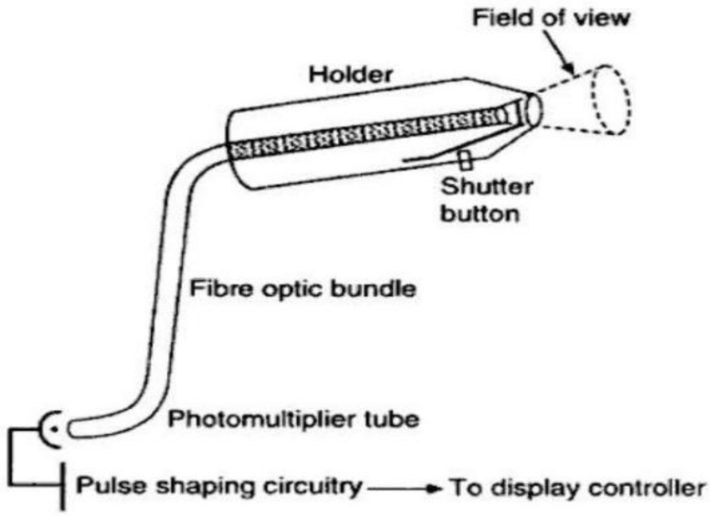


The mouse (Figure 2.13) is a pointing device which has been gaining importance with the advent of microprocessors and the pull-down menus associated with application software. The mouse operates on three principles: mechanical, optical and optomechanical. The mechanical mouse contains a free-floating ball with rubber coating on the underside which, when moved on a firm plane surface, is able to follow the movement of the hand. The motion of the ball is resolved into X- and Y-motions by means of the two rollers pressed against the ball. They, in turn, control the cursor on the screen, which can then be utilized for any desired applications by means of the clicking of the buttons on the mouse. This can only suffice to point on the screen but not for giving positional data. Further, the mouse is a relative device and not an absolute pointing device.

Unlike the mechanical one, the optical mouse is used in conjunction with a special surface (the mouse pad). Movements over this surface are measured by a light beam modulation and optical encoding techniques. Since the light source is located at the bottom, the mouse must be in contact with the surface tor the screen cursor to follow its movements. Pushbuttons may be mounted on top of the mouse and programmed to execute various functions.

1.11.3 Light pen

A lightpen resembles a fountain pen in the method of holding, but it works on the principle of light rather than ink, from which it derives its name. The lightpen is a pointing or picking device that enables the user to select a displayed graphics item on a screen by directly touching its surface in the vicinity of the item. The application program processes the information generated from the touching to identify the selectable item to operate on. The lightpen itself does not emit light but rather detects it from the graphics items displayed on the screen. Using the emitted light as an input, it sends an interrupt signal to the computer to determine which was seen by the pen. The lightpen normally operates as a logical pick in conjunction with a vector refresh display.



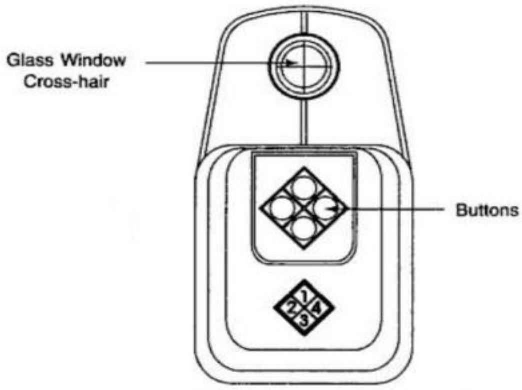
1.11.4 Joystick

Vertical and horizontal displacements of a joystick produce corresponding movements of the cursor on the screen. The extreme positions of these displacements correspond to the four corners of the screen. A joystick (Figure **2.**16) may be equipped with a rotating knob on the top, which can be used to enter a third axis value, thus making the joystick a three-dimensional input device. Springs are often provided to return the joystick to its position at the centre. Joysticks are suitable for raster display systems and have become very popular in the home computer market. In CAD systems, they are most effectively used in conjunction with screen display type menu facilities.

1.11.5 Digitiser

A digitizer is the most widely used input medium by the CAD designer. It is used for converting the physical locations into coordinate values so that accurate transfer of data can be achieved. Very high resolution in the order of 0.1 mm or better can be achieved. A tablet is essentially a low resolution digitizer having a small work area. The work area corresponds to the full CRT screen.

The designer can work with any pointing device similar to a pen, and do normal writing on the tablet as if he were doing so on a drawing board. The movement of the pen tip would be communicated onto the screen, which the designer can modify depending on the software at his disposal. Since it gives natural feel to a designer for free form sketching (which can be straightened if necessary by the software), it is generally preferred as a pointing device in CAD applications. Another kind of pointing device used in tablets is a puck, which has a cross hair line cursor and a number of buttons, as shown in Fig. 2.5 as used normally with other digitizers. This would be useful for the menu selection. The buttons can be assigned for different auxiliary functions.



Puck or Pointing Device used with Tablets and Digitizers

Digitizer

A digitizer consists of a rectangular smooth surface as a draughting board, as shown in Fig. 2.6. Underneath this surface would be a position-sensing mechanism. The designer interacts through the hand-held locator which contains a number of buttons. The designer can move the puck to the desired position and then by pressing one of the buttons to initiate a certain action. A digitizer is an absolute measuring device.

1.11.6 Trackball

A trackball is similar in principle to a joystick but it allows more precise fingertip control. The ball rotates freely within its mount. The trackball is used in radar and flight control systems. The trackball is used to navigate the screen display cursor.

1.12 CLASSIFICATION OF HARDWARE CONFIGURATIONS

The classification hardware configuration is as follows:

(a) Mainframe-based systems

(b) Minicomputer-based systems

(c) Microcomputer-based systems

(d) Workstation-based systems

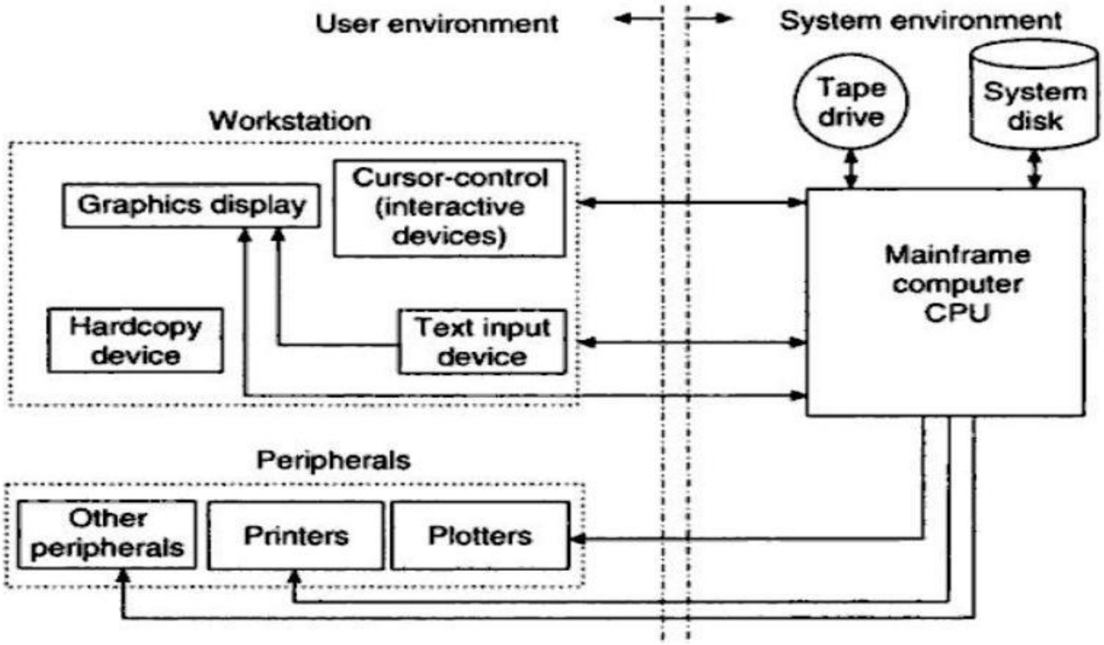
1.12.1 Mainframe-based Systems

Mainframe-based CAD/CAM systems are used in large organizations for handling massive amounts of data and a multitude of concurrent activities of remote separate software applications. Mainframes often host hundreds of remote workstations operating and communicating over a vast network (sometimes covering thousands of kilometers and crossing international boundaries).

Below Figure shows a schematic of the mainframe-based CAD system components and details of a workstation. The computer environment is divided into:

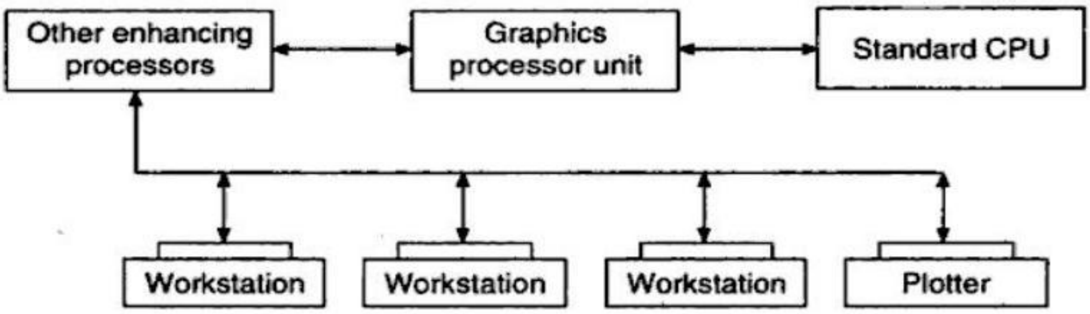
- The user environment
- The system environment

The user environment signifies the components and the area which the user can access. These components include primarily workstations and peripherals. The mainframe can support as many workstations as possible to avoid degradation of the response time between the users and the system. A typical workstation consists of input and output devices. The input devices may include cursor control devices for graphics input and text input devices. The cursor can be controlled via a light pen, joystick, mouse, electronic pen with a digital tablet, thumbwheel, or trackball. Text input can be input through a keyboard, which may have programmed function keys. Output devices consist of a graphics display with a hardcopy printer to provide convenient raster plots of full screen contents.



1.12.2 Minicomputer-based Systems

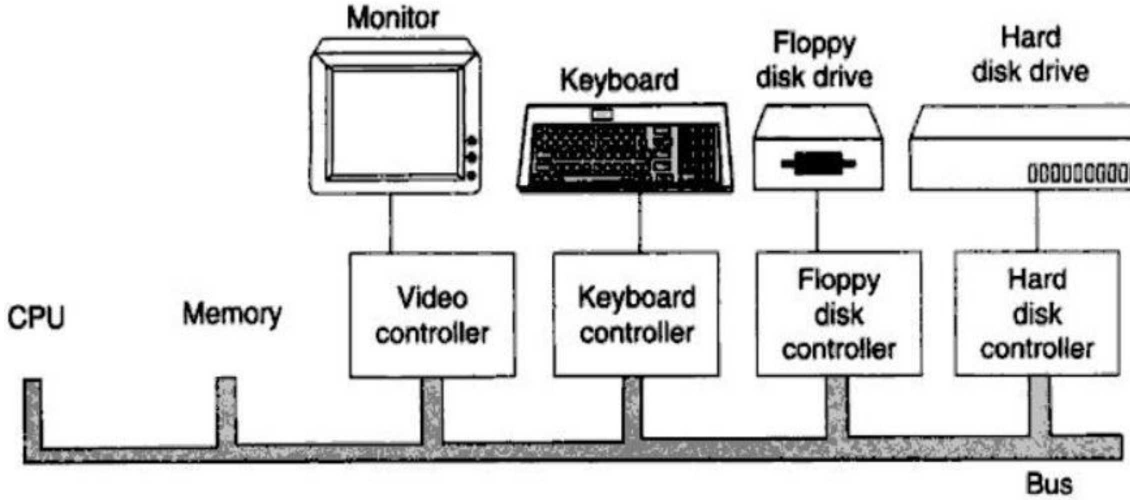
The development of VLSI (very large scale integrated) circuits has changed the basic principles of computer architecture and has directly led to the proliferation of minicomputers. Early versions on minis were 16-bit word, slow and limited-storage computers.



The DEC (Digital Equipment Corporation) PDP series offers a typical example. In the late 1970s, the arrival of super 32-bit word and virtual memory operating systems, boosted CAD/CAM applications and facilitated decentralization from mainframes. Minicomputers have enabled the rapid growth of the CAD/CAM industry. The 32-bit minicomputer is capable of handling complex geometric software and large quantities of data. The schematic of minicomputer is shown in above figure.

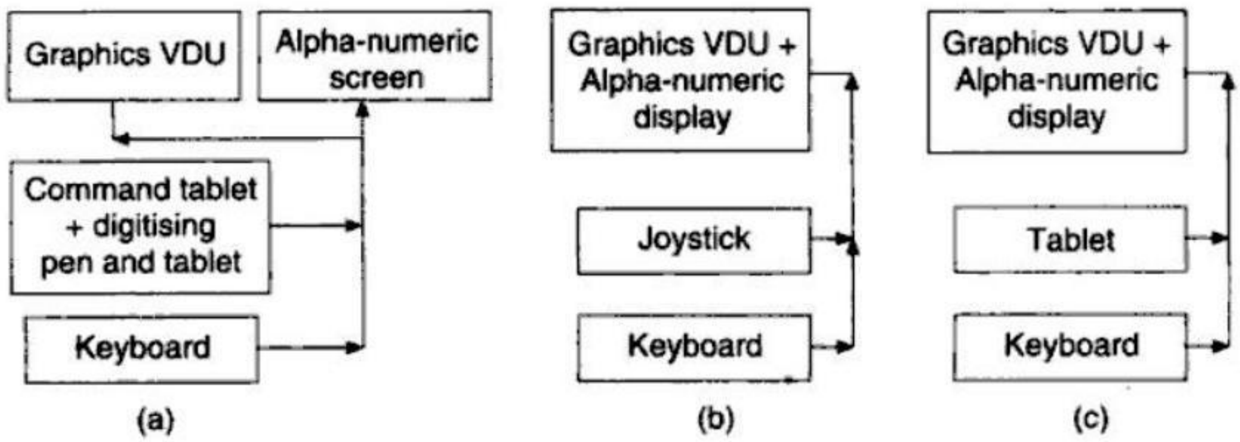
1.12.3 Microcomputer-based Systems

The advent of the IBM Personal Computer (PC) provided the first significant impetus for CAD on micros. Two main factors are responsible for the popularity and fast emergence of micro-based CAD systems. First, the speed, size, and accuracy problems are being reduced. Microcomputers of a 32-bit word length are available with enough memory size, disk storage, and speed for CAD/CAM applications. Second, various application programs have matured and cover most, if not all user needs.



1.12.4 Workstation-based Systems

Graphics terminals attached to mainframes, minis, or PCs do not qualify as workstations. These terminals may be referred to as work stations* (two words). A workstation can be defined as a 'work station' with its own computing power to support major software packages, multitasking capabilities demanded by increased usage and complex tasks, and networking potential with other computing environments. The workstation concept seems to form (he basis of the present generation of CAD/CAM systems.



The basic elements of a CAD workstation are:

- A graphics screen called the VISUAL DISPLAY UNIT (VDU)
- An ALPHA-NUMERIC DISPLAY (word and number screen)
- A workstation PROCESSOR

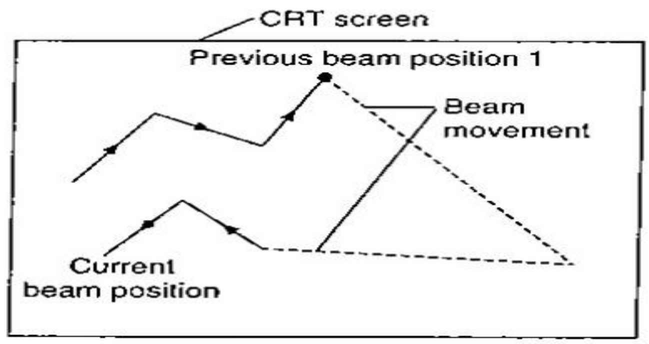
- An electronic COMMAND TABLET
- A MENU facility
- A CURSOR CONTROL device
- A KEYBOARD
- A PRINTER/PLOTTER device

1.13 GRAPHICAL DISPLAYS

The graphical display enables the user to view images and to communicate with the displayed images by adding, deleting, blanking and moving graphics entities on the display screen. Various display technologies are now available based on the concept of converting the computer electrical signals into visible images at high speed. The graphics display can be divided into two types based on the scan technology used to control the electron beam when generating graphics on the screen. These are:

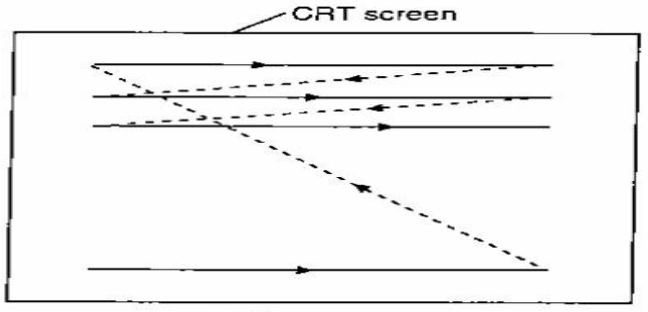
- Random scan
- Raster scan

In random scan, graphics can be generated by drawing vectors or line segments on the screen in a random order, which is controlled, by the user input and the software. The principle of random scan is illustrated in below figure.



Random scan

In raster scan, the screen is canned from left to right, top to bottom, all the time to generate graphics. The principle of random scan is illustrated in below figure.

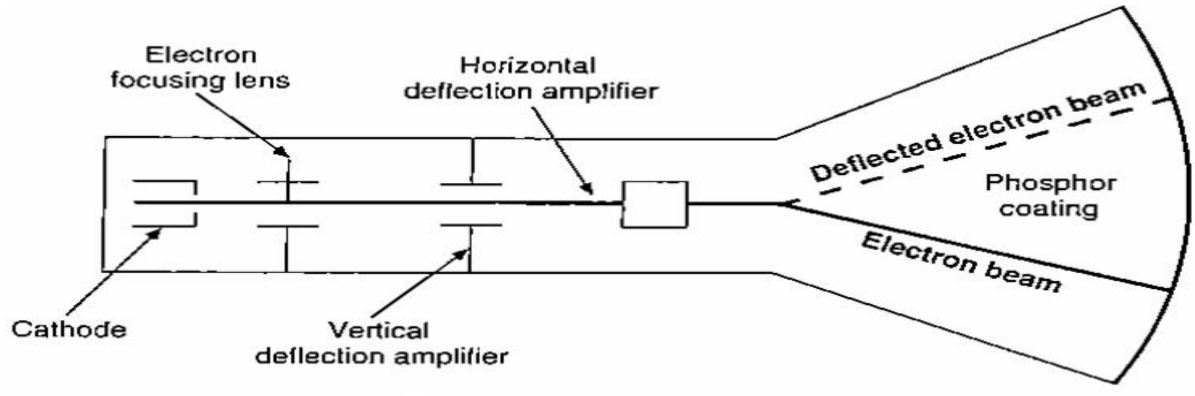


Raster scan

The graphic display technologies include:

- CRT (cathode ray tube)
- Liquid crystal display
- Plasma panel display

The CRT is basically an evacuated glass tube in which a beam of electrons is fired from an electron gun onto a phosphor-coated screen, resulting in an illuminated trace being displayed on the screen.

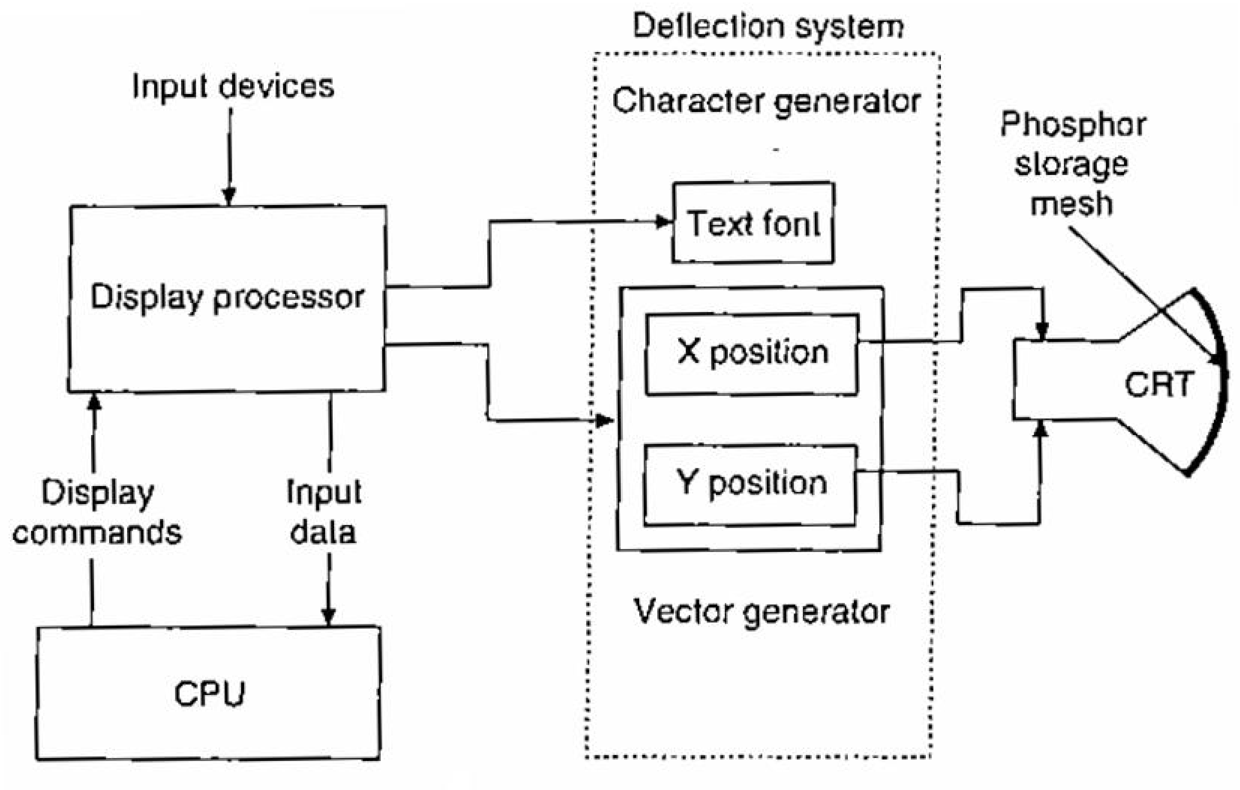


Schematic of a CRT..

Various types of CRT displays are broadly categorized into:

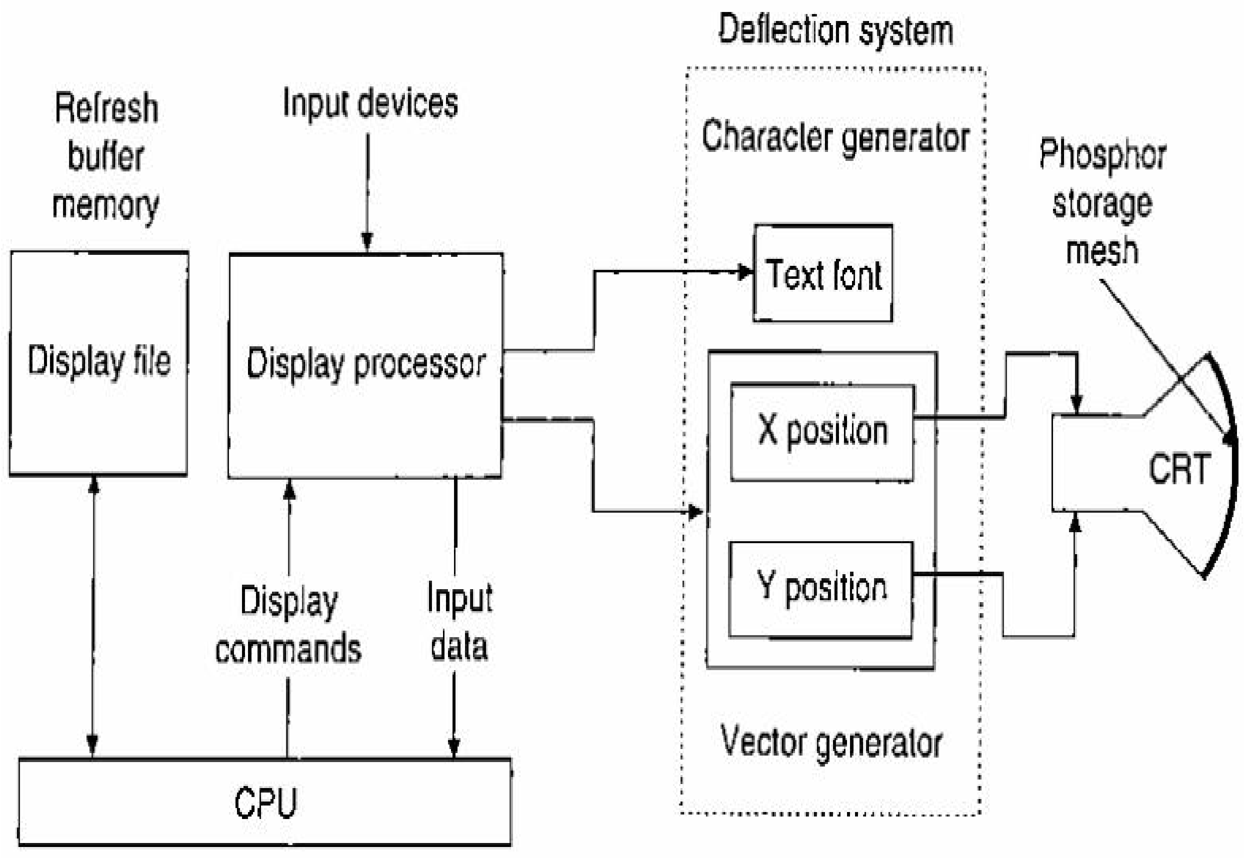
- Direct view storage tube (DVST)
- Vector refresh
- Raster refresh

The **DVST** (Direct View Storage Tube) has the standard CRT electron gun and deflection system for location of the beam onto the screen. The picture is stored as a charge in the phosphor mesh located behind the screen surface. Once displayed, the picture remains on the screen until it is explicitly erased. Therefore, complex pictures can be drawn without flicker at high resolution. One cannot alter a DVST picture except by erasing the entire screen and drawing it again. The inability to erase and edit individual areas of the drawing is a major drawback of the DVST system. Colored pictures are not usually available with a DVST. This can be a distinct disadvantage, particularly for three-dimensional drawings. Animation is also difficult to achieve, a factor that effectively disallows such vital facilities as tool-path simulation, and dynamic analysis of mechanisms.



Direct view storage tube.

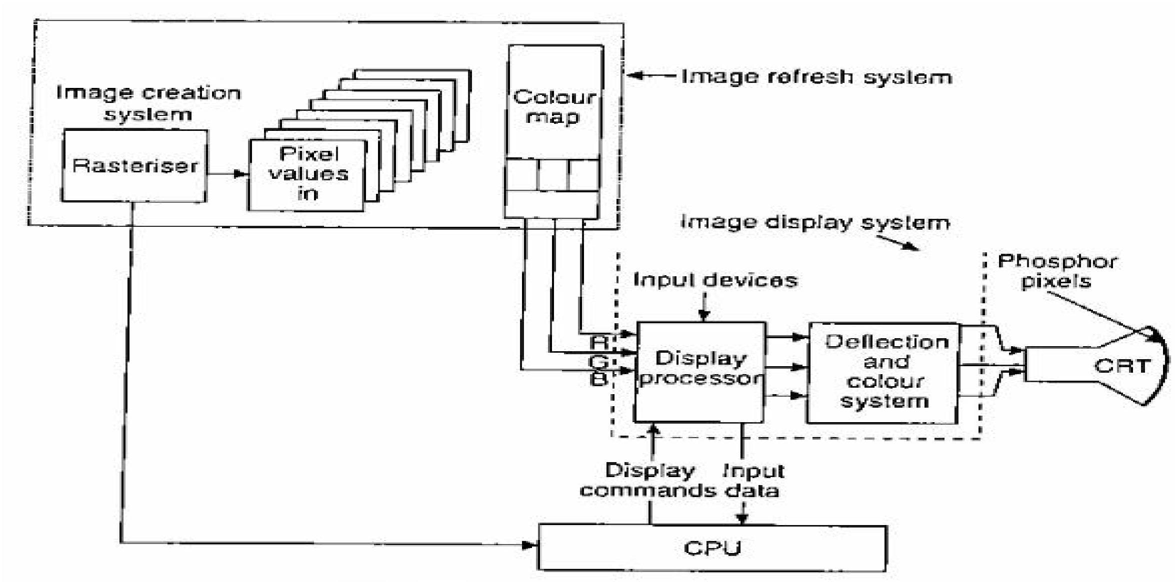
In **vector refresh display,** the deflection system of the CRT is controlled and driven by the vector and character generators and digital-to-analog converters. The refresh buffer stores the display file that contains points, lines, characters, and other attributes of the picture to be drawn. These commands are interpreted and processed by the display processor. The electron beam accordingly excites the phosphor that glows for a short period. In order to maintain a steady flicker-free image, the screen must be refreshed or re-drawn at least 30 or 60 times per second. Vector refresh displays are particularly noted for their bright, clear image, and high drawing speed. The refresh operation is well-suited to fast moving animation of the screen display in either 2D or 3D. The chief disadvantages of vector refresh displays are their high cost, and their tendency to flicker on complex drawings if the refresh rate becomes less than the flicker threshold of the eye. Color displays are possible, but again are only available at high cost.



Vector refresh display.

Raster refresh display works on the principle of a domestic television set. In raster display, the display screen area is divided horizontally and vertically into a matrix of small elements called picture elements (pixels). A pixel is the smallest addressable area on a screen as shown in Figure 2.25. A n N x M resolution defines a screen with N rows and M columns. Each row defines a scan line. A typical resolution of a raster display is 1280 X 1204. The pixels are controlled by the electron beam as it sweeps across the screen from one side to the other. The beam always starts its sweep from the top left-hand corner of the screen, regardless of what has been drawn, finishes on a horizontal line to the right, moves down one row of pixels, returns, and starts again from the left. The display is completed when the beam has reached the bottom right of the screen. It then refreshes by commencing the whole procedure again at the top left. Each refresh operation takes about 0.02 seconds. Images are displayed by converting geometric in format ion into pixel values, which arc then converted into electron beam deflection through the display processor and the deflection system.

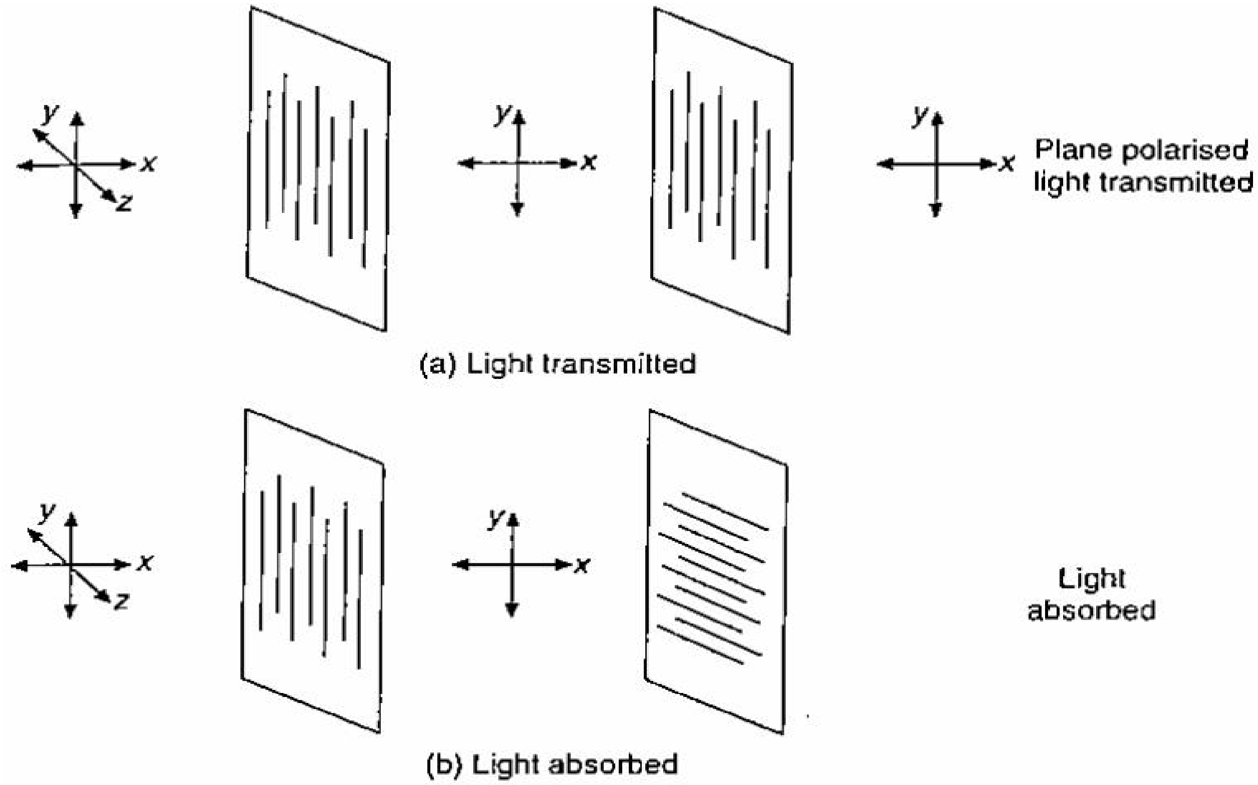
In a **color raster display**, there are three electron guns, one for each of the primary colors, red, green and blue. The electron guns are frequently arranged in a triangular pattern corresponding to a similar triangular pattern of red, green and blue phosphor dots on the face of the CRT. In order to ensure that the individual electron guns excite the correct phosphor dots (e.g., the red gun excites only the red phosphor dot), a perforated metal grid is placed between the electron guns and the face of the CRT. The perforations in the shadow mask are arranged in the same triangular pattern as the phosphor dots.



Colour raster refresh display

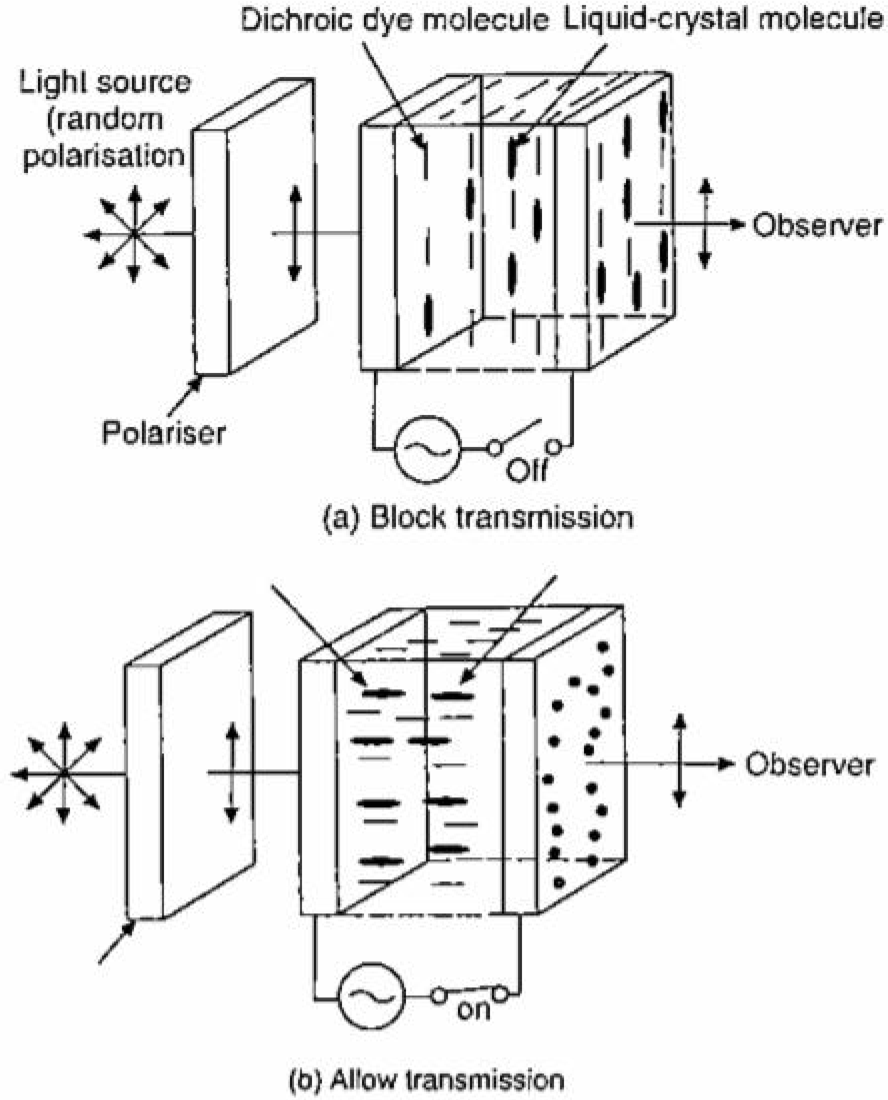
The distance between perforations is called the pitch. The color guns are arranged so that the individual beams converge and intersect at the shadow mask. Upon passing through [he hole in the shadow mask, the red beam, for example, is prevented or masked from intersecting either the green or blue phosphor dot; it can only intersect the red phosphor dot. By varying the strength of the electron beam for each individual primary color, different shades (intensities) are obtained. These primary color shades are combined into a number of colors for each pixel.

In a **liquid crystal display** transmitted or blocked, depending upon the orientation of molecules in the liquid crystal. The polarizing characteristics of certain organic compounds are used to modify the characteristics of the incident light. The basic principles of polarized light are shown in below figure. In figure (a) non-coherent light is passed through the first (left) polarizer. The resulting transmitted light is polarized in the *x-y* plane. Since the polarizing axis of the second polarizer is also aligned with the *x-y* plane, the light continues through the second polarizer. In figure (b) the polarizing axis of the second polarizer is rotated 90° to that of first. Consequently, the plane polarized light that passed through the first polarizer is absorbed by the second.



Polarisation of light.

Color liquid crystal displays use colored filters or phosphors with twisted nematic technology or use guest-host (dye) technology. Guest-host liquid crystal displays combine dichromic-dye guest molecules with the host liquid crystal molecules. The spectral characteristics of different guest molecules are used to produce different colors. The application of an electric field realigns the orientation of both the guest and host molecules, lo allow transmission of light. A typical guest-host transmissive liquid crystal display is shown in below figure.



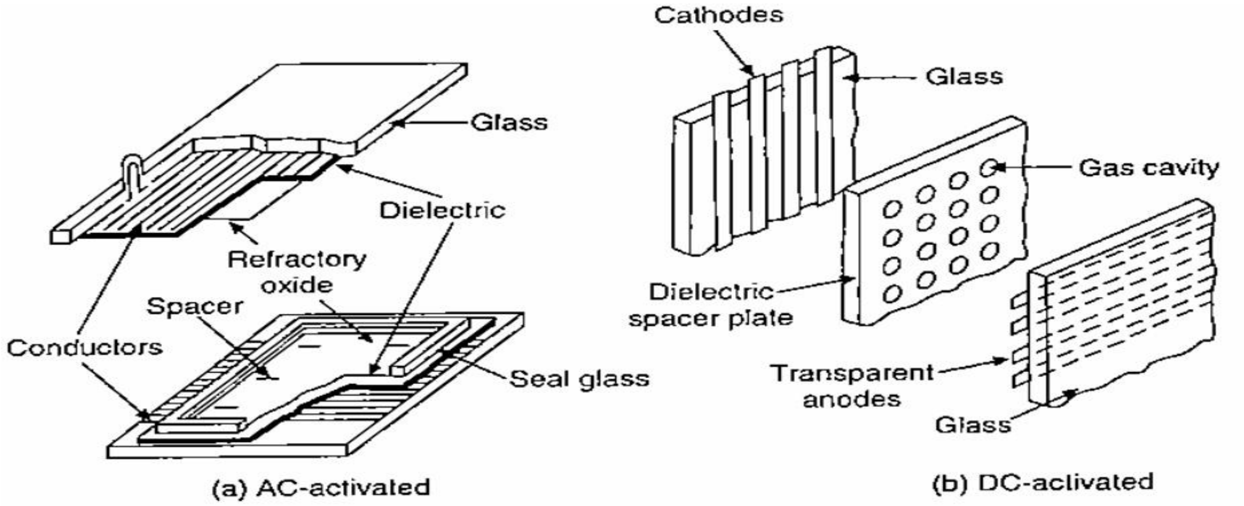
Guest-host liquid crystal display.

The **plasma display** contains a gas at low pressure sandwiched between horizontal and vertical grids of fine wires. A tower voltage will not start aglow but will maintain a glow once it is started. Normally, the wires have this low voltage between them. To see a pixel, the voltage is increased momentarily on the wires that intersect the desired point. To extinguish a pixel, the voltage on the corresponding wires is reduced until the glow cannot be maintained.

Plasma displays can be AC or DC or hybrid AC/DC activated. AC and DC plasma displays are shown in below Figure. The DC-activated display consists of a dielectric spacer plate, which contains the gas cavities sandwiched between plates containing the row-column conductors. The electric field is applied directly to the gas. A DC-activated plasma display requires continuous refreshing.

In the AC-activated plasma display, a dielectric layer is placed between the conductors and the gas. Thus, the only coupling between the gas and the conductors is capacitive. Hence, an AC-voltage is required to dissociate the gas. AC-activated plasma displays have bistable memory; thus, the necessity to continuously refresh the display is eliminated. Bistable memory is obtained by using a low AC voltage to keep alive voltage. The characteristic capacitive coupling provides enough voltage to maintain the activity in the conducting pixels, but not enough to activate non-conducting pixels.

A hybrid AC/DC plasma display uses DC voltage lo prime the gas and make it more easily activated by the AC voltage. The principal advantage of the hybrid AC/DC plasma display is reduced driver circuitry



Basic structure of gas discharge plasma displays.

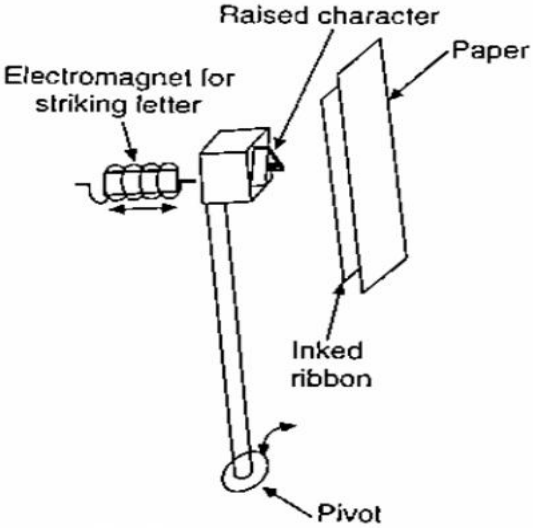
1.14 HARDCOPY PRINTERS AND PLOTTERS

Printers and plotters are used to create check plots for offline editing and producing final drawings and documentation on paper. Printers usually provide hard copies of text as well as graphics.

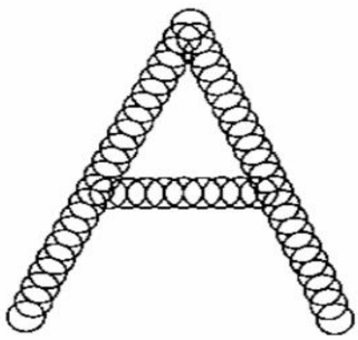
Printers are classified as follows on the basis of three principal technologies used for their operation:

- Impact dot matrix printer
- Ink jet printer
- Laser printer

Impact dot matrix printer: This is an electromechanical device, which creates images on paper from thousands of tiny dots when thin wires create an impact on an ink ribbon. The working principle of dot matrix printer is shown in Figure. Text characters and graphics elements are not displayed as separate items. The complete display is built up from reciprocating horizontal sweeps of the printing head as the paper winds around a rotating drum. Thus, the hard copy is constructed from dots in a similar manner to a raster screen display, with the resulting appearance being much the same. The resolutions that are available vary but range from 60 dots per inch lo 240 dots per inch. Their cost is comparatively low, but a major disadvantage is their noise because of the impact of the pins on the paper. For example, the letter ʿA' is printed with 24 overlapping needles shown in Figure.

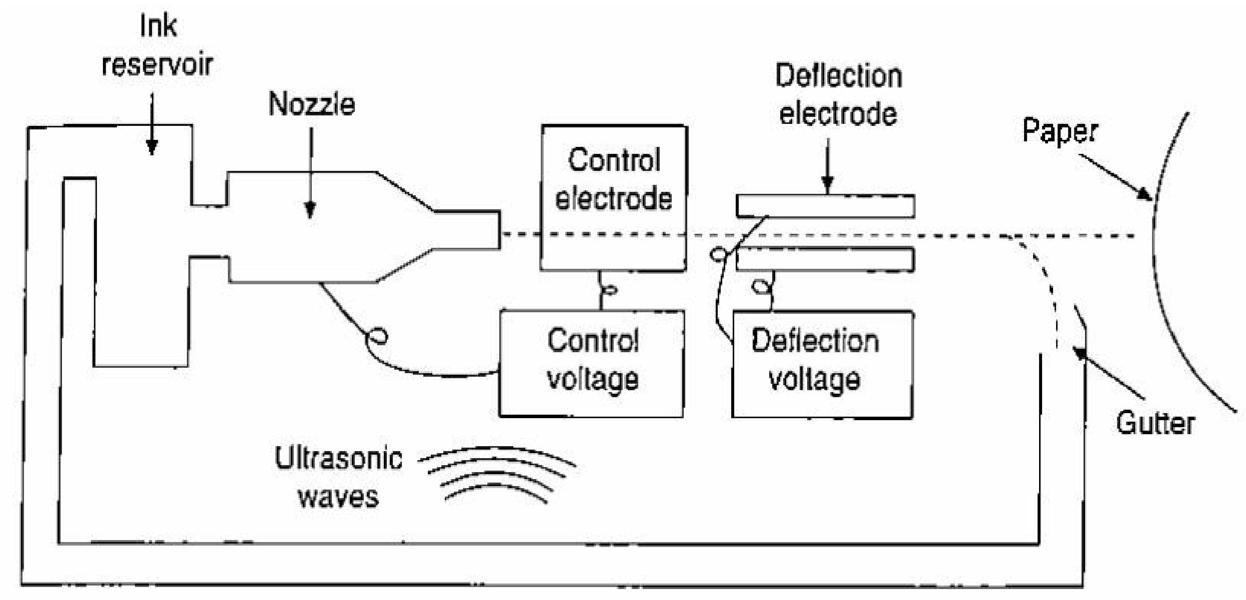


Impact dot matrix printer.


The letter 'A' printed with 24 overlapping needles.

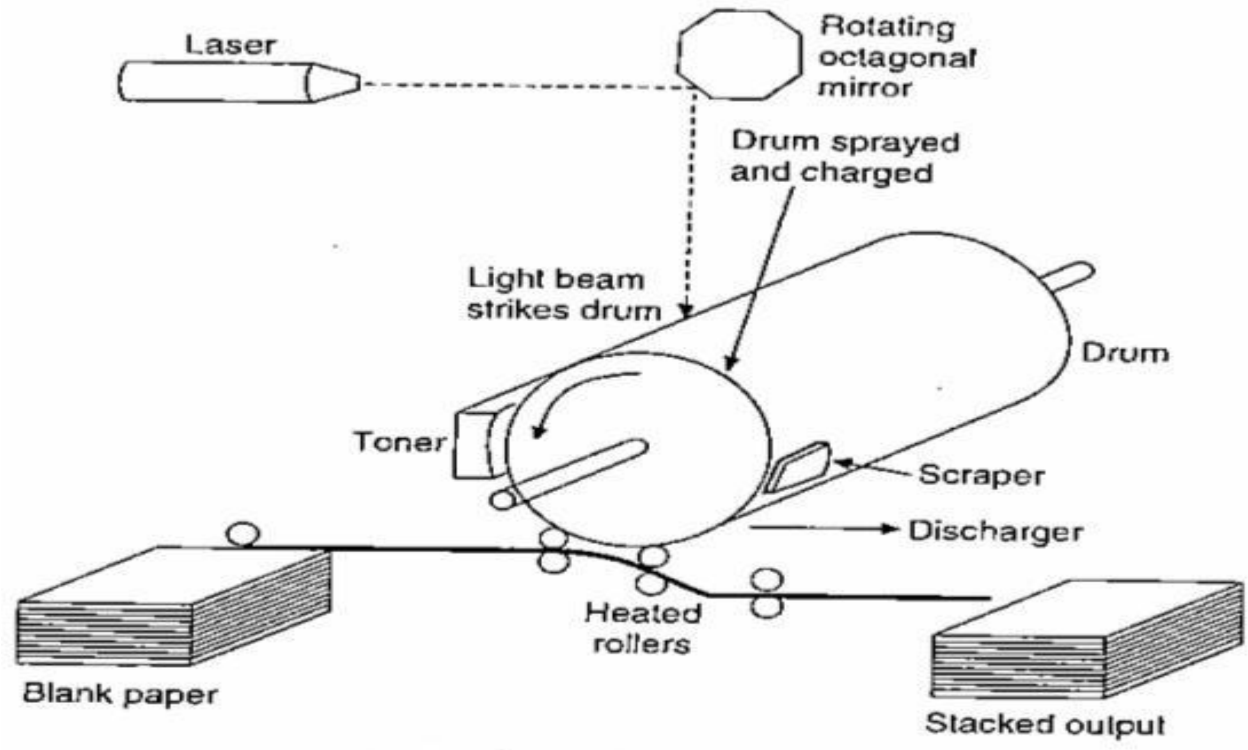
Ink jet printer: This is a raster scan device. The basic principle is to shoot tiny droplets of ink onto a medium. There are two types of ink jet printers, continuous flow and drop-on-demand. The continuous flow ink jet produces a stream of droplets by spraying ink out of the nozzle. The stream of ink from the nozzle is broken up into droplets by ultrasonic waves. If ink is desired on the medium, selected droplets are electrostatically charged. Deflection plates are then used to direct the droplet onto the medium. If not, the droplet is deflected into a gutter, from which the ink is returned to the reservoir. Paper and transparency film are typical media. This system is shown in Figure.

A drop-on-demand printer fires ink at the medium only if a dot is required at a particular location. Here, ink from a reservoir is supplied to a nozzle under pressure. The ink is fired on demand by applying an electric voltage to a piezoelectric crystal as the head makes a pass across the medium. When a voltage is applied, the piezoelectric crystal expands, decreasing the volume of the ink chamber. These causes a drop of ink lo squirt out of the nozzle. Release of the voltage causes the piezoelectric crystal lo contract, decreasing the volume of the reservoir and sucking the link back onto the nozzle. The resolution of ink jet printers is determined by the size of the droplet and hence by the size of the nozzle. Because of the extremely small nozzle size required, nozzle clogging, ink contamination and air bubbles in the ink can be significant problems.



Continuous

Laser printer: This is essentially an electrostatic plain paper copier with the difference that the drum surface is written by a laser beam. The working principle of a laser printer is illustrated in below figure. The heart of the printer is a rotating precision drum. At the start of each page cycle, it is charged up to about 1000 volts and coated with a photosensitive material. Then light from a laser is scanned along the length of the drum much like the electron beam in a CRT only instead of achieving the horizontal deflection using a voltage, a rotating octagonal mirror is used to scan the length of the drum. The light beam is modulated to produce a pattern of light and dark spots. The spots where the beam hits lose their electrical charge. After a line of dots has been painted, the drum rotates a fraction of a degree to allow the next line to be painted. Eventually, the first line of dots reaches the toner, a reservoir of an electroslatically sensitive black powder. The toner is attracted to those dots that are still charged, thus forming a visual image of that line. A little later in the transport path, the toner-coated drum is pressed against the paper, thus transferring the black powder to the paper. The paper is then passed through heated rollers to bind the toner to the paper permanently, fixing the image. Later in its rotation, the drum is discharged and scraped clean of any residual toner, preparing it for being charged and coated again for the next page.



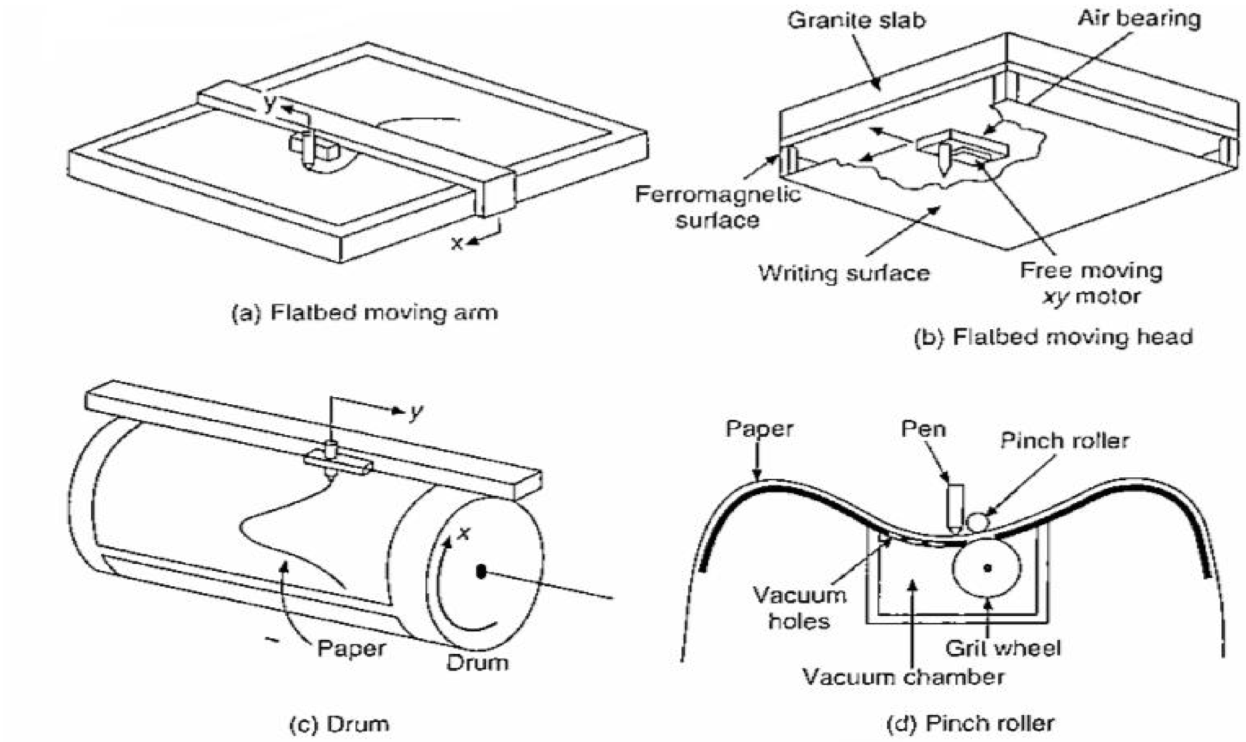
Operation of a laser printer.

Plotter: This is a widely accepted output device for CAD/CAM applications. A large range (A0-A4) of plotters of varying sizes and prices are available. The accuracies achievable are very high and the plots can be made on all types of media such as paper, tracing paper and acetate film. There are three common types of conventional pen plotters: flatbed, drum and pinch roller. Pens may be-of wet ink, Ballpoint or felt-tip type. The basic mechanisms are shown in below Figure.

In a moving-arm flatbed plotter, the medium is fixed in position on the bed of the plotter. Two-dimensional motion of the plotting head is obtained by the movement of an arm suspended across the width of the plotter bed. This provides motion in one direction. Motion in the second direction is obtained by moving the plotting head along the suspended arm.

A moving head flatbed head plotter uses a plotting tool carriage suspended above the bed by magnetic forces that are counter-balanced by an air bearing. This arrangement provides nearly frictionless movement. Movement of the head in two dimensions is controlled electromagnetically by using the Sawyer motor principle.

In the drum plotter the paper is attached to a drum that rotates back and forth, thereby providing movement in one axis. The pen mechanism moves in the transverse direction to provide movement along the other axis.



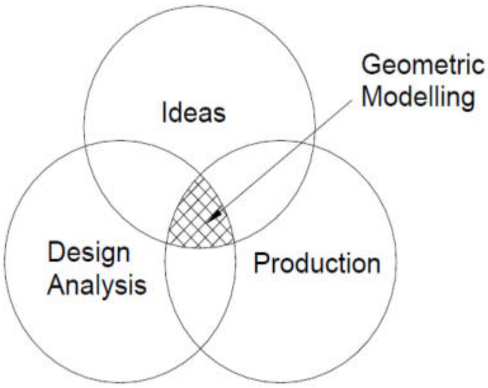
schematic diagrams of pen and ink plotters

1.15 ROLE OF COMPUTER IN MANUFACTURING

- Coordinate measuring machine (CMM)
- Rapid prototyping
- Standardization and Localization
- Conceptual modeling
- FMS (ASRS, AGV, CONVEYERS)
- CIM (Business data processing system)
- JIT, Kanban system
- Inspection
- Robots
- Machine vision
- Coefficient of thermal expansion
- Bill of material (MRP)
- PLM (product lifecycle management)
- Supply chain management
- Feed rotes, D.C, M/C speed
- Scheduling of parts
- Digital manufacturing

GEOMETRIC MODELING

3.1 INTRODUCTION



Geometric modeling is a branch of applied mathematical and computational geometry that studies methods and algorithms for mathematical description of shapes

The shapes studied in Geometric modeling are mostly 2-Dimensional or 3-Dimensional although many of its tools and principles can be applied to sets of any finite dimension. Most Geometric modeling is done with computer and computer based applications. 2-Dimensions models are important in computer typography (The art and technique of arranging type in order to make language visible) and technical drawings. 3-Dimensional models are central to CAD and CAD many applied technical fields. Such as civil, mechanical, architecture, geology, medical image processing.

3.2 NEED OF GEOMETRIC MODELING

For manufacturing automobile engine it require around 10,000 drawings models in various departments with different styles. Once models are prepared using any CAD software, these models can be used in almost all departments of the organization which includes-

1. Designing the parts and assemblies and then performing tolerance analysis of the assemblies
2. Preparation of production drawings of individual parts, subassemblies, assemblies, tooling and jig-fixtures
3. Making structural, thermal and kinetic analysis
4. Considering volume of parts and after extracting material properties from material library, cost estimation can be easily done
5. Process plans are also prepared for all the components
6. Using CAM software's, we can model as input for CNC programming

7. Programming the movement of the components from one station to another is possible using various material devices such as robots, conveyors, automated guided vehicles
8. Using coordinate measuring machine (CMM) dimensional and geometric accuracies are checked by extracting various dimensions and parametric from the models only
9. Other supporting activities such as material requirement and procurement, preparation of bill of materials, manufacturing resource requirement, planning and scheduling, analysis

With competitions products etc are also possible once geometric models are available thus for all these activities, geometric models becomes the central that will be manipulate at all these storages. While modeling, geometric models are prepared in such a way that the other modules such as CAM, CAE, Mechanism systems are able to use this information in the most optimal and efficient way.

3.3 REQUIREMENTS OF GEOMETRIC MODELING

The requirement of geometric modeling is manifold. The conceptual design is the basis of the generation of geometric model. The choice of the geometric model depends on the mechanical functions to be performed by it. A valid geometric model is created by CAD system and its model database is stored. The database of geometric modeling is used for engineering analysis and for design optimization. Design testing and evaluation may necessitate changing the geometric model before finalizing it. When the final design is achieved, it is documented and used for subsequent manufacturing applications, quality and cost analysis.

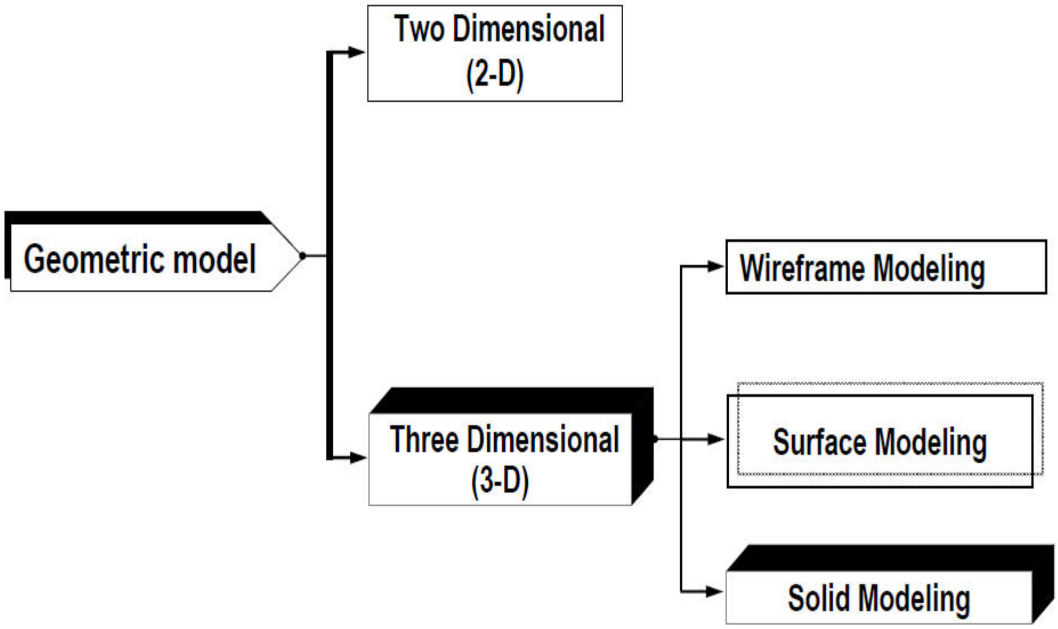
Good geometric model is designed based in the following important guidelines-

1. Modeling method must be easy to use
2. Completeness of part representation
3. Representation should be able to represent a useful set of geometric objects
4. Model should not create any ambiguity (The ability to express more than one interpretation) to users. A given representation should correspond to one and only one solid
5. To represent the solid normally there should only unique way. With this one can compare two identical solid representations
6. A geometric model must be very accurate. There should not be any approximation
7. Geometric modeling should not create any invalid or impossible models
8. The various transformations such as move, rotation, scale etc and manipulations such as union, intersect, subtract etc should able to be performed on geometric model

9. A good representation should be compact enough for saving space and allow for efficient algorithms to determine desired physical characteristics
10. Geometric model should have shading and rendering (Generation an image for a model by means of a computer program) capability to give realistic effect to the model

3.3 GEOMETRIC MODELS

The geometric models are broadly classified on the basis of geometric construction into the following categories



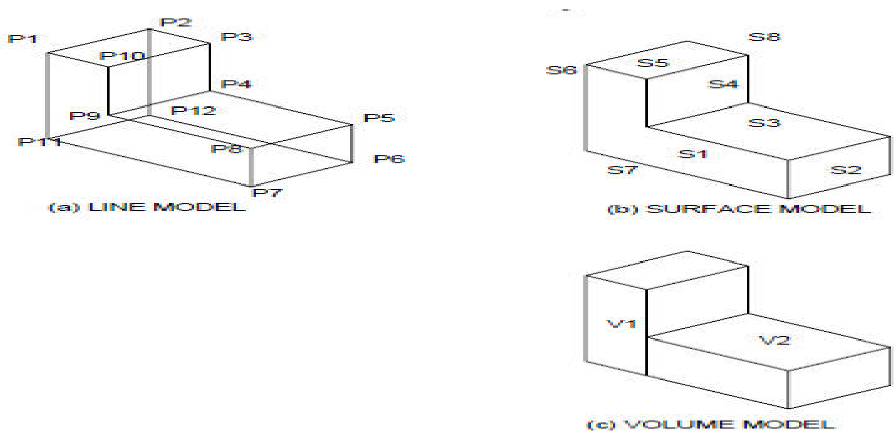
1. Two Dimensional (2D)
2. Three Dimensional (3D)

3.3.1 Two Dimensional (2D)

The 2D modeling includes the construction of geometrical faces, plane drawings, 2D views (Top, Front, Right, and Light views) of objects. Presently, the application of 2D model is limited to drafting, sheet metal manufacturing, Spot welding, Laser cutting etc.

3.3.2 Three dimensional (3D)

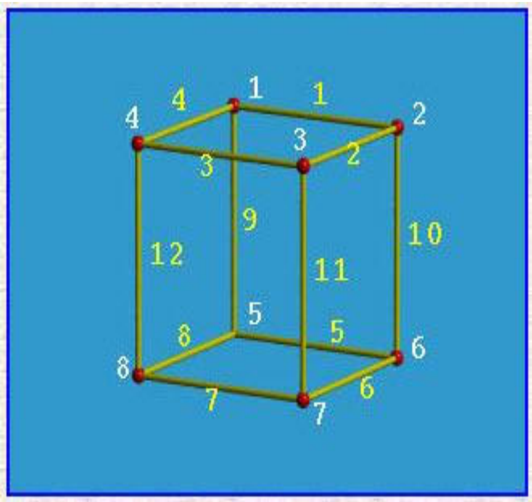
The 3D modeling is widely used for engineering applications. It provides all the information required for animation, design analysis and manufacturing. The 3D objects are shown in below figure.



(a) LINE MODEL (b) SURFACE MODEL (c) VOLUME MODEL

The 3D models are further sub-divided into **three** groups:

1. **Wireframe modeling**



Edge Table		
Edge #	Start Vertex	End Vertex
1	1	2
2	2	3
3	3	4
4	4	1
5	5	6
6	6	7
7	7	8
8	8	5
9	1	5
10	2	6
11	3	7
12	4	8

Vertex Table			
Vertex #	x	y	z
1	1	1	1
2	1	-1	1
3	-1	-1	1
4	-1	1	1
5	1	1	-1
6	1	-1	-1
7	-1	-1	-1
8	-1	1	-1

Wireframe modeling is the oldest and simplest methods of geometric modeling which can be used to store model mathematically in the computer memory. It contains information about the locations of all the points (vertices) and edges in space coordinates. Various wireframe entities are points, lines, planer arcs, circle, curves etc. Each vertex is defined by x, y, z coordinates. Edges are defined by a pair of vertices and faces are defined as three or more edges. Thus wireframe is a collection of edges, there is no skin defining the area between the edges. This is the lowest level of modeling and has serious limitations. But it some applications such as tool path simulation it is very convenient to use wireframe models.

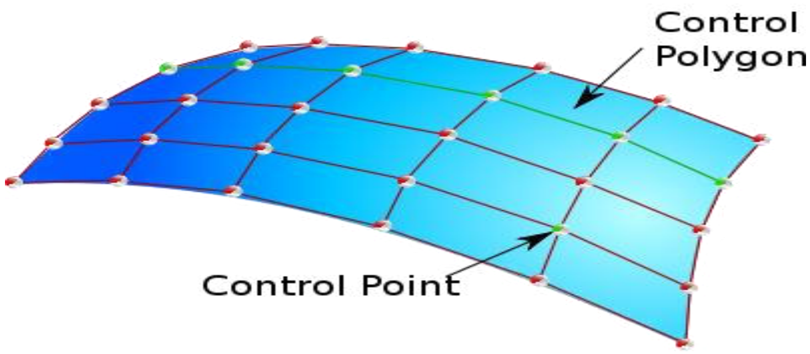
Advantages of wireframe models:

1. It is simple methods and requires less memory space
2. It forms the basis for surface and solid modeling
3. Manipulations in the model can be done easily and quickly

Disadvantages:

1. One of the serious limitation in the ambiguity of orientation and viewing plane
2. Cannot model complex curve surfaces
3. Does not represent an actual solid (no surface and volume)
4. Physical properties such as mass, surface area, volume, centre of gravity etc are not possible to calculate
5. Wireframe models has no knowledge of surface faces, therefore it will not detect interface between two matting components and this is serious drawback especially in component assembly, kinematic analysis, NC tool and robot arm simulation

2. Surface modeling



Surface modeling is the next stage of wireframe modeling. In wireframe modeling models are unable to represent complex surfaces of objects like car, ship, aeroplane, wings, castings etc. only a surface profile of these objects. A surface model represents the skin of an object. These skins have no thickness or material type. Surface models define the surface properties, as well as the edges of objects. These are often capable of clearly representing the solid from the manufacturing. However, no information regarding the interior of the solid model would be available which could be relevant for generating the NC cutter data. Further the calculation of properties such as mass and inertia etc would be difficult. Surface modeling facilities would be available as part of the modeling technique and would be used when such surface is present in the product for design. For example this method is used mode for specific non-analytical surfaces, called sculptures surfaces such as those used for modeling the car bodies and ship-hulls. There are a number of mathematical techniques available for handling these surfaces such as Bezier and B-splines.

Advantage:

1. Eliminates much ambiguity and non-uniqueness present in wireframe models by hiding lines not seen

2. Renders the model for better visualization and presentation, objects appear more realistic
3. Provides the surface geometry for CAM, NC machine
4. Provides the geometry needed by the manufacturing engineer for mould and die design
5. This can be used to design and analysis complex free-formed surfaces of ship hulls, aeroplane fuselages and bodies
6. Surface properties such as roughness, color and reflectivity can be assigned and demonstrated

Disadvantages:

1. Provides no information about the inside of an object
2. Curved surfaces need a fine mesh to be accurate
3. Provides wrong results if mesh is too coarse
4. Complicated computation, depending on the number of surfaces

3. Solid modeling

Solid modeling is the most powerful of 3D modeling technique. This includes vertices (nodes), edges, surfaces, weight and volume. This model consisting of the complete description of the solid in a certain form is the most ideal representation, as all the information requires at every stage of product cycle can be obtained with technique. Defining an object with a solid model is the easiest way of the available three modeling techniques. The model is a complete and unambiguous representation of a precisely enclosed and filled volume. Solid model contain bath geometric and available to represent the solid, but geometry two techniques are very famous, these are constructive solid geometry (CSG) and boundary representation (B-rep)

Advantages:

1. Mass properties such as area, volume, weight, centre of gravity and moment of inertia can be determined quickly
2. It allows the design engineer to develop and evaluate alternative concepts for parts and assemblies while the design is still a theoretical model.
3. Solid models are non-ambiguous
4. Easily exported to different FEM programs for analysis
5. It can be used in newly manufacturing techniques; CIM, CAM, design for manufacturing (DFM)
6. 2D standard drawings, assembly drawings and exploded drawings are generated from the model

Disadvantage:

1. More intensive computation than wireframe and surface modeling
2. Requires more powerful computers (faster with the more memory)

3.4 DIFFERENCE AMONG WIREFRAME, SURFACE AND SOLID MODELING

Parameter	Wireframe model	Surface model	Solid model
1. Computer memory	Less	Moderate	Large
2. Entities used	Points, line, circle, arc, ellipse, synthetic curves, such as Bezier, hermite, B-spline etc.	Plane, revolve, ruled, tabulated, free form surfaces	Solid primitives as cone, cube, wedge, cylinder, sphere etc
3. Input data required	More	Moderate	Less
4. Automatic orthographic, perspective, isometric view generation	Impossible	Impossible	Easily possible
5. NC code generation	Not possible	Automatic possible	Automatic possible
6. Interference between matting parts	Not possible to detect	Can detect	Can detect
7. Rendering and shadow effect	Not possible	possible	possible
8. Cross sectioning	Not possible done manually	Not possible	Possible done automatically
9. Elimination of hidden lines	Done manually	May be possible	Possible
10. Calculation of physical properties such as volume, surface area, center of gravity, M.I etc	Not possible	Possible to calculate some properties	Possible to calculate all properties required for analysis
11. Design parameters optimization	Not possible	Not possible	Possible
12. Generation of assembly and detail drawings from model and vice versa	Not possible	Not possible	Possible
13. CAD/CAM/CAE modules	Drafting	Drafting, design	Drafting, design, manufacturing, analysis, assembly, mechanism, optimization

3.5 MODELING FACILITIES

The total modeling facilities that one would look for in any system can be broadly categorized as follows:

- The geometric modeling features
- The editing or manipulation features
- The display control facilities

- The drafting facility
- The programming facility
- The analysis features
- The connecting features

3.5.1 Geometric Modeling Features

The various geometric modeling and construction facilities that one should expect to have in any good system are as follows:

1. Various features to aid geometric construction methods, such as Cartesian and polar coordinates, absolute and incremental dimensions, various types of units, grip, snap, object snap, layer etc
2. All 2D analytical features, such as points, lines, arcs, circles, coins, splines, fillets, chamfers etc. In each of these features, various constructional features including interactive and dynamic dragging facilities
3. Majority of the 3D wireframe modeling facilities includes 3D lines, 3D faces, ruled surfaces, linear sweep from 2D topology with any sweep direction, rotational sweep and tapered sweep. General sweep with twist. Rotational about an axis or radial offset for generating helical or spiral shapes
4. Solid modeling with various basic primitives such as block, cylinder, sphere, cone, prism, torus, pyramid, quadrilateral, along with the ability to apply the Boolean operation on any solid that can be constructed using the other techniques available in the modeler
5. Skinning around regular and arbitrary surface. Profiles (cross-sections), both analytical and arbitrary places across any 3D curve
6. Sculptured surfaces of the various types like Bezier, Coons and other free form surfaces
7. Comprehensive range of transformation facilities for interactively assembling the various solid models generated by the modeler with features such as surfaces filling and trimming

3.5.2 Editing or Manipulation Features

These set of facilities refer to the way the geometric data, once created, would be used to advantage for further modeling. Using these facilities, it would be possible to use the geometry created earlier to complete the modeling, thus improving the productivity of the designer. The facilities designed in this category are:

1. Transformation such as move, copy, rotate, scale, elongate or compress, mirror or to any arbitrary coordinate frame
2. The editing features used to alter the already drawn geometric entities, such as stretching, trimming or trimming to any intersection, delete or erase, undo or redo
3. Symbols in drawing refer to often-repeated together set in number of drawings, which may consist of a number of geometric entities that are grouped together and stored as a symbol. This symbol can be recalled at any scale, at any angle or exploded if necessary to treat all of them as separate entities. Symbols can also be of parametric type so that a large variation in symbols can be done without much effort
4. Some of editing facilities are : resizing, relocating and duplicating, filleting and chamfering, windowing, clipping and zooming, exploding, mirroring, lengthening and shortening, renaming named objects, editing solid

3.5.3 Display Control Facilities

In this range of features are all the facilities needed for interacting with the modeling system so as to obtain the necessary feedback at the right time during the modeling stage. The facilities required are:

Window – to identify a set of entities for any possible display or editing function

Zoom – to change the scale of display of the image selected in the screen

Pan – to move the image on screen without changing the scale at which the drawing is displayed on the screen

Hidden – to remove hidden lines or hidden surfaces for viewing the geometry in proper form

Shading – to show the 3D view of the image on screen complete with the light source location and the resulting light and shade as it appears on the image

Animation – is the display of a number of images in sequence to imitate the actual motion of the part

*Clippin*g – helps in discarding the part of the geometry outside the viewing window, such that all the transformations that are to be carries out for zooming and panning of the image on the screen are applied only on the necessary geometry. This improves the response of the system.

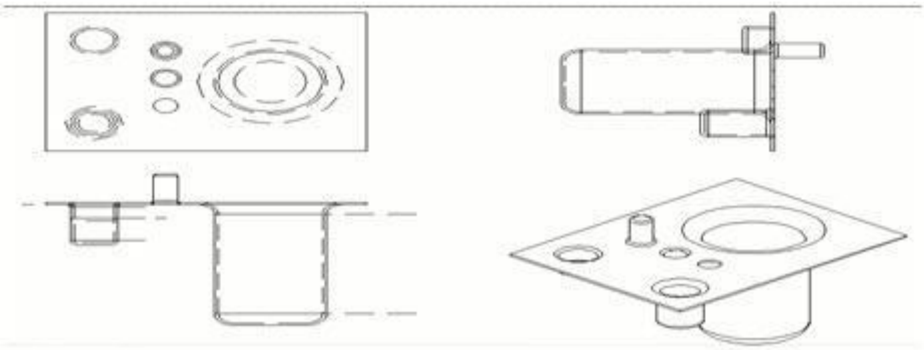
Some other facilities that are required are: *isometric views, sectioning, orthographic* *views, perspective views*

3.5.4 Drafting Features

These facilities refer to the way the model developed can be utilized for purpose of transmitting the information in hard copy form for other applications, such as par prints onto the shop floor or maintenance manuals for the equipment. A really large range of facilities are required in this particular category and it is sometimes treated as a separate module in the modeling system

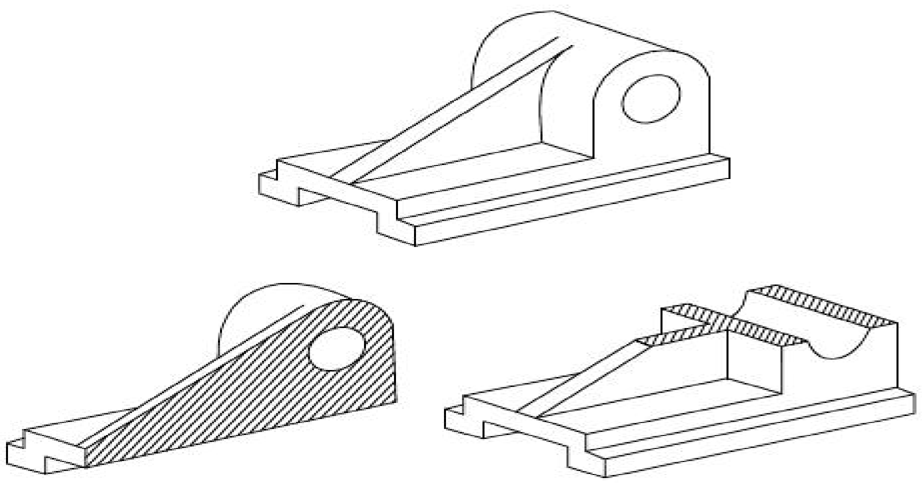
The ability to get various types of lines drawn and provide ample notes in the form of text addition at various locations in the drawing. The text handling capability in terms of font changing and different methods of text presentation should be available.

A large number of types of views should be obtained from the solid model of the geometry stored in the database. The types of views required may be as for display functions, such as perspective views, orthographic views (Shown in below figure), isolated views and axonometric views.



Orthographic views from a Geometric model

It is necessary that the views being shown should be sectioned to get a better appreciation of the model. For this purpose, the section planes may be simple or complex orientations. After sectioning the system should have the automatic ability to show the sectioning details (Shown in below figure) in the form of typical crosshatching depending upon the standard practice.



3.5.5 Programming Facility

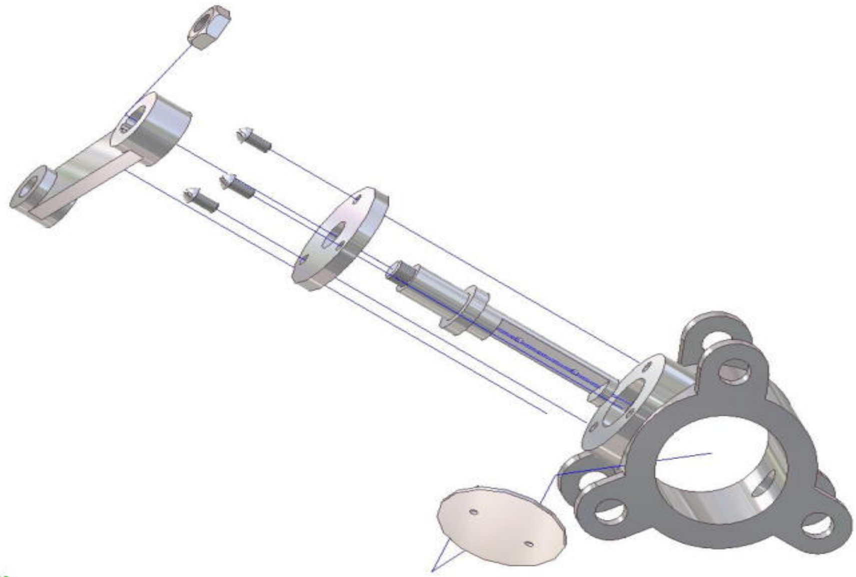
Programming ability (MACRO programming) within a CAD system is going to be a very useful feature. It is well known that not all kinds of facilities would be available in any general-purpose CAD system. Therefore, it is necessary that the CAD system would have to be customized for a given range of application process specific to the company. For this purpose, if a programming facility exists in a CAD system, it is possible to program specifically for an application, making use of all the features available in the system for either modeling or for any specific application based on the information generated during the modeling. Some such examples are the GRIP in unigraphics and GLUE in CAM-X. The availability of such a program helps the user to input the least amount of information for any required design, if the application programs are written well using the programming language.

3.5.6 Analysis and Optimization Features

In this range, the kind of analysis facilities that are require to e carried on the product models being generated should be considered. The simplest kind to the most sophisticated features may be available under this category. The simplest facilities may be calculated perimeter, area, volume, mass, centre of gravity, moment of inertia, radius of gyration etc.

Besides these simple features of analysis, a general-purpose analysis that is normally carried is the Finite Element Analysis (FEA). The geometric model created as above could be conveniently passed onto the FEA through an intermediate processor called a Finite Element Methods (FEM), which converts the geometric data into the finite element mesh and calculates all the data required for the analysis and then transmits it to the FEA program. Examples are the SUPERTAB for GEOMOD and the GFEM for the unigraphics.

Another important feature essential in the modeling system used by the mechanical engineering industries is the assembly facility with the associated interference checking. By this, products individually modeled can be assembly joints are analyzed. This would be further used along with animation facility, if present, to see the performance of the assembly in service. Along with the assembly facility, the other facility needed is the ability to explode an assembly (Show in above figure) for the creation of technical illustrations for the user and maintenance manual preparation.



3.5.7 Connecting Features

Modeling is only the start of the complete process of a product evolution and as such the data generated is used directly by the other systems. It is therefore, necessary that the internal data format in which the data is stores by the modeling system should be well documented and should also have very good connectivity (data interfacing) with other allied modules. Identically, an integrated data base structure would be useful where in all the various modules share the common database. This would only be possible if all the modules are developed at a single developer as in the case of ProEngineer or Unigrapchis for CAD/CAM integration.

3.6 GEOMETRIC CONSTRUCTION METHODS

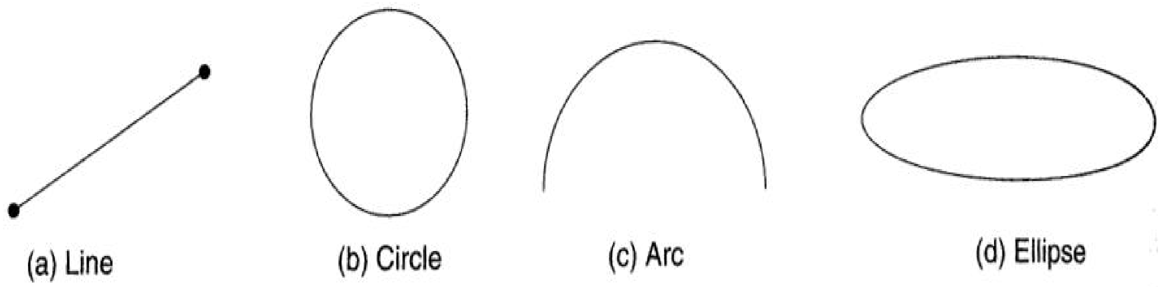
The three-dimensional construction methods are:

- Wireframe modeling
- Surface modeling
- Solid modeling
- Extrusion
- Sweeping

* Feature modeling
* Lofting
* Tweaking

3.6.1 Wireframe Modeling

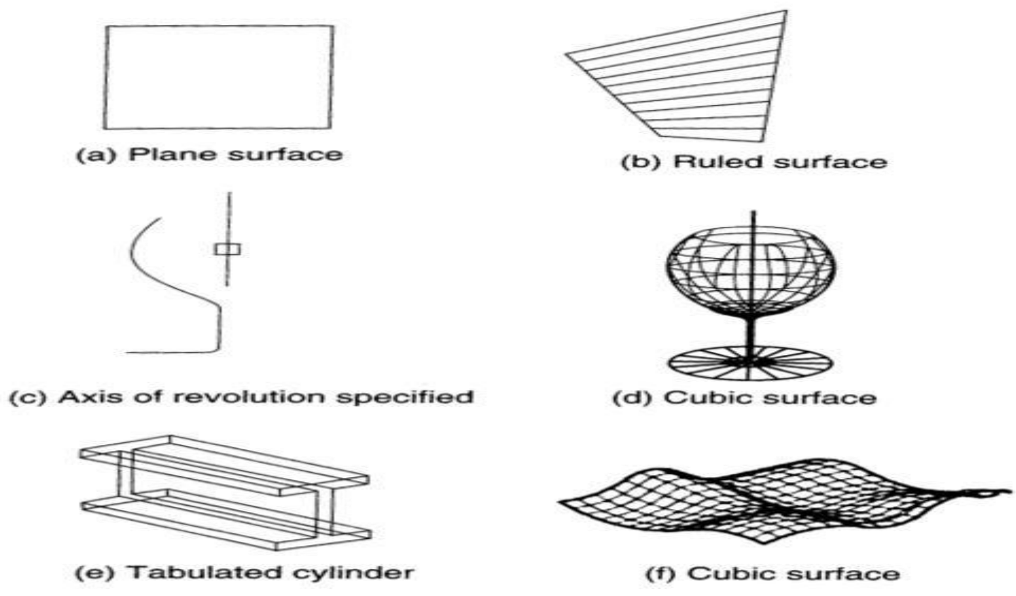
Wireframe modeling uses geometric primitives for the construction of models. The geometric primitives are points, lines, arcs and circles, conies, cubic curve, Bezier curve and B-spline curve.



Wireframe primitives.

3.6.2 Surface Modeling

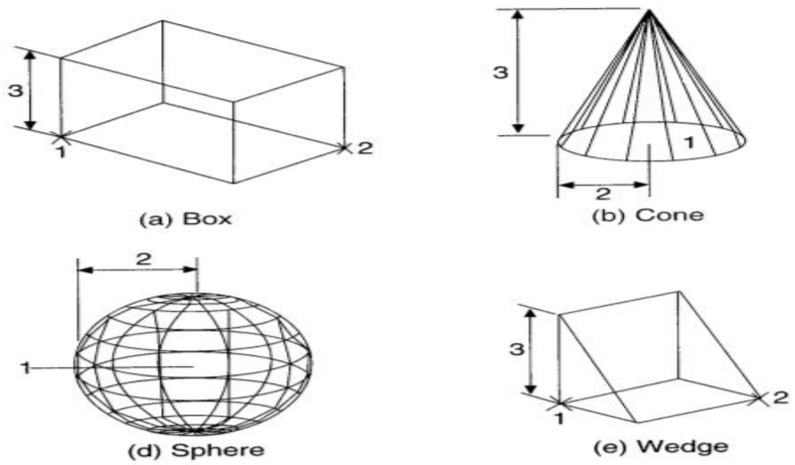
Surface models are generated by using surface primitives such as plane surface, ruled surface, surface of revolution, tabulated cylinder, fillet surface, offset surface, Bezier surface, B-spline surface and coons patch.



Surface entities.

3.6.3 Solid Modeling

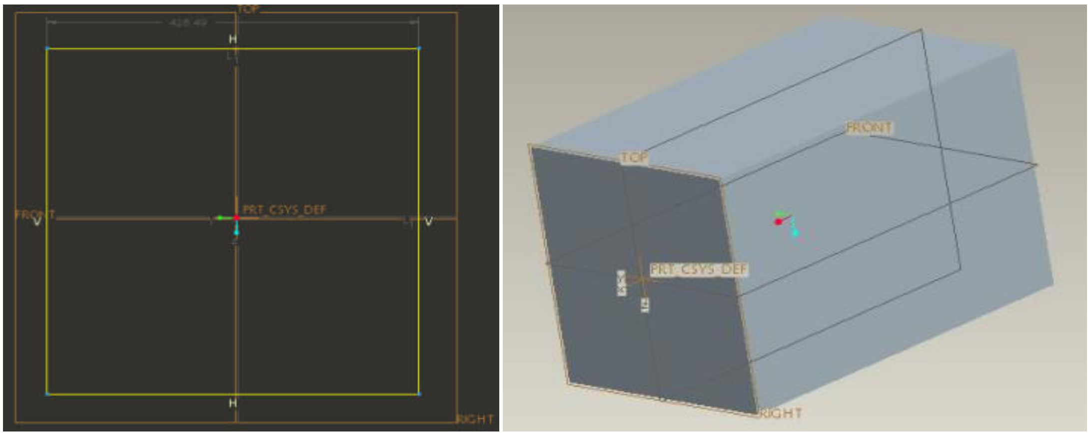
Solid models are constructed by the boundary representation (B-rep) method or by constructive solid geometry (CSG). The solid entities of CSG modeling are box, cone, sphere, cylinder, prism, wedge and torus. CSG modeling constructs solid models through Boolean operations (union, subtraction and intersection) on solid entities.



Solid primitives.

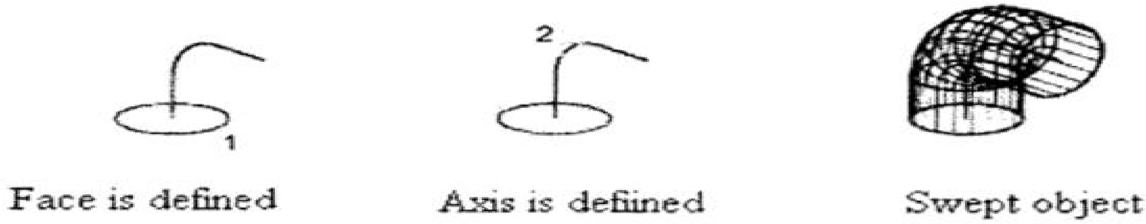
3.6.4 Extrusion

In extrusion, a three-dimensional solid is created by extruding the face in a direction perpendicular to it as shown in below figure.



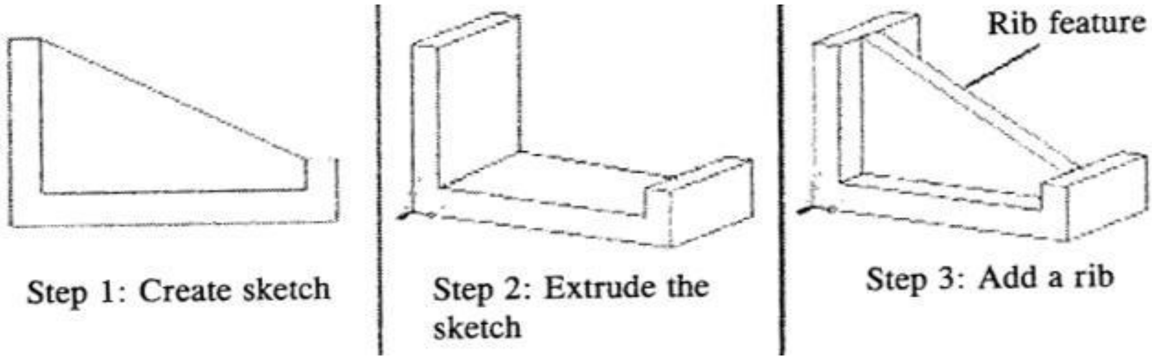
3.6.5 Sweeping

Sweeping is based on the notation of moving a point, curve, or a surface along a given path. A sweep may be linear or non-linear. The linear sweep may involve extrusion or revolving.



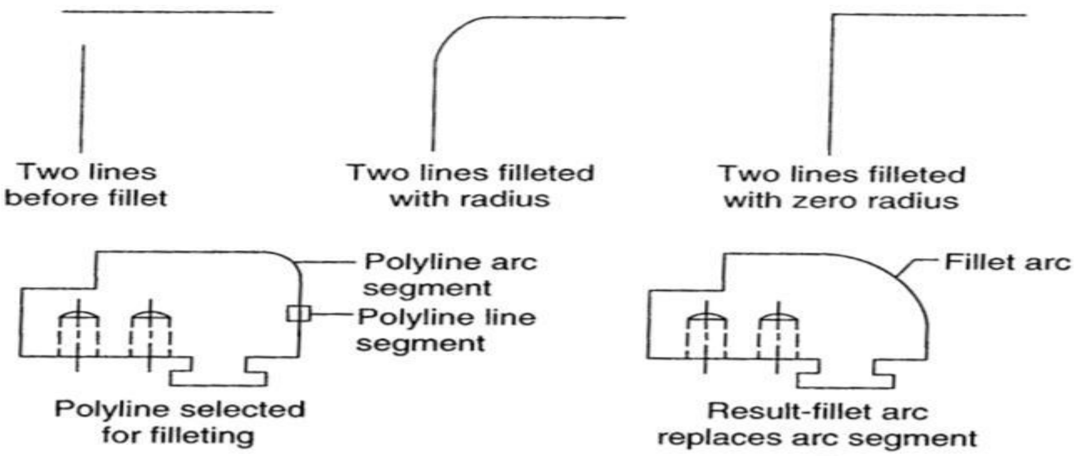
3.6.6 Feature Modeling

This creates solid models from a shape by an operation. The shape is a two-dimensional sketch for example, ribs, bosses, cuts and holes. The operation may involve extrusion, sweeping, revolving etc. Feature modeling is shown in below Figure.



3.6.7 Filleting

Filleting implies the rounding of a corner to eliminate its sharpness. The fillet radius is the radius of the arc that connects filleted objects. Changing the fillet radius affects subsequent fillets. If you set the fillet radius to 0, filleted objects are trimmed or extended until they intersect, but no arc is created. Filleting is shown in below Figure.

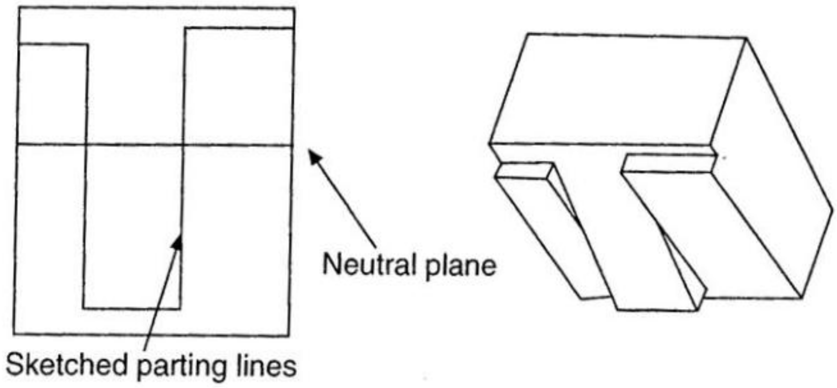


Filleting.

3.6.8 Tweaking

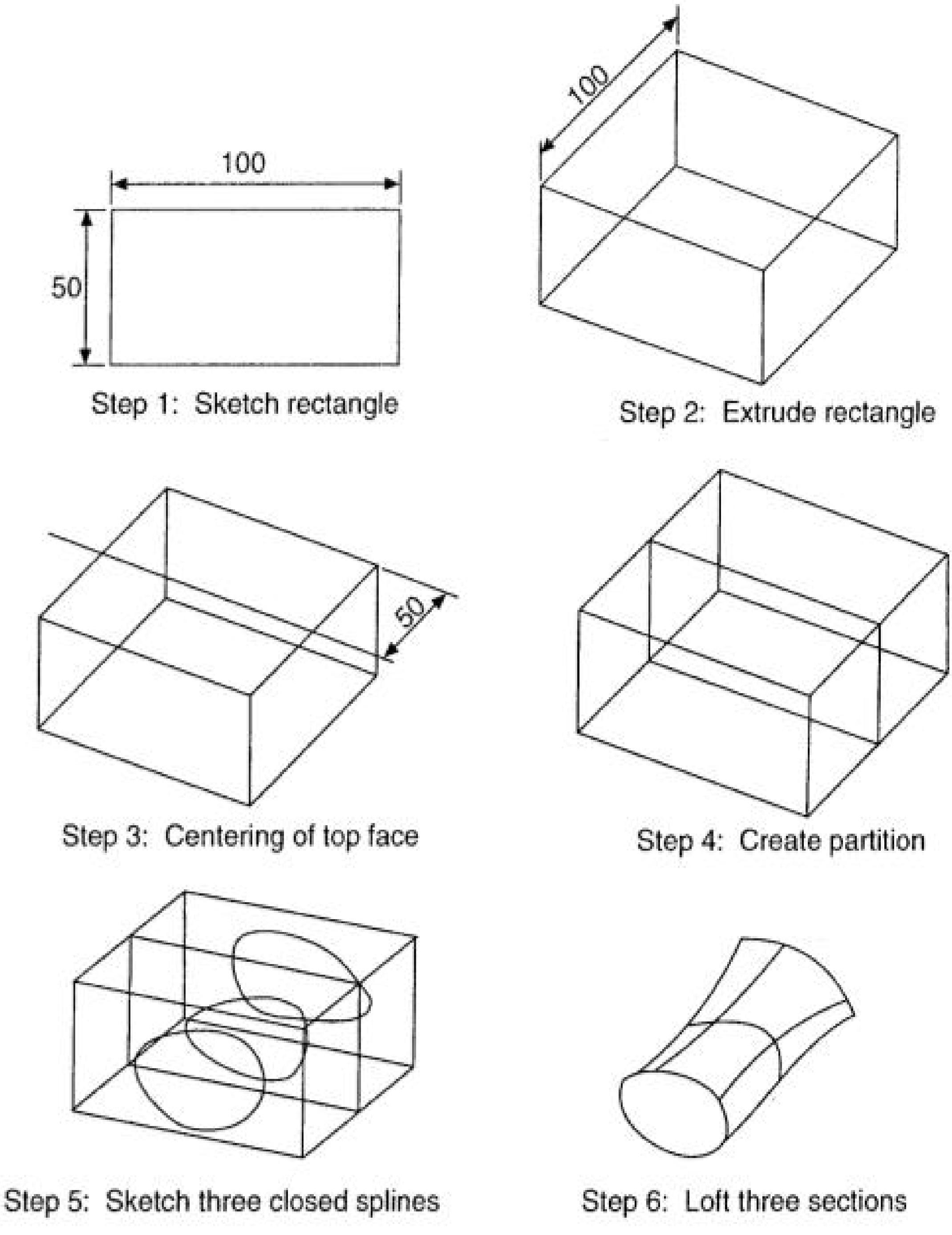
Tweaking uses several features to deform or alter (tweak) the surface of the part. Tweaking is not applicable to CSG solid models, splitting sketch drafts is shown in below Figure. This is because the CSG models retain the geometry and topology modeled from the primitives. The tweak menu lists the following options:

1. Draft
2. Local Push
3. Radius Dome
4. Section Dome
5. Offset
6. Replace
7. Ear
8. Lip
9. Patch
10. Spinal Bend
11. Free Form
12. Draft Offset



3.6.9 Lofting

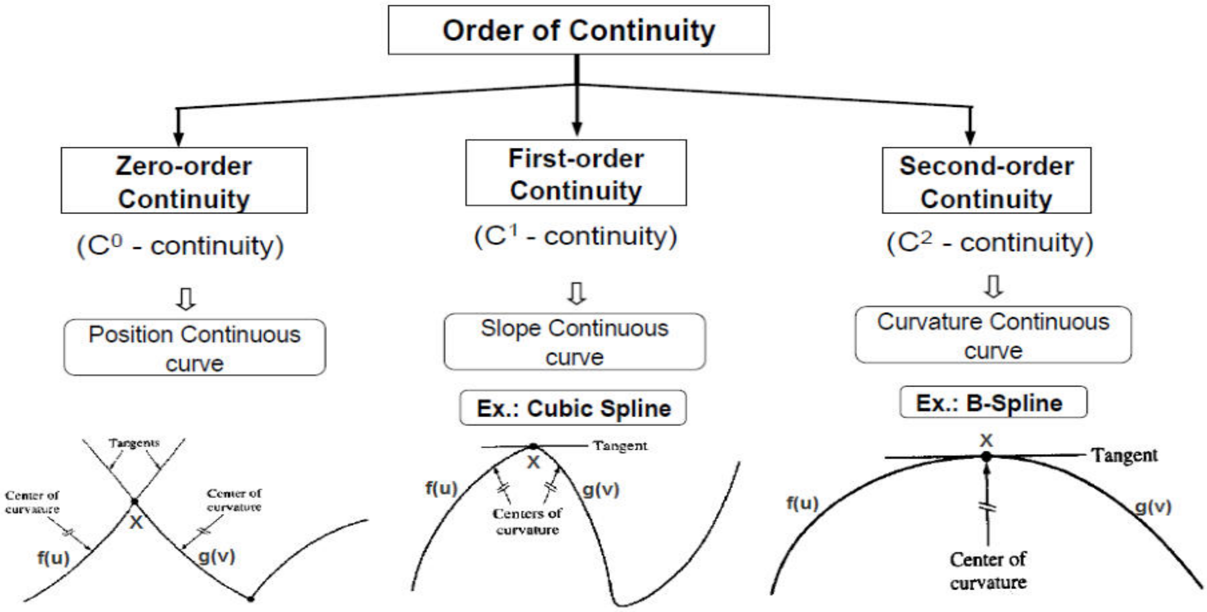
Lofting is used to create a model with a variant cross-section along a linear/non-linear axis. The lofting procedure is illustrated in below figure.



Lofting.

3.7 CURVATURE CONTINUITY

Mathematically, synthetic curves represented the problem of constructing a smooth curve that passes through given data points. Therefore the typical form of these curves is a polynomial. Various continuity requirements can be specified at the data points to impose various degrees of smoothness upon the resulting curve. The order of continuity becomes important when a complex curve is modeled by several curve segments pieced together end-to-end.



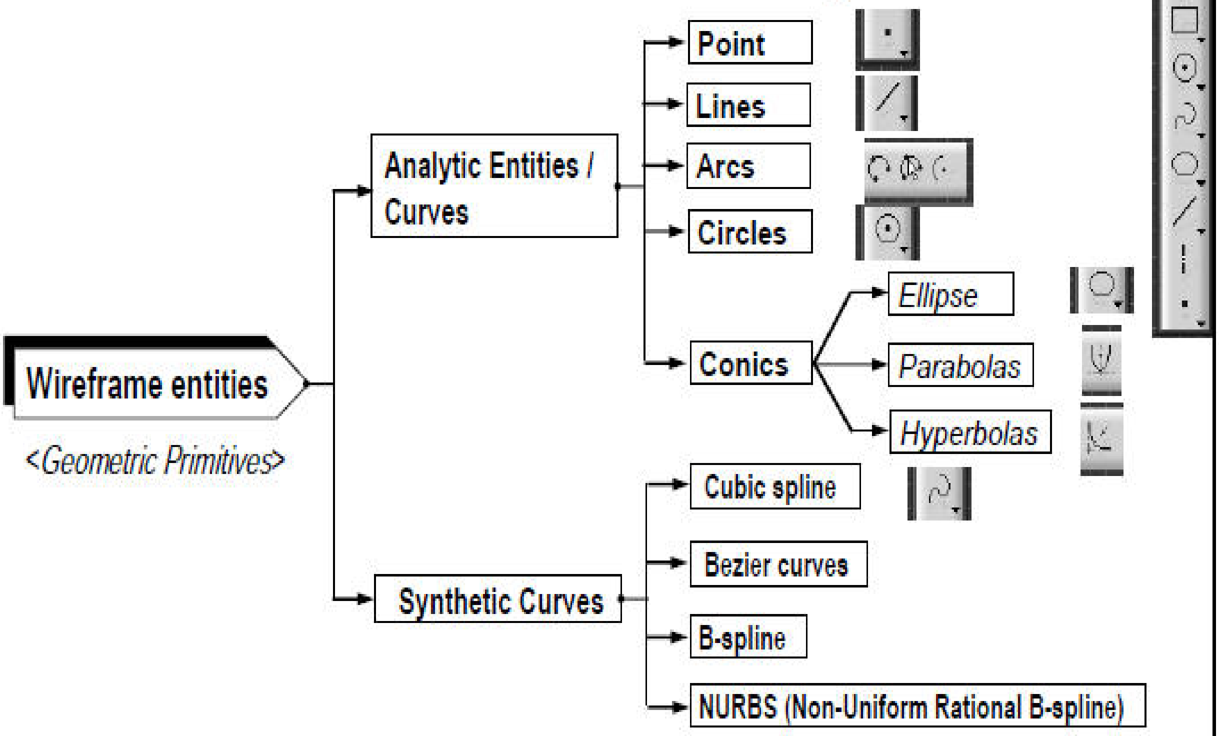
Two boundary curve segments shown in above figure are meeting at a vertex X. let these two curves be described as **f**(u) and **g**(v). Where u and v are values in intervals [a, b] and [m, n] respectively. The problem is: how these curves join together in a 'smooth' way.

Consider the 'endpoint' of curve **f**(u) and the 'start point' of curve **g**(m). If **f**(b) and **g**(m) are equal as shown in above figure a, say curves **f**() and **g**() are $\mathbf{C^0}$ continuity at **f**(b) = **g**(m).

If for all i<=k, the i-th derivatives at **f**(b) and **g**(m) are equal, say that the curves are $\mathbf{C^k}$ continuity at point **f**(b) = **g**(m). Intuitively,

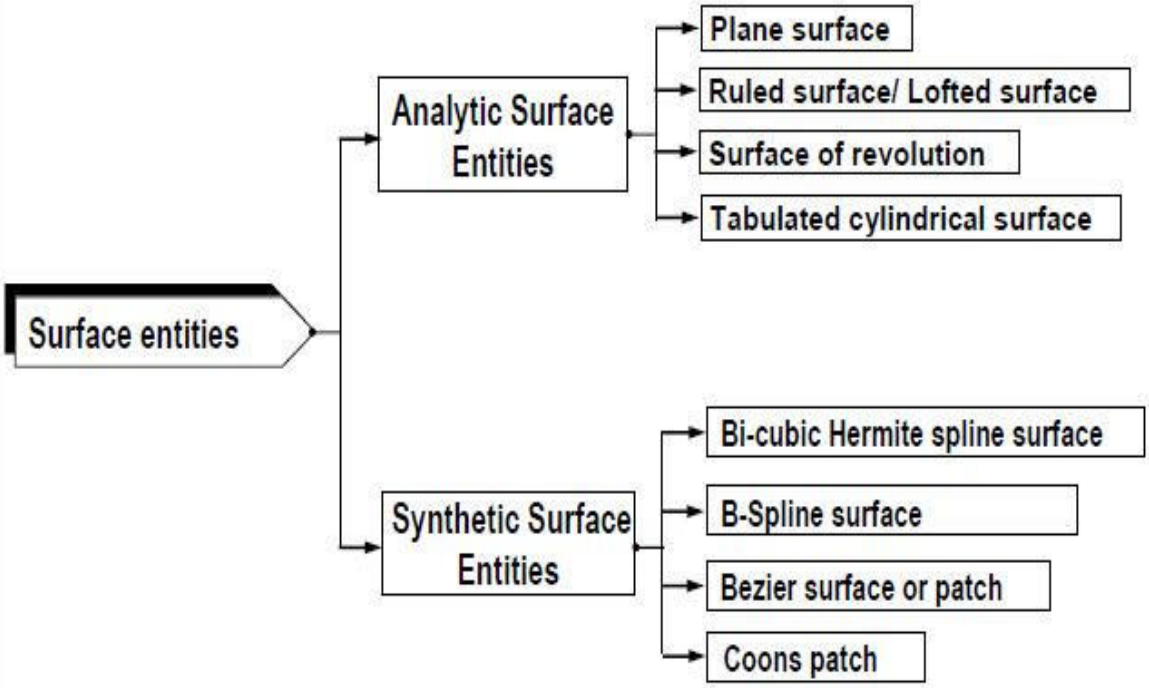
- $\mathbf{C^0}$ continuity (point/ position continuity) – Continuity of end point only (or) continuity of position
- $\mathbf{C^1}$ continuity (tangent continuity) – Tangent continuity or first derivate if position
- $\mathbf{C^2}$ continuity (curvature continuity) – Hydrodynamic character, light reflection curvature continuity (or) second derivative of position

Wireframe Modeling



Analytic Curve	*Synthetic Curve*
- are described by analytic equations	- are described by a set of data points (i.e. control points)

Surface Modeling



Curve segment : is the fundamental building block for curve entities

Surface patch : is the fundamental building block for surfaces