SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I – FUNDAMENTALS OF CAD/CAM - SMEA1501

1. FUNDAMENTALS OF CAD/CAM

Computer-aided design (CAD) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. Computer-aided manufacturing (CAM) is an application technology that uses computer software and machinery to facilitate and automate manufacturing processes. Many CAD vendors market fully integrated CAM systems, aptly called CAD/CAM systems. These CAD/CAM packages deliver many advantages. For starters, they feature a common user interface that allows CAD operators to quickly learn the software. Moreover, users can easily transfer CAD data to the CAM system without worrying about translation errors or other difficulties. And finally, some integrated systems provide full associatively, which means that any modification to the CAD model will prompt the associated tool path to be automatically updated. Computer Aided Design (CAD) has completely changed the drafting business and made the storage and retrieval of projects much easier. However, manual drawing is still very important and provides the basics of learning to draw.

The first system were very expensive, the computer graphics technology was not so advanced at that time and using the system required specialized H/W and S/W which was provided mainly by the CAD vendors. The first CAD systems were mainframe computer supported systems, while today the technology is for networked but stand alone operating workstations (UNIX or WINDOWS based systems). AUTODESK was the first vendor to offer a PC based CAD system the AUTOCAD (beginning of 1980). Today WINDOWS is the main operating system for CAD systems.

The first applications were for 2D-Drafting and the systems were also capable of performing only 2D modeling. Even today 2D-drafting is still the main area of application (in terms of number of workplaces). Later, (mid-1980), following the progress in 3D modeling technology and the growth in the IT H/W, 3D modeling systems are becoming very popular. 3D modeling are at the beginning wire frame based. Aerospace and automotive industries were using surface modeling systems for exact representation of the body of the product. At the same time solid modeling was recognized as the only system, which could provide an unambiguous representation of the product, but it was lacking adequate support for complex part representations. Today we are experiencing a merge of solid and surface modeling technology. Most solid modeling systems are capable of modeling most of industrial products. Systems sold today (especially for mechanical applications, which are the majority of systems sold world-wide) are characterized as NURBS (Non Uniform Rational B-Spline) based systems, employing solid modeling technology, and they are parametric and feature based systems. The use of CAD systems has also been expanded to all industrial sectors, such AEC, Electronics, Textiles, Packaging, Clothing, Leather and Shoe, etc. Today, numerous CAD systems are offered by several vendors, in various countries.

1.1. BENEFITS OF CAD OVER MANUAL DRAWING:

- No need for scaling. All drawing is done full size.
- Both two and three dimensional drawings can be produced.
- The screen drawing area can be set to any size with the click of a button
- Work is copied and stored off the computer for security – you may never lose your work again.
- All of the tools needed are supplied by the program.
- Drawings are stored on disk rather than in a bulky folder.
- Absolute accuracy can be maintained.

- Dimensioning is almost automatic.
- Production details can be extracted directly from the drawing.
- Parts of drawings can be saved and used in other drawings.
- Eliminates the need for full size set outs.
- Everything you learn about manual drawing technique applies to CAD/CAM drawing development.
- The images are displayed on the PC screen and, with the click of a button, can be put on paper using printers or plotters.

1.2. MORPHOLOGY OF DESIGN (OR THE DESIGN PROCESS

The design process mainly consists of six phases as shown in figure.

Recognition of need: When someone realizes that problem exists, for which a product can be designed.

Define the problem: Specify the item to be designed. This includes the cost, operating performance and characteristics functions.

Synthesis: Each subsystem of the designed is thoroughly conceptualized and analyzed, and if some shortcomings are there, improve this with the help of software like CAD.

Analysis and optimization: The product is redesigned and analyzed again and again. This process will go on till the designed is optimized.

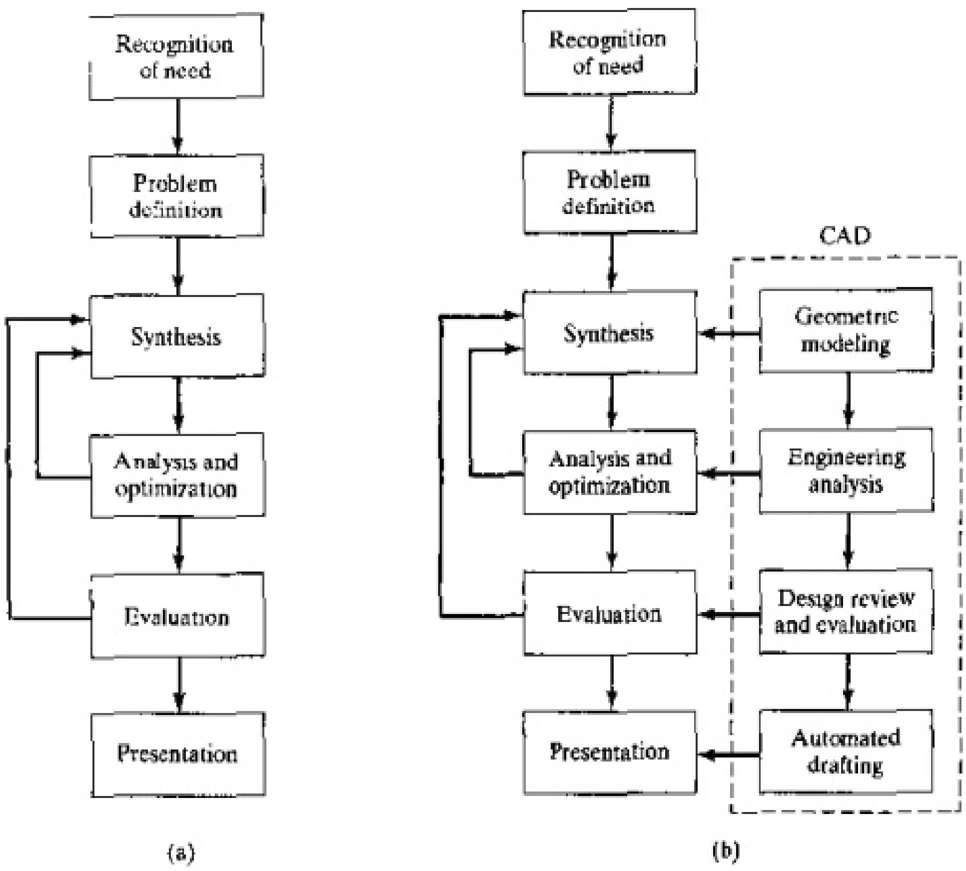


Fig 1.1. Design Process

Evaluation of design: Measure and test the design as specified in the problem definition phase. Tests are to be conducted on prototype model.

Presentation: Make the final drawing of the design by mentioning its material, size and assembly list. It means a database of the design is created for manufacturing.

1.3. APPLICATION OF CAD

1.3.1. Computer-aided design (CAD)

Defined as any design activity that involves the effective use of the computer to create, modify, analyze, or document an engineering design. CAD is most commonly associated with the use of an interactive computer graphics system, referred 10 as a CAD system. The term CAD/CAM system is also used if it supports manufacturing as well as design applications. With reference to the six phases of design defined previously, a CAD system can beneficially be used in four of the design phases, as indicated in Table.

Computer-Aided Design Applied to Four of the Shigley Design Phases

Design Phase	*CAD Function*
1. Synthesis	Geometric modeling
2. Analysis and optimization	Engineering analysis
3. Evaluation	Design review and evaluation
4. Presentation	Automated drafting

Table 1.1. Design phases and CAD functions

1.3.2. *Geometric Modeling*

Geometric modeling involves the use of a CAD system to develop a mathematical description of the geometry of an object. The mathematical description, called a *geometric model,* is contained in computer memory. This is used for the CAD system to display an image of the model on a graphics terminal and toper-form certain operations on the model. These operations include creating new geometric models from basic building blocks available in the system, moving the images around on the screen, zooming in on certain features of the image, and so forth. These capabilities permit the designer to construct a model of a new product (or Its components) or to modify an existing model. One classification distinguishes between two dimensional (2D) and three dimensional (3D) models. Two dimensional models are best utilized for design problems in two dimensions, such as flat objects and layouts of buildings. In the first CAD systems developed in the early 1970s, 2·0systems were used principally as automated drafting systems. They were often used for 3D objects, and it was left to the designer or draftsman to properly construct the various views of the object. Three dimensional CAD systems are capable of modeling an object in three dimensions. The operations and transformations on the model are done by the system in three dimensions according to user instructions. This is helpful in conceptualizing the object since the true *3D*model can be displayed in various views and from different angles. Geometric models in CAD can also be classified as being either wireframe models or solid models. A wireframe model uses inter-connecting lines (straight line segments) to depict the object. Wireframe models of complicated geometries can become somewhat confusing because all of the lines depicting the shape of the object are usually shown, even the lines representing the other side of the object. Techniques are available for removing these so-called hidden lines, but even with this improvement, wireframe representation is still often inadequate. Solid models are a more recent development in geometric modeling. In solid modeling, an object is modeled in solid three dimensions, providing the user with a vision of the object very much like it would be seen in real life. More important for engineering purposes, the geometric model is stored in the CAD system as a 3D solid model. thus providing a more accurate representation of the object. This is useful for calculating mass properties, in assembly to perform interference checking between mating components, and in other engineering calculations. Finally, two other features in CAD system models are color and animation. Some CAD systems have color capability in addition to black-and-white. The value of color is largely to enhance the ability of the user to visualize the object on the graphics screen. For example, the various components of an assembly can be displayed in different colors, thereby permitting the parts to be more readily distinguished. Animation capability permits the operation of mechanisms and other moving objects to be displayed on the graphics monitor.

1.3.3. Engineering Analysis.

After a particular design alternative has been developed, some form of engineering analysis often must be performed as part of the design process. The analysis may take the form of stress-strain calculations, heat transfer analysis, or dynamic simulation. The computation are often complex and time consuming, and before the advent of the digital computer, these analyses were usually greatly simplified or even omitted in the design procedure. The availability of software for engineering analysis on a CAD system greatly increases the designer's ability and willingness. to perform a more thorough analysis of a proposed design. The term *computer-aided engineering* (CAE) is often used for engineering analyses performed by computer. Examples of engineering analysis software in common use on CAD systems include:

- *Mass properties analysis*, which involves the computation of such features of a solid object as its volume, surface area, weight, and center of gravity. It is especially applicable in mechanical design. Prior to CAD, determination of these properties often required painstaking and time consuming calculations by the designer.
- *Interference checking.* This CAD software examines 2D geometric models consisting of multiple components to identify interferences between the components. It is useful in analyzing mechanical assemblies, chemical plants, and similar multi component designs.
- *Tolerance analysis.* Software for analyzing the specified tolerances of a product components is used for the following functions: (1) to assess how the tolerances may affect the product's function and performance, (2) to determine how tolerances may influence the ease or difficulty of assembling the product and (3) to assess how variations in component dimensions may affect the overall size of the assembly.
- *Finite element analysis.* Software for finite element analysis (FEA), also known as *finite element modeling* (FEM). is available for use on CAD systems to aid in stress-strain, heat transfer, fluid flow, and other engineering computations, Finite element analysis is a numerical analysis technique for determining approximate solutions to physical problems described by differential equations that are very difficult or impossible to solve. In FEA. The physical object is modeled by an assemblage of discrete interconnected nodes (finite elements), and the variable of interest (e.g., stress, strain, temperature) in each node can be described by relatively simple mathematic cal equations, By solving the equations for each node. the distribution of values of the variable throughout the physical object is determined.

- *Kinematic and dynamic analysis.* Kinematic analysis involves the study of the operation of mechanical linkages to analyze their motions. A typical kinematic analysis consists of specifying the motion of one or more driving members of the subject linkage, and the resulting motions of the other links are determined by the analysis package. Dynamic analysis extends kinematic analysts by including the effects of the mass of each linkage member and the resulting acceleration forces as well as any externally applied forces.
- *Discrete-event simulation.* This type of simulation is used to model complex operational systems, such as a manufacturing cell or a material handling system, as events occur at discrete moments in time and affect the status and performance of the system. For example, discrete events in the operation of a manufacturing cell include parts arriving for processing or a machine breakdown in the cell. Measures of the status and performance include whether a given machine in the cell is idle or busy and the overall production rate of the cell. Current discrete-event simulation software usually includes an animated graphics capability that enhances visualization of the system's operation.

1.3.4. Design Evaluation and Review

Design evaluation and review procedures can be augmented *by* CAD. Some of the CAD features that are helpful in evaluating: and reviewing a proposed design include:

- A*utomatic dimensioning* routines that determine precise distance measures between surfaces on the geometric model identified hy the user.
- *Error checking.* This term refers 10 CAD algorithms that are used to review the accuracy and consistency of dimensions and tolerances and to assess whether the proper design documentation format has been followed.

1.3.5. Automated Drafting

The fourth area where CAD is useful (step 6 in the design process) is presentation and documentation. CAD systems can be used as automated drafting machines to prepare highly accurate engineering drawings quickly. It is estimated that a CAD system increases productivity in the drafting function by about fivefold over manual preparation of drawings

1.4. PRODUCT CYCLE COMPUTER AIDED DESIGN

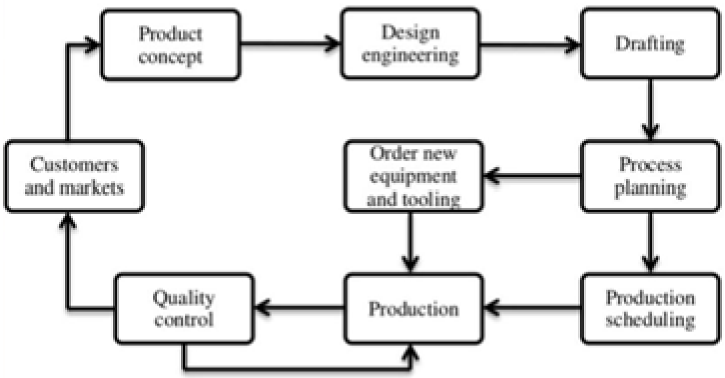


Fig 1.2: Product life cycle

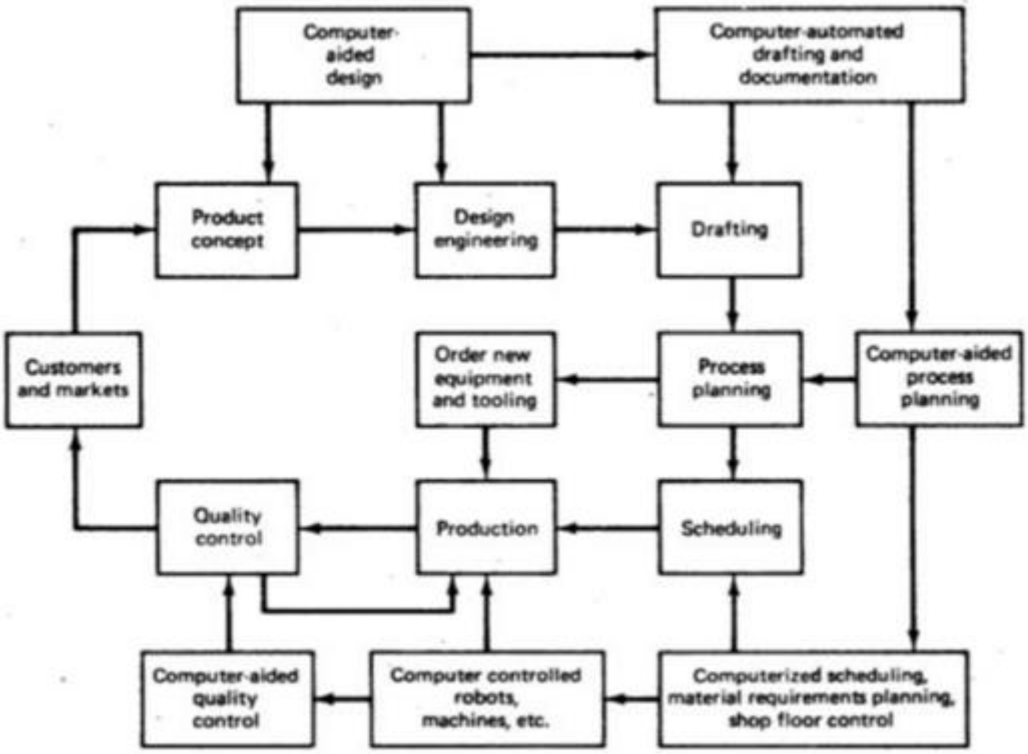


Fig 1.3: Implement of CAD/CAM in Product life cycle

1.5. DATABASE MANAGEMENT

The manufacturing database and its management are major issues in CIM. The issues are complex but they are beginning to be addressed in a number of ways, including schemes for organizing data, standards for product data exchange and standards for communication protocols. The standards for product data exchange are discussed and communication protocols have been discussed elsewhere. This chapter hence is devoted to the organization of data.

A major problem to be solved to implement CIM has always been that of distributing information among different computer based systems. As indicated in earlier chapters CIM is typically integration of islands of computer aided functions running on different computers using different databases.

Joining those islands into an effective CIM enterprise requires proper methods of processing information. Information, if it is to be useful, must be appropriate, machine-interpretable, and available when and where it is needed.

1.5.1. Features of A Database Management System

A database management system consists of a collection of interrelated data and a set of programs to access that data. Database management involves:

- Organize a database.
- Add new data to the database.
- Sort the data in some meaningful order.

- Search the database for types of information.
- Print the data into formatted reports.
- Edit the data.

1.5.2. Database Administrator

The person responsible for managing the database is often referred to as database administrator. His functions include:

- Creating the primary database structure
- Backing up and restoring data in case of crash
- Modifying the structure
- Transfer data to external files
- Allocate and control user access rights
- Monitoring performance

1.5.3. Comparison of Database and Traditional File Systems

File system represents a tight coupling between physical data and user's program. They lack almost all the flexibilities offered by DBMS. Most of the indispensable facilities of DBMS of are, therefore forced to be absorbed by user's program. In other words besides the logic of the application the user has to provide logic for constructing the logical view of data, has to interpret the operations on the logical view and translate them in to the primitive file operations, and has to be responsible for maintaining the files that store the physical data. The tight coupling and interdependence of between a user's application and the physical data would not allow sharing of the same data by other applications that may need to view and manipulate them differently.

This then forces the data to be duplicated among various applications. File systems lack dynamism in the sense that the application programs are designed, coded, debugged, and catalogued ahead of time for the preconceived requests and applications. The following list summarizes the problems of file systems that can be overcome by DBMS.

i. Data dependence

ii. Rigidity

iii. Static nature

iv. Lack of integration

v. Data duplication

vi. Inconsistency

vii. Difficulty in sharing information

viii. Inefficiency

ix. Inability to handle ado requests.

1.6. PRINCIPLES OF COMPUTER GRAPHICS

Traditionally drawings are prepared on plane drawing sheets. This has several limitations. The sketches have to be made only in two dimensions. Though the depth can be represented by pictorial projections like isometric and perspective projections, the projections have to be necessarily reduced to two dimensions. Use of computer graphics has opened up tremendous possibilities for the designer. Some of them are listed below:

Use of computer graphics has opened up tremendous possibilities for the designer. Some of them are listed below:

- The object is represented by its geometric model in three dimensions (X,Y and Z).
- The mathematical representation reduces creation of views like orthographic, isometric, axonometric or perspective projections into simple viewing transformations.
- Though the size of the screen is limited, there is no need to scale the drawings.
- Drawings can be made very accurate.
- The geometric models can be represented in color and can be viewed from any angle. Sections can be automatically created.
- The associatively ensures that any change made in one of the related views will automatically reflect in other views.
- Revision and revision control are easy.
- Drawings (geometric models) can be modified easily.
- More important than all, drawings can be reused conveniently.
- Storage and retrieval of drawings are easy

Modern computer graphics displays are simple in construction. They consist of basically three components.

i. Monitor
ii. Digital Memory or Frame Buffer
iii. Display Controller

Most of the computer graphics displays use raster CRT which is a matrix of discrete cells each of which can be made bright. A graphic entity like line or circle is represented as a series of points or dots‖ on the screen. Therefore, it is called as a point plotting device. The video display screen is divided into very small rectangular elements called a picture element or pixel.

This happens to be the smallest addressable screen element. Graphic images are formed by setting suitable intensity and color to the pixels which compose the image. Depending upon the resolution screens may have varying number of pixels. For example, an SVGA monitor with a resolution of 1024 x 768 will have 1024 pixels in every row (X - direction) and 768 pixels in every column (Y-direction). Monitors of larger size will have resolution of 1024 x 1024 or more.

A raster scan system displays the image on a CRT in a certain fixed sequence. The refresh rate is the number of complete images or frames scanned per second. In the case of interlaced refresh cycle odd numbered raster lines are refreshed during 1/60th of a second. Even numbered raster lines are refreshed during the next 1/60th of a second. In non-interlaced displays, all lines are refreshed in 1/60th of a second. The quality of no interlaced display is hence, superior. These systems, however, require expensive frame buffer memory and display controller.

1.6.1. Graphic primitives

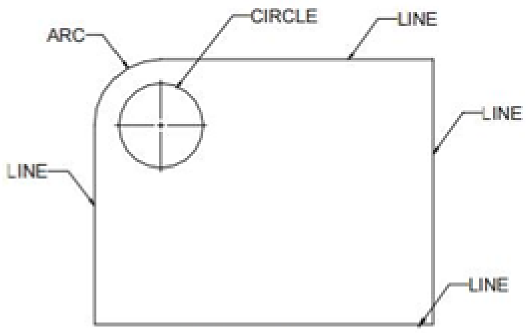


Fig 1.4. Primitives

A drawing is created by an assembly of points, lines, arcs, circles. For example, drawing shown in Fig 1.4. consists of several entities. In computer graphics also drawings are created in a similar manner. Each of these is called an entity. The drawing entities that a user may find in a typical CAD package include : point line construction line, multi-line, polyline circle spline arc ellipse polygon rectangle.

1.6.2. Point plotting

The frame buffer display is an example of a point plotting device. The smallest unit accepted by such displays is a single pixel. To construct a useful picture on a point plotting device, a picture must be built out of several hundreds of pixel.

1.6.3. Drawing of lines

Straight line segments are used a great deal in computer generated pictures. The following criteria have been stipulated for line drawing displays.

- Lines should appear straight
- Lines should terminate accurately
- Lines should have constant density
- Line density should be independent of length and angle
- Line should be drawn rapidly

The process of turning on the pixels for a line segment is called vector generation. If the end points of the line segment are known, there are several schemes for selecting the pixels between the end pixels. One method of generating a line segment is a symmetrical digital differential analyzer (DDA)

1.7 COMPUTER AIDED PROCESS MONITORING

The advances in automation have enabled industries to develop islands of automation. Examples are flexible manufacturing cells, robotized work cells, flexible inspection cells etc.

One of the objectives of CIM is to achieve the consolidation and integration of these islands of automation.

This requires sharing of information among different applications or sections of a factory, accessing incompatible and heterogeneous data and devices. The ultimate objective is to meet the competition by improved customer satisfaction through reduction in cost, improvement in quality and reduction in product development time.

CIM makes full use of the capabilities of the digital computer to improve manufacturing. Two of them are:

i. Variable and Programmable automation
ii. Real time optimization

The computer has the capability to accomplish the above for hardware components of manufacturing (the manufacturing machinery and equipment) and software component of manufacturing (the application software, the information flow, database and so on).

The capabilities of the computer are thus exploited not only for the various bits and pieces of manufacturing activity but also for the entire system of manufacturing. Computers have the tremendous potential needed to integrate the entire manufacturing system and thereby evolve the computer integrated manufacturing system.

1.8 ADAPTIVE CONTROL

Adaptive control is the ability to modify a program in real time, based upon sensory data. Robots can make use of abilities such as orienting parts based on features, following a changed path, or recognizing work pieces. Adaptive control requires sensory input and the ability to respond to that input.

Adaptive control will greatly enhance role of the industrial robots in the computer integrated factory. The robot endowed with ability to adjust to its environment, reduces scrap and rework, and a robot equipped with adaptive control can perform quality - control functions integral with its tasks.

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions. Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing themselves.

1.9 COMPUTER AIDED MANUFACTURING

Computer-aided manufacturing (CAM) is defined as the effective use of computer technology in manufacturing planning and control. CAM is most closely associated with functions in manufacturing engineering, such as process planning and numerical control (NC) part programming. The applications of CAM can be divided into two broad categories:(1) manufacturing planning and (2) manufacturing control.

CAM applications for manufacturing planning are those in which the computer is used indirectly to support the production function, but there is no direct connection between the computer and the process. The computer is used "offline" to provide information for the effective planning and management of production activities. The following list surveys the important applications of CAM in this category:

- *Computer-aided process planning (CAPP).* Process planning is concerned with the preparation of route sheets that list the sequence of operations and work centers required 10 produce the product and its components. CAPP systems are available today to prepare these route sheets.
- *Computer-assisted NC part programming.* or complex part geometries, computer assisted part programming represents a much more efficient method of generating the control Instructions for the machine tool than manual part programming is.
- *Computerized machinability data systems.* One of the problems in operating a metal cutting machine tool is determining the speeds and feeds that should be used to machine a given work part. Computer programs have been written to recommend the appropriate cutting conditions to use for different materials. The calculations are based on data that have been obtained either in the factory or laboratory that relate tool life to cutting conditions.
- *Development of work standards.* The time study department has the responsibility for setting time standards on direct labor jobs performed in the factory. Establishing standards have direct time study can be a tedious and time-consuming task. There are several commercially available computer packages for setting work standards. These computer programs 'use standard time data that have been developed for basic work elements that comprise any manual task. By summing the limes for the individual element, required to perform a new Job, the program calculates the standard lime for the job.
- *Cost estimating,* The task of estimating the cost of a new product has been simplified in most industries by computerizing several of the key steps required to prepare the estimate. The computer is programmed to apply the appropriate labor and overhead rates to the sequence of planned operations for the components of new products. the program then sums the individual component costs from the engineering bill of materials to determine the overall product cost.
- *Production and inventory planning.* The computer has found widespread use in many of the functions in production and inventory planning. These functions include: maintenance of inventory records, automatic reordering of stock items when inventory is depicted. production scheduling, maintaining current priorities for the different production orders, material requirements planning, and capacity planning.
- *Computer-aided line balancing.* Finding the best allocation of work elements among stations on an assembly line is a large and difficult problem if the line is of significant size. Computer programs have been developed to assist in the solution of this problem.

The second category of CAM application is concerned with developing computer systems to implement the manufacturing control function. Manufacturing control is concerned with managing and controlling the physical operations in the factory. These management and control areas include:

- *Process monitoring and control.* Process monitoring and control is concerned with observing and regulating the production equipment and manufacturing processes in the plant. The applications of computer process control arc pervasive today in automated production systems. They include transfer lines, assembly systems. NC, robotics. material handling and flexible manufacturing systems.
- *Quality control: Qua1ity* control includes a variety of approaches to ensure the highest possible quality levels in the manufactured product.
- *Shop floor control.* Shop floor control refers to production management techniques for collecting data from factory operations and using the data to help control production and inventory in the factory.
- *Inventory control.* Inventory control is concerned with maintaining the most appropriate levels of inventory in the face of two opposing objectives: minimizing the investment and storage costs of holding inventory and maximizing service to customers.
- *Just-in-time production systems.* The term just-in-time refers to a production system that is organized to deliver exactly the right number of each component to downstream workstations in the manufacturing sequence just at the lime when that component ts needed. The term applies not only to production operations but 10 supplier delivery operations as well.

1.10 DESIGN FOR MANUFACTURING

Design for Manufacturing (DFM) and design for assembly (DFA) are the integration of product design and process planning into one common activity. The goal is to design a product that is easily and economically manufactured. The importance of designing for manufacturing is underlined by the fact that about 70% of manufacturing costs of a product (cost of materials, processing, and assembly) are determined by design decisions, with production decisions (such as process planning or machine tool selection) responsible for only 20%.

The heart of any design for manufacturing system is a group of design principles or guidelines that are structured to help the designer reduce the cost and difficulty of manufacturing an item. The following is a listing of these rules.

1. *Reduce the total number of parts.* The reduction of the number of parts in a product is probably the best opportunity for reducing manufacturing costs. Less parts implies less purchases, inventory, handling, processing time, development time, equipment, engineering time, assembly difficulty, service inspection, testing, etc. In general, it reduces the level of intensity of all activities related to the product during its entire life. A part that does not need to have relative motion with respect to other parts, does not have to be made of a different material, or that would make the assembly or service of other parts extremely difficult or impossible, is an excellent target for elimination. Some approaches to part-count reduction are based on the use of one-piece structures and selection of manufacturing processes such as injection molding, extrusion, precision castings, and powder metallurgy, among others.

2. *Develop a modular design.* The use of modules in product design simplifies manufacturing activities such as inspection, testing, assembly, purchasing, redesign,

maintenance, service, and so on. One reason is that modules add versatility to product update in the redesign process, help run tests before the final assembly is put together, and allow the use of standard components to minimize product variations. However, the connection can be a limiting factor when applying this rule.

3. *Use of standard components.* Standard components are less expensive than custom-made items. The high availability of these components reduces product lead times. Also, their reliability factors are well ascertained. Furthermore, the use of standard components refers to the production pressure to the supplier, relieving in part the manufacture's concern of meeting production schedules.

4. *Design parts to be multi-functional.* Multi-functional parts reduce the total number of parts in a design, thus, obtaining the benefits given in rule 1. Some examples are a part to act as both an electric conductor and as a structural member, or as a heat dissipating element and as a structural member. Also, there can be elements that besides their principal function have guiding, aligning, or self-fixturing features to facilitate assembly, and/or reflective surfaces to facilitate inspection, etc.

5. *Design parts for multi-use*. In a manufacturing firm, different products can share parts that have been designed for multi-use. These parts can have the same or different functions when used in different products. In order to do this, it is necessary to identify the parts that are suitable for multi-use. For example, all the parts used in the firm (purchased or made) can be sorted into two groups: the first containing all the parts that are used commonly in all products. Then, part families are created by defining categories of similar parts in each group. The goal is to minimize the number of categories, the variations within the categories, and the number of design features within each variation. The result is a set of standard part families from which multi-use parts are created. After organizing all the parts into part families, the manufacturing processes are standardized for each part family. The production of a specific part belonging to a given part family would follow the manufacturing routing that has been setup for its family, skipping the operations that are not required for it. Furthermore, in design changes to existing products and especially in new product designs, the standard multi-use components should be used.

6. *Design for ease of fabrication.* Select the optimum combination between the material and fabrication process to minimize the overall manufacturing cost. In general, final operations such as painting, polishing, finish machining, etc. should be avoided. Excessive tolerance, surface-finish requirement, and so on are commonly found problems that result in higher than necessary production cost.

6. *Avoid separate fasteners*. The use of fasteners increases the cost of manufacturing a part due to the handling and feeding operations that have to be performed. Besides the high cost of the equipment required for them, these operations are not 100% successful, so they contribute to reducing the overall manufacturing efficiency. In general, fasteners should be avoided and replaced, for example, by using tabs or snap fits. If fasteners have to be used, then some guides should be followed for selecting them. Minimize the number, size, and variation used; also, utilize standard components whenever possible. Avoid screws that are too long, or too short, separate washers, tapped holes, and round heads and flatheads (not good for vacuum pickup).

Self-tapping and chamfered screws are preferred because they improve placement success. Screws with vertical side heads should be selected vacuum pickup.

TABLE 25.4 General Principles and Guidelines in DFM/A

Guideline	*Interpretation and Advantages*
Minimize number of components	Reduced assembly costs. Greater reliability in final product. Easier disassembly in maintenance and field service. Automation is often easier with reduced part count. Reduced work-in-process and inventory control problems. Fewer parts to purchase; reduced ordering costs.
Use standard commercially available components	Reduced design effort. Fewer part numbers Better inventory control possible. Avoids design of custom-engineered components. Quantity discounts possible.
Use common parts across product lines	Group technology (Chapter 15) can be applied. Quantity discounts are possible. Permits development of manufacturing cells.
Design for ease of part fabrication	Use net shape and near net shape processes where possible. Simplify part geometry; avoid unnecessary features. Avoid surface roughness that is smoother than necessary since additional processing may be needed.
Design parts with tolerances that are within process capability	Avoid tolerances less than process capability (Section 21.1.2). Specify bilateral tolerances. Otherwise, additional processing or sortation and scrap are required.
Design the product to be foolproof during assembly	Assembly should be unambiguous. Components designed so they can be assembled only one way. Special geometric features must sometimes be added to components.
Minimize flexible components	These include components made of rubber, belts, gaskets, electrical cables, etc. Flexible components are generally more difficult to handle.
Design for ease of assembly.	Include part features such as chamfers and tapers on mating parts. Use base part to which other components are added. Use modular design (see following guideline). Design assembly for addition of components from one direction, usually vertically; if mass production, this rule can be violated because fixed automation can be designed for multiple direction assembly. Avoid threaded fasteners (screws, bolts, nuts) where possible, especially when automated assembly is used; use fast assembly techniques such as snap fits and adhesive bonding. Minimize number of distinct fasteners.
Use modular design	Each subassembly should consists of 5-15 parts. Easier maintenance and field service. Facilitates automated (and manual) assembly. Reduces inventory requirements. Reduces final assembly time.
Shape parts and products for ease of packaging	Compatible with automated packaging equipment. Facilitates shipment to customer. Can use standard packaging cartons.
Eliminate or reduce adjustments	Many assembled products require adjustments and calibrations. During product design, the need for adjustments and calibrations should be minimized because they are often time consuming in assembly.

Table 1.2. General principles of DFMA

7. *Minimize assembly directions*. All parts should be assembled from one direction. If possible, the best way to add parts is from above, in a vertical direction, parallel to the gravitational direction (downward). In this way, the effects of gravity help the assembly process, contrary to having to compensate for its effect when other directions are chosen.

8. *Maximize compliance*. Errors can occur during insertion operations due to variations in part dimensions or on the accuracy of the positioning device used. This faulty behavior can cause damage to the part and/or to the equipment. For this reason, it is necessary to include compliance in the part design and in the assembly process. Examples of part built-in compliance features include tapers or chamfers and moderate radius sizes to facilitate insertion, and nonfunctional external elements to help detect hidden features. For the assembly process, selection of a rigid-base part, tactile sensing capabilities, and vision systems are example of compliance. A simple solution is to use high-quality parts with designed-in-compliance, a rigid-base part, and selective compliance in the assembly tool.

9. *Minimize handling.* Handling consists of positioning, orienting, and fixing a part or component. To facilitate orientation, symmetrical parts should be used when ever possible. If it is not possible, then the asymmetry must be exaggerated to avoid failures. Use external guiding features to help the orientation of a part. The subsequent operations should be designed so that the orientation of the part is maintained. Also, magazines, tube feeders, part strips, and so on, should be used to keep this orientation between operations. Avoid using flexible parts - use slave circuit boards instead. If cables have to be used, then include a dummy connector to plug the cable (robotic assembly) so that it can be located easily. When designing the product, try to minimize the flow of material waste, parts, and so on, in the manufacturing operation; also, take packaging into account, select appropriate and safe packaging for the product.

1.10. CURVES & SURFACES AND 2D & 3D TRANSFORMATIONS

1.10.1. 2D TRANSFORMATIONS

Transformation means changing some graphics into something else by applying rules. We can have various types of transformations such as translation, scaling up or down, rotation, shearing, etc. When a transformation takes place on a 2D plane, it is called 2D transformation.

1.10.1.1. 2D Translation:

Translation moves an object to a different position on the screen. You can translate a point in 2D by adding translation coordinate (tx, ty) to the original coordinate X, Y to get the new coordinate X ′ , Y ′.

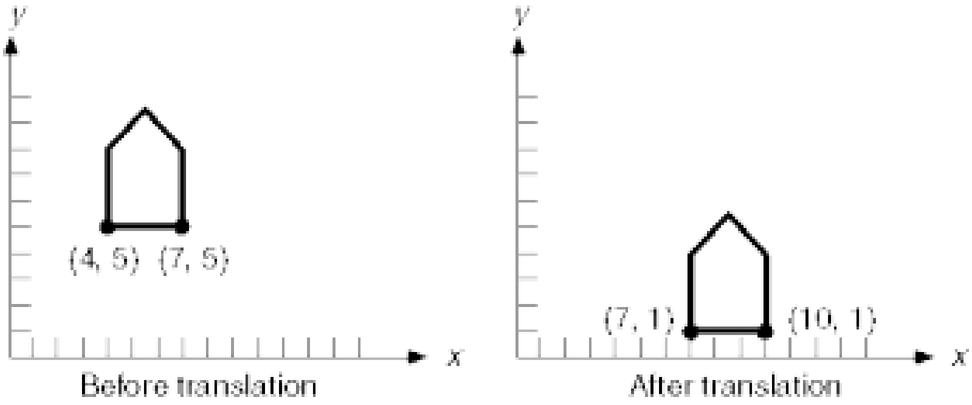
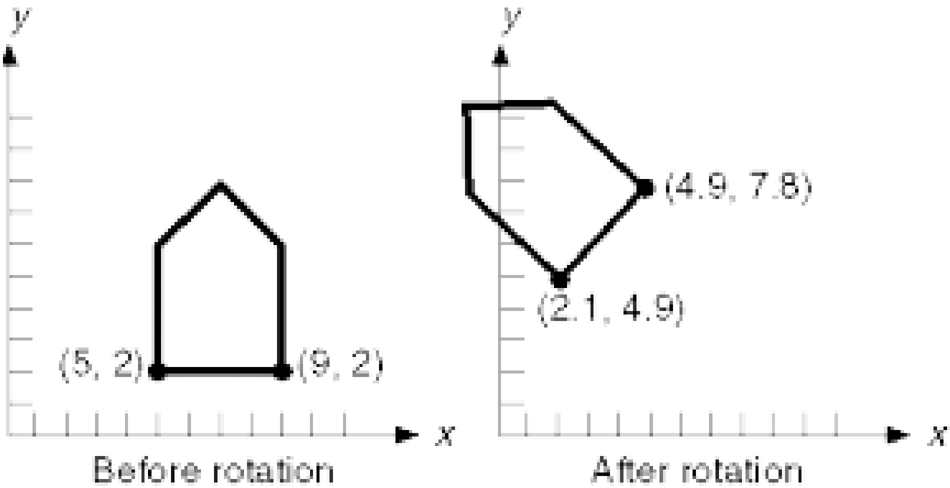


Fig 1.10.1. 2D Translation

$$x' = x + d_x \qquad \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} d_x \\ d_y \end{bmatrix}$$
$$y' = y + d_y$$

1.10.1.2. 2D Rotation

In rotation, we rotate the object at particular angle θ theta from its origin. From the following figure, we can see that the point PX, Y is located at angle φ from the horizontal X coordinate with distance r from the origin. Let us suppose you want to rotate it at the angle θ. After rotating it to a new location, you will get a new point P’ X′ , Y ′ .



$$P' = R \times P$$

Fig 1.10.2. 2D Rotation

$$x' = x\cos(\alpha) - y\sin(\alpha)$$
$$y' = x\sin(\alpha) + y\cos(\alpha)$$
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

1.10.1.3. 2D SCALING

To change the size of an object, scaling transformation is used. In the scaling process, you either expand or compress the dimensions of the object. Scaling can be achieved by multiplying the original coordinates of the object with the scaling factor to get the desired result. Let us assume that the original coordinates are X, Y, the scaling factors are (SX, SY), and the produced coordinates are X ′ , Y ′ . This can be mathematically represented as shown below − X' = X . SX and Y' = Y . SY The scaling factor SX, SY scales the object in X and Y direction respectively.

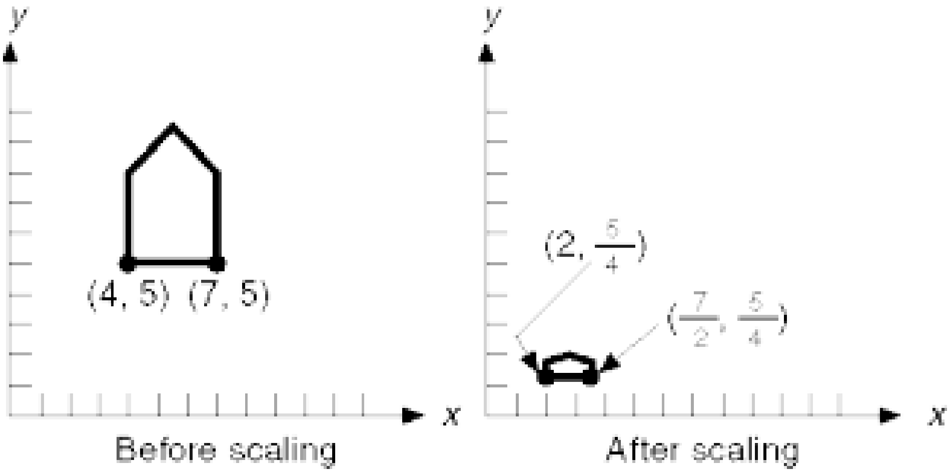


Fig. 1.10.3. 2D Scaling

$$x' = s_x \times x$$
$$y' = s_y \times y$$
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \times \begin{bmatrix} x \\ y \end{bmatrix}$$

1.10.1.4. 2D SHEARING

A transformation that slants the shape of an object is called the shear transformation. There are two shear transformations X-Shear and Y-Shear. One shifts X coordinates values and other shifts Y coordinate values. However; in both the cases only one coordinate changes its coordinates and other preserves its values. Shearing is also termed as Skewing.

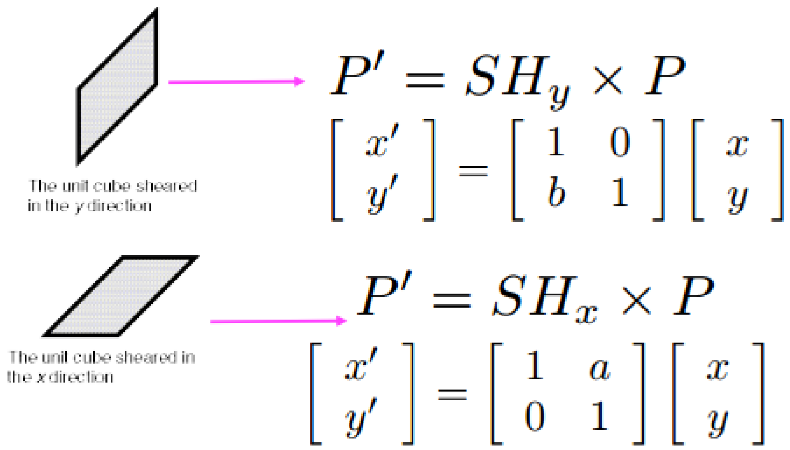


Fig. 1.10.4. 2D Shearing

1.10**.1.4.1. X-Shear**

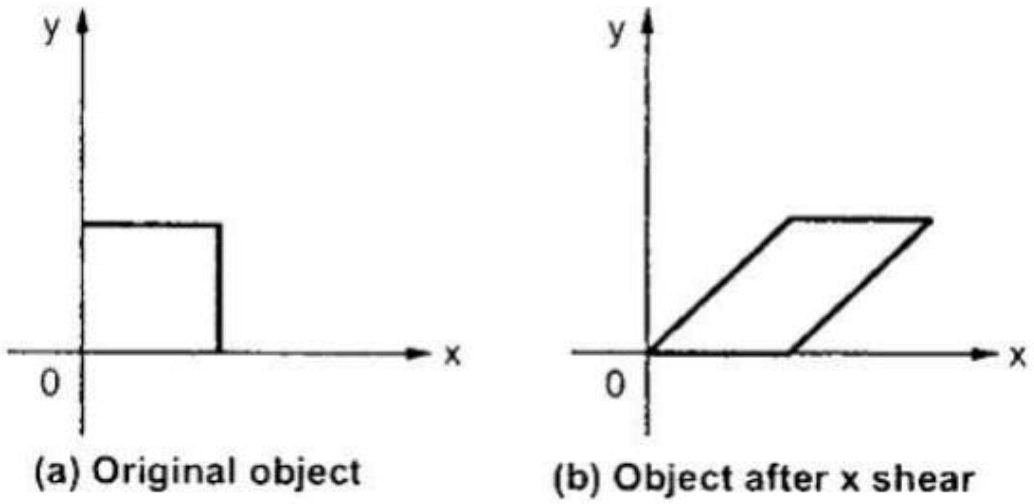


Fig. 1.10.5. X-Shear

The X-Shear preserves the Y coordinate and changes are made to X coordinates, which causes the vertical lines to tilt right or left as shown in below figure.

1.10**.1.4.2. Y-Shear**

The Y-Shear preserves the X coordinates and changes the Y coordinates which causes the horizontal lines to transform into lines which slopes up or down as shown in the following figure.

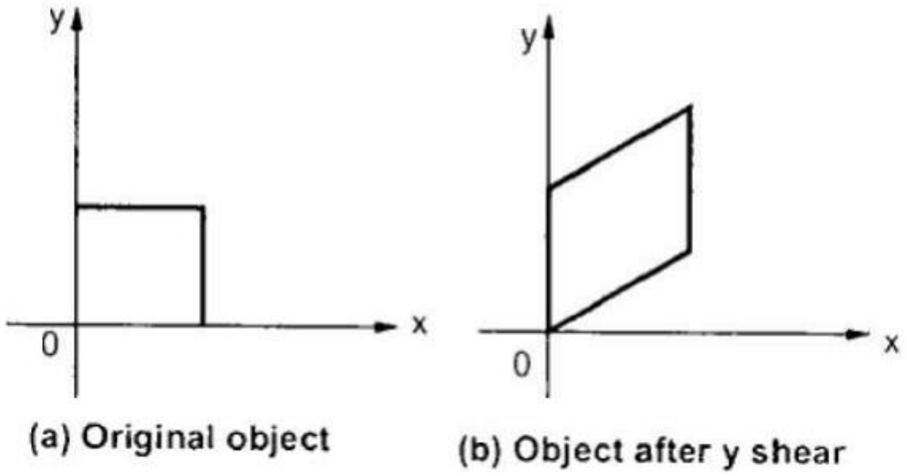


Fig. 1.10.6. Y-Shear

1.10.1.5. 2D REFLECTION

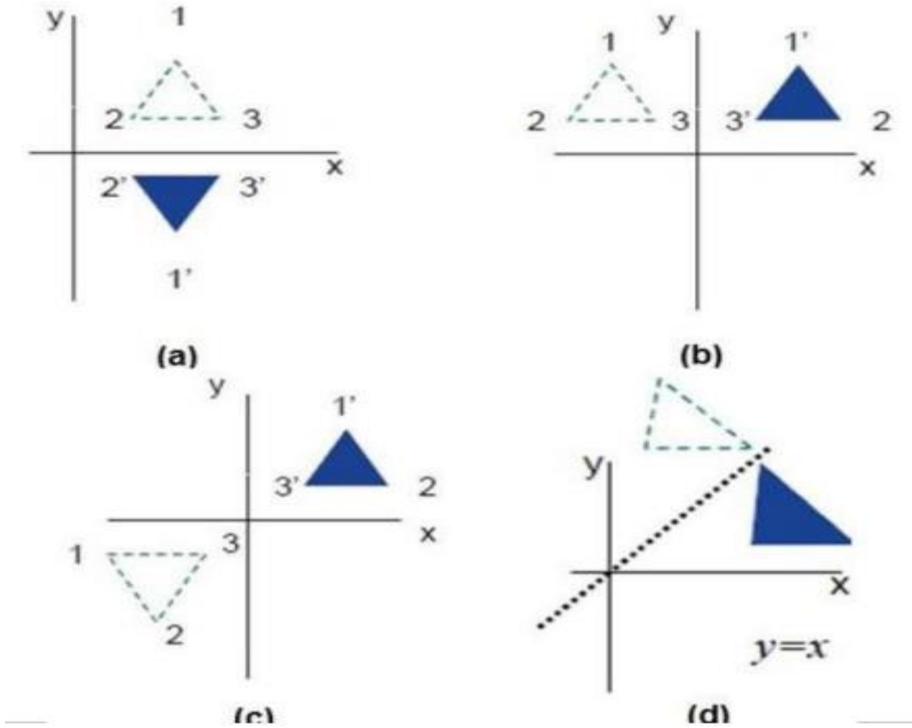


Fig. 1.10.6. Y-Shear

Reflection is the mirror image of original object. In other words, we can say that it is a rotation operation with 180°. In reflection transformation, the size of the object does not change. The following figures show reflections with respect to X and Y axes, and about the origin respectively.

1.10**.2. 3D TRANSFORMATIONS**

In homogeneous coordinates, 3D transformations are represented by 4x4 matrices. A point transformation is performed.

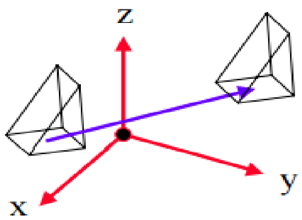
$$\begin{bmatrix} a & b & c & t_x \\ d & e & f & t_y \\ g & h & i & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & c & t_x \\ d & e & f & t_y \\ g & h & i & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

- P in translated to P' by:

$$\begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} x+t_x \\ y+t_y \\ z+t_z \\ 1 \end{bmatrix}$$

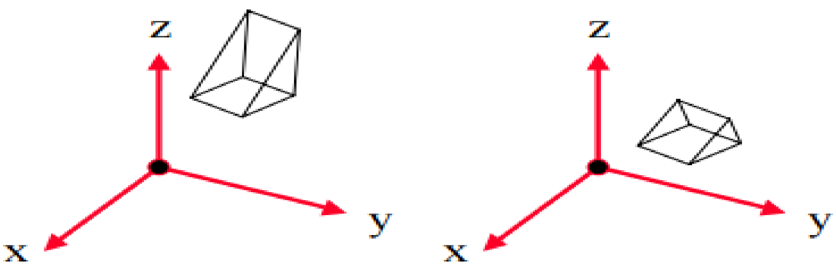
Or $T\,P = P'$



- Inverse translation: $T^{-1}P' = P$

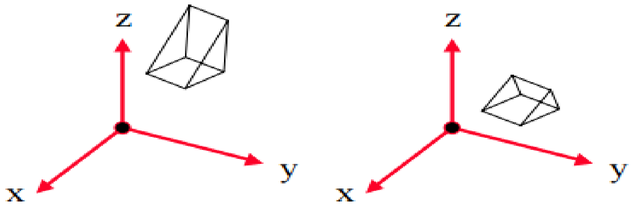
$$\begin{bmatrix} a & 0 & 0 & 0 \\ 0 & b & 0 & 0 \\ 0 & 0 & c & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} ax \\ by \\ cz \\ 1 \end{bmatrix}$$

Or $S\,P = P'$

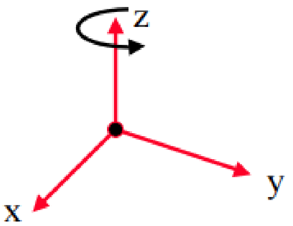


$$\begin{bmatrix} a & 0 & 0 & 0 \\ 0 & b & 0 & 0 \\ 0 & 0 & c & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} ax \\ by \\ cz \\ 1 \end{bmatrix}$$

Or $\quad SP = P'$



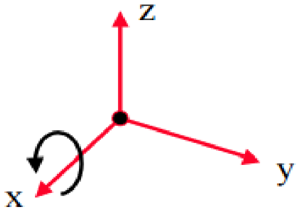
z-axis



$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$p' = R_z(\theta)p$$

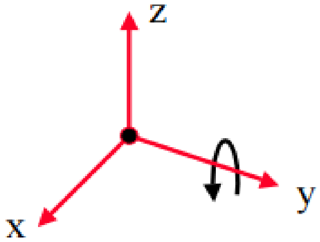
x-axis



$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$p' = R_x(\theta)p$$

y-axis



$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$p' = R_y(\theta)p$$

CAD/CAM

Custom Software
Development
tools
experience
customization
parser
customer
system
e-solution
agile web
computer
application
design
batch
improvement
solution
opportunity
maintenance
integrity
expertise
user
network
technology
support
performance
product
data
content
innovation
query
on demand
strategy
quality
migration
website
database
legacy
programming
project
outsourcing
intelligence
mobile
practical
client
testing
file
management
systems
javascript
internet
program
retail
ideas
business
market
services
interface

CAD/CAM - SYLLABUS

SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY — SCHOOL OF MECHANICAL ENGINEERING

SMEA1501	CAD / CAM	L	T	P	Credits	Total Marks
		3	0	0	3	100

COURSE OBJECTIVES

- To provide the fundamental information about computer graphics, elements of CAD/CAM and basic understanding about transformations, clipping, windowing and hidden line removal.
- To provide strong understanding of various wireframe, surface and solid modelling techniques used for generating computer models.
- To provide the details on how computer applications are useful directly and indirectly for the manufacturing applications.

COURSE OUTCOMES

On completion of the course, students will be able to

CO1 - Understand the fundamental information about computer graphics, elements of CAD/CAM and apply the knowledge of transformations, clipping, windowing and hidden line removal for simple problems.

CO2 - Learn various wireframe and surface modelling techniques used for generating computer models.

CO3 - Explain various solid modelling techniques, assembly modelling and drafting facilities provided by CAD packages.

CO4 - Explain the file structure of various product data exchange file formats and their applications.

CO5 - Analyze the details on computer applications used directly for the manufacturing applications.

CO6 - Analyze the details on computer applications used indirectly for the manufacturing industry.

CAD/CAM - SYLLABUS

UNIT 1 FUNDAMENTALS OF CAD/CAM **9 Hrs.**

Introduction: Elements of CAD, Elements of CAM, CAD/CAM integration, Advantages and applications. Computer graphics: Input and output devices, CAD/CAM databases, Requirements of Computer graphics packages. Transformations: Geometric transformation versus viewing transformation, Basic transformation matrices, such as translation, rotation and scaling.

UNIT 2 GEOMETRIC MODELLING - I **9 Hrs.**

Wireframe modelling of analytical curves, such as line, circle and conics, and synthetic curves, such as Hermite cubic spline, Bezier curve and B-Spline curve. Surface modelling of analytical surfaces, such as plane surface, ruled surface, surface of revolution and tabulated cylinder, and synthetic surfaces, such as Hermite cubic surface, Bezier surface and B-Spline surface.

UNIT 3 GEOMETRIC MODELING - II **9 Hrs.**

Solid modelling techniques: Constructive solid geometry (CSG) representation and Boundary representation. Assembly modelling: Assembly of part drawing, Approaches, Interferences of positions and orientation. Graphics standards: Product data exchange, File format of DXF, IGES and STEP files. Capabilities of modelling & analysis packages.

UNIT 4 COMPUTER AIDED MANUFACTURING - I **9 Hrs.**

NC, DNC and CNC machine tools. NC Programming: point to point and continuous path machining approaches, G Codes, M Codes, Canned cycles, Manual NC programming for turning and milling operations. Use of computer applications in inspection, rapid prototyping, material handling and other manufacturing related tasks.

UNIT 5 COMPUTER AIDED MANUFACTURING - II **9 Hrs.**

Computer Aided Process Planning (CAPP): Traditional process planning, Benefits of CAPP, Variant and Generative approaches. Computer integrated production system (CIPS): Traditional production planning, Benefits of CIPS, Master production Schedule, Material Requirement Planning, Inventory Management, Capacity planning, Shop floor control.

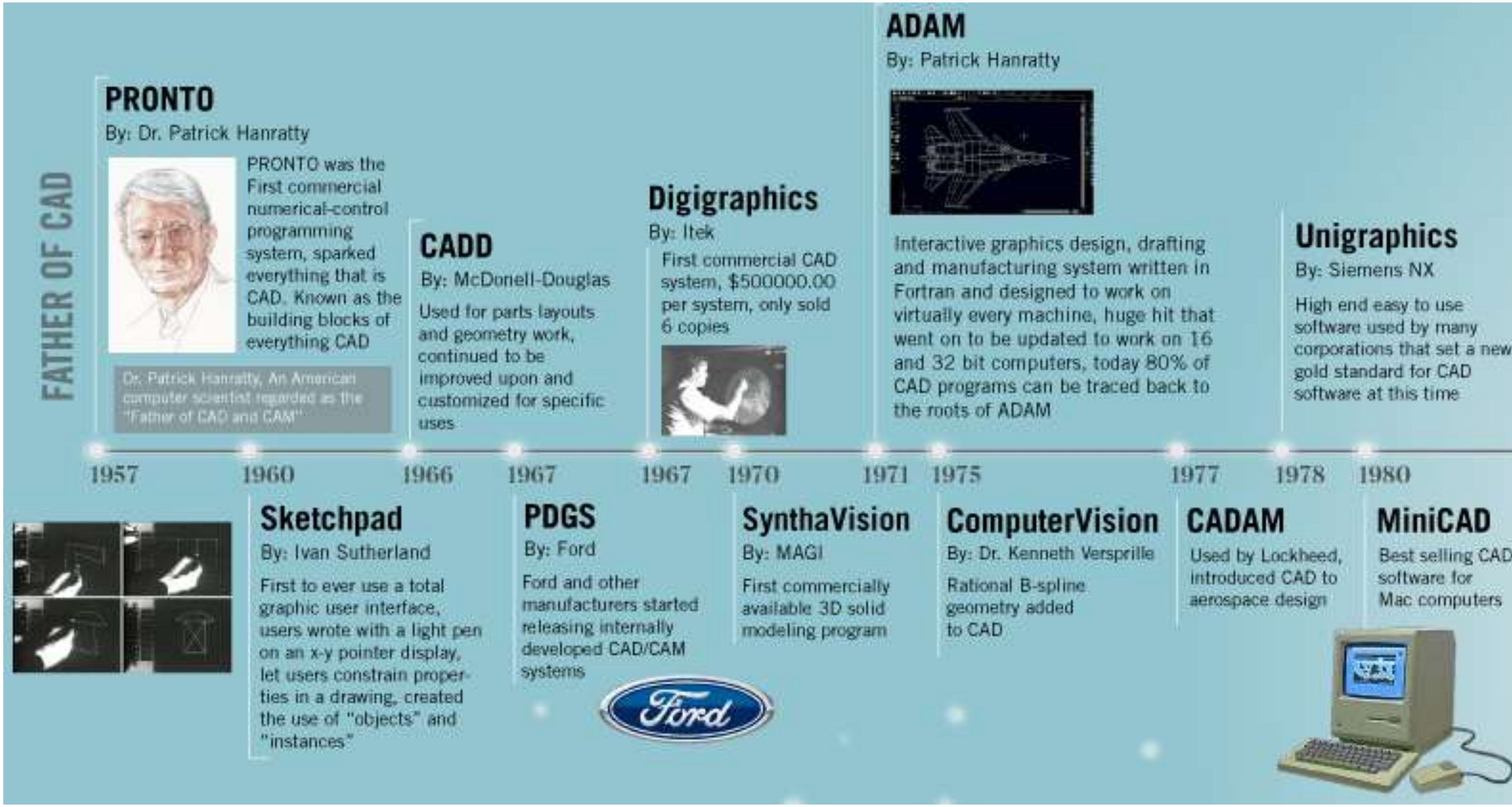
Max. 45 Hrs.

CAD/CAM - SYLLABUS

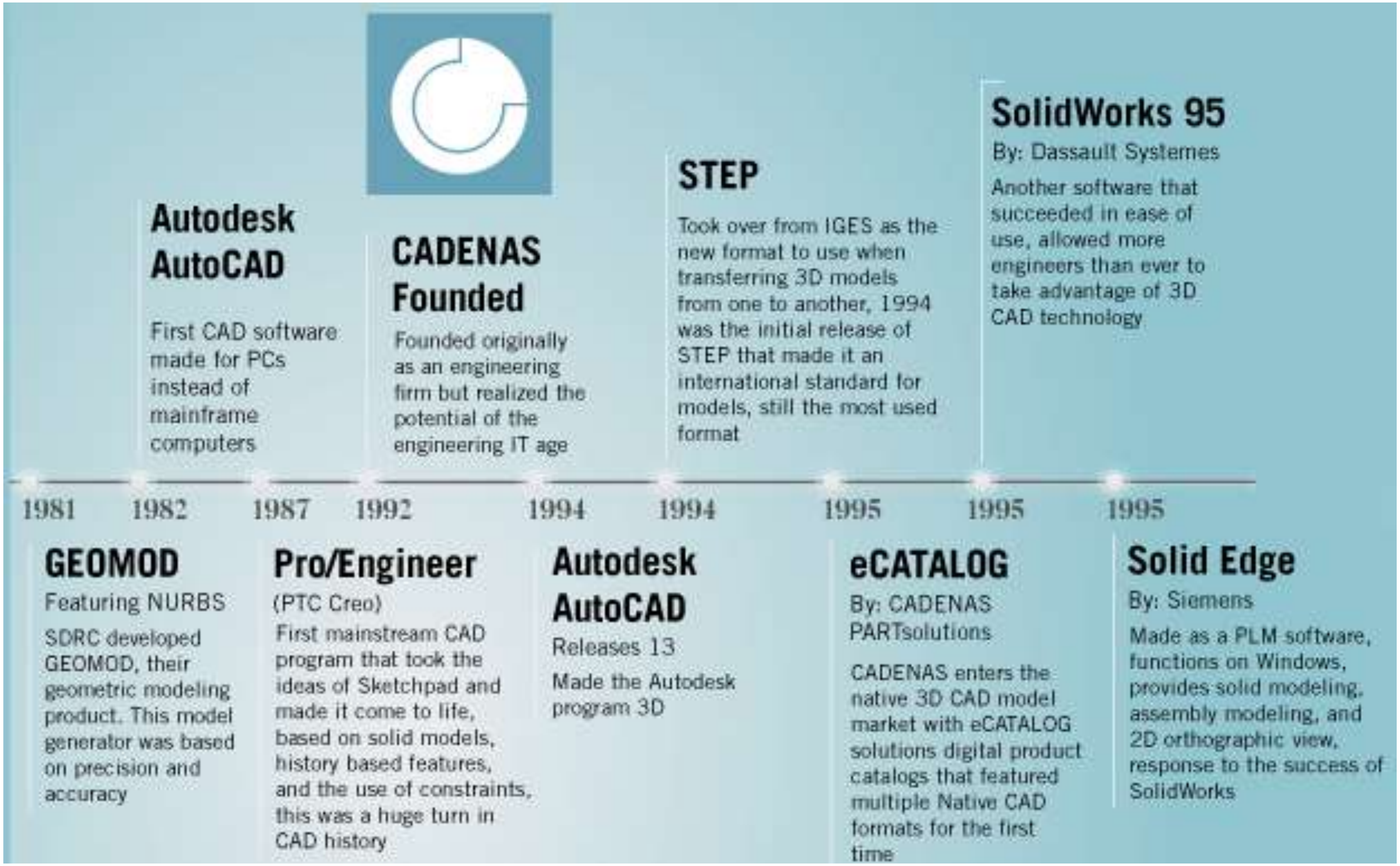
TEXT / REFERENCE BOOKS

1. Ibrahim Zeid and R. Sivasubramanian, "CAD/CAM : Theory and Practice: Special Indian Edition", 2nd Edition, McGraw Hill Education, 2009.
2. M. Groover and E. Zimmers, "CAD/CAM Computer-Aided Design and Manufacturing", 1st Edition, Pearson Education, 2003.
3. Donald D. Hearn and M. Pauline Baker, "Computer Graphics, C Version", 2nd Edition, Pearson Education, 2014.
4. John F. Hughes, Andries van Dam, Morgan McGuire, David F. Sklar, James D. Foley, Steven K. Feiner and Kurt Akeley, "Computer Graphics: Principles and Practice", 3rd Edition, Pearson Education, India, 2013.
5. Mikell P Groover, "Automation, Production Systems, And Computer-Integrated Manufacturing", 4th Edition, Pearson Education, 2014.
6. Mike Mattson, "CNC Programming: Principles and Applications", 1st Edition, Delmar, 2013.
7. M. Adithan and B.S. Pable, "CNC Machines", 3rd Edition, New Age International Publishers, 2018.

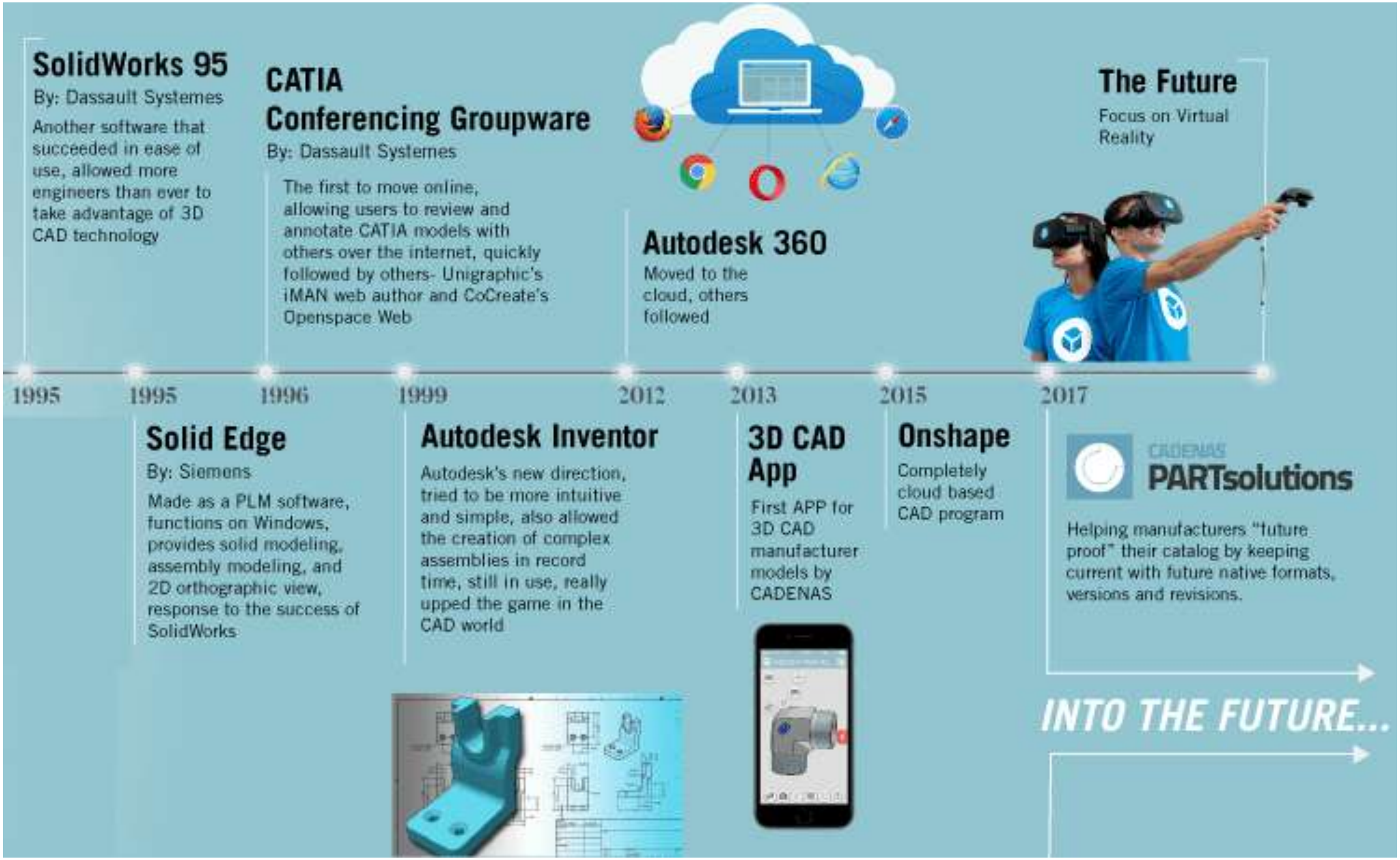
History of CAD/CAM



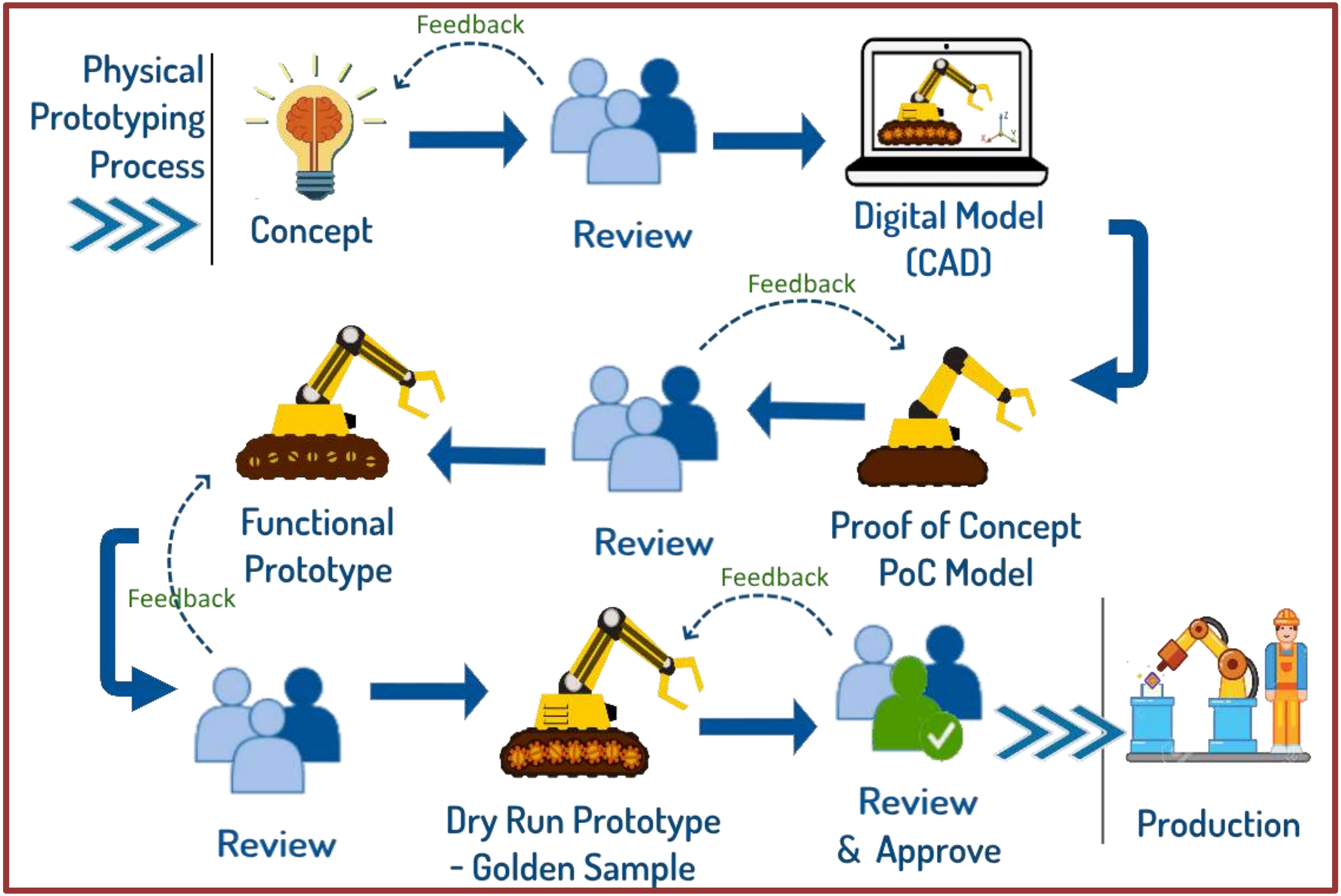
History of CAD/CAM



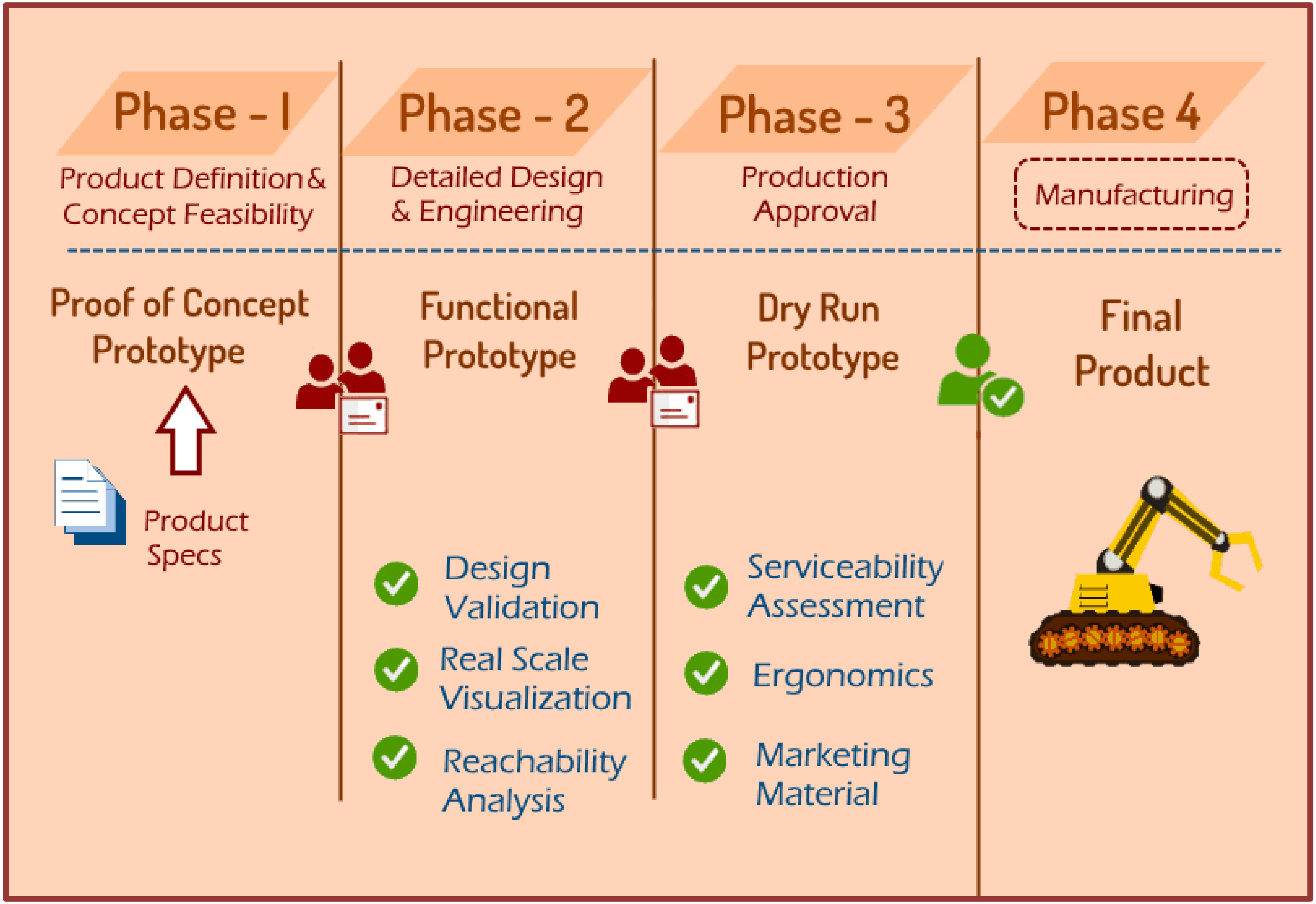
History of CAD/CAM



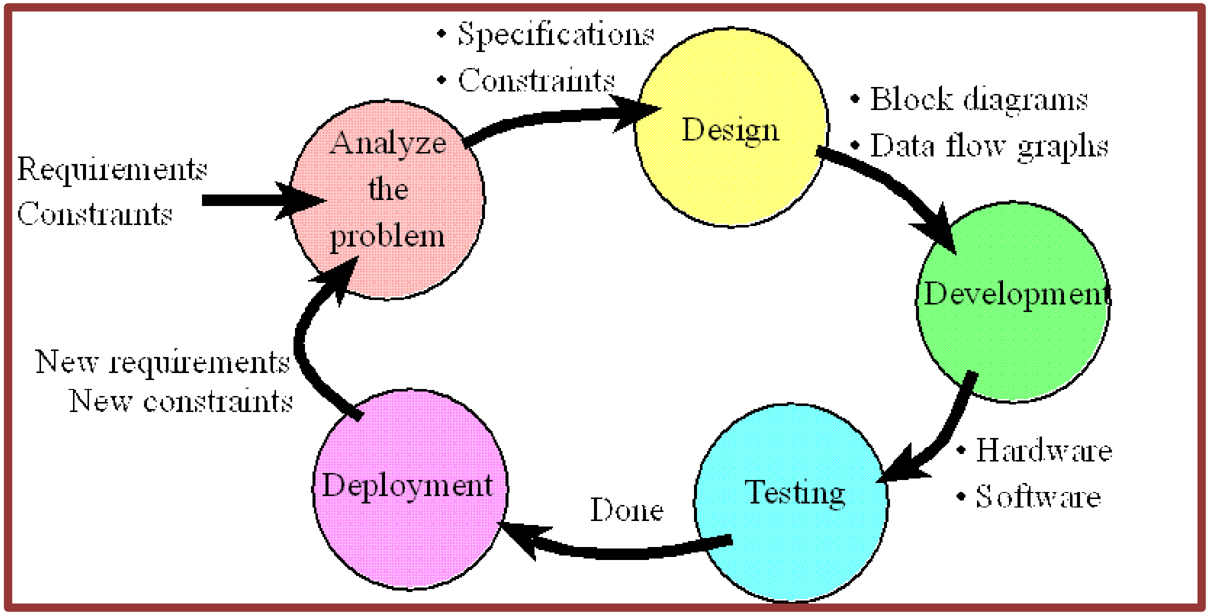
Fundamentals of CAD/CAM

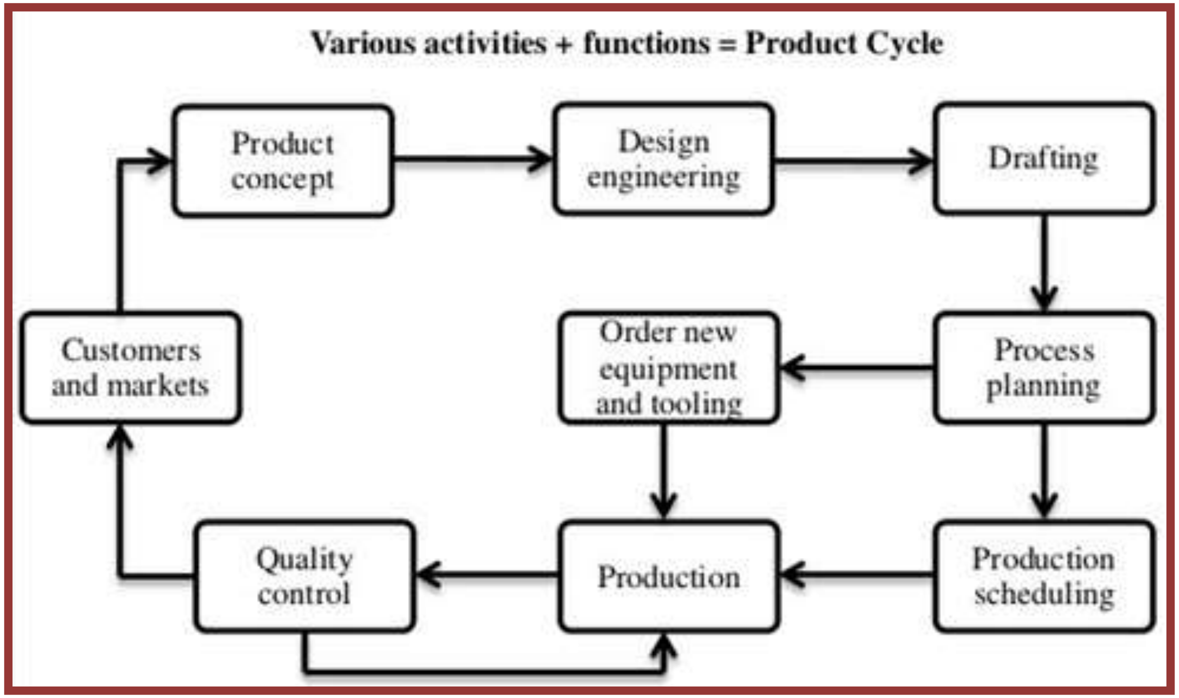


Fundamentals of CAD/CAM



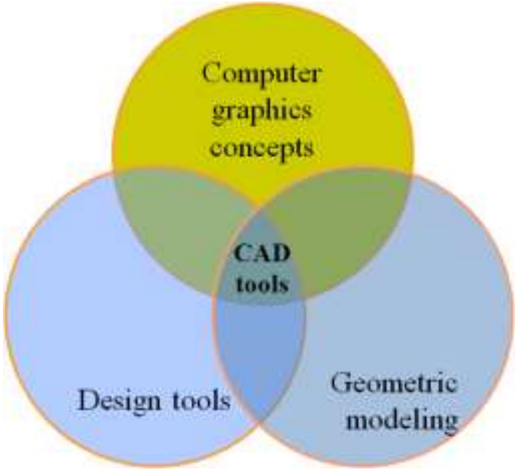
Product Life Cycle



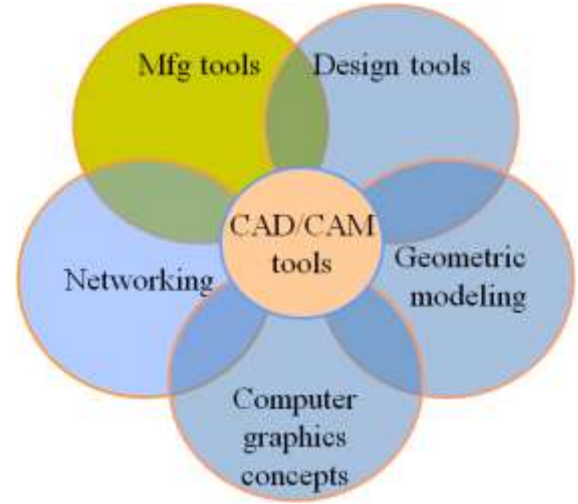


Fundamentals of CAD/CAM

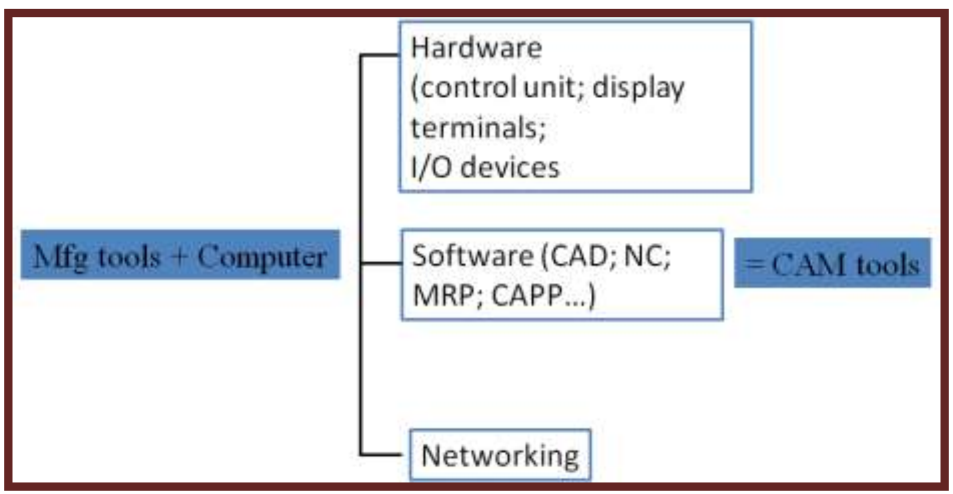
Definitions of CAD Tools Based on Their Constituents



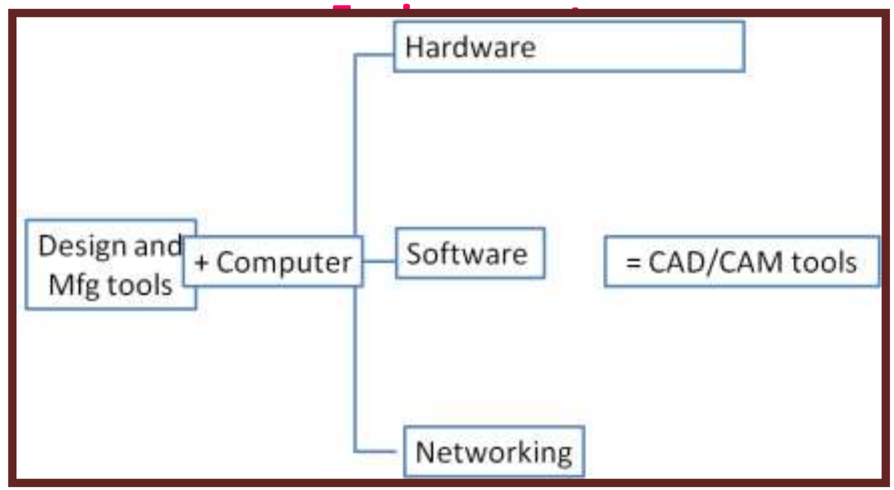
CAD/CAM Tools Based on Their Constituents



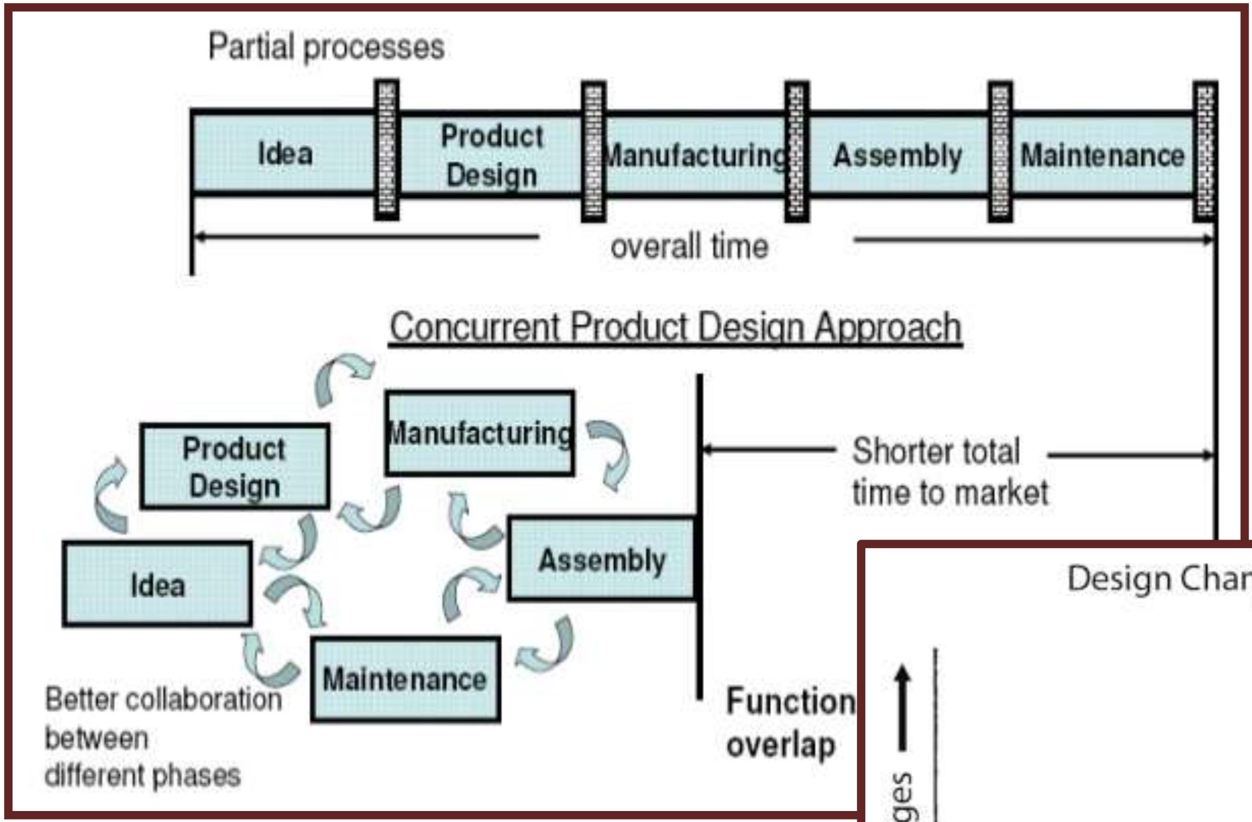
CAM Tools Based on Their Implementation in a Manufacturing Environment

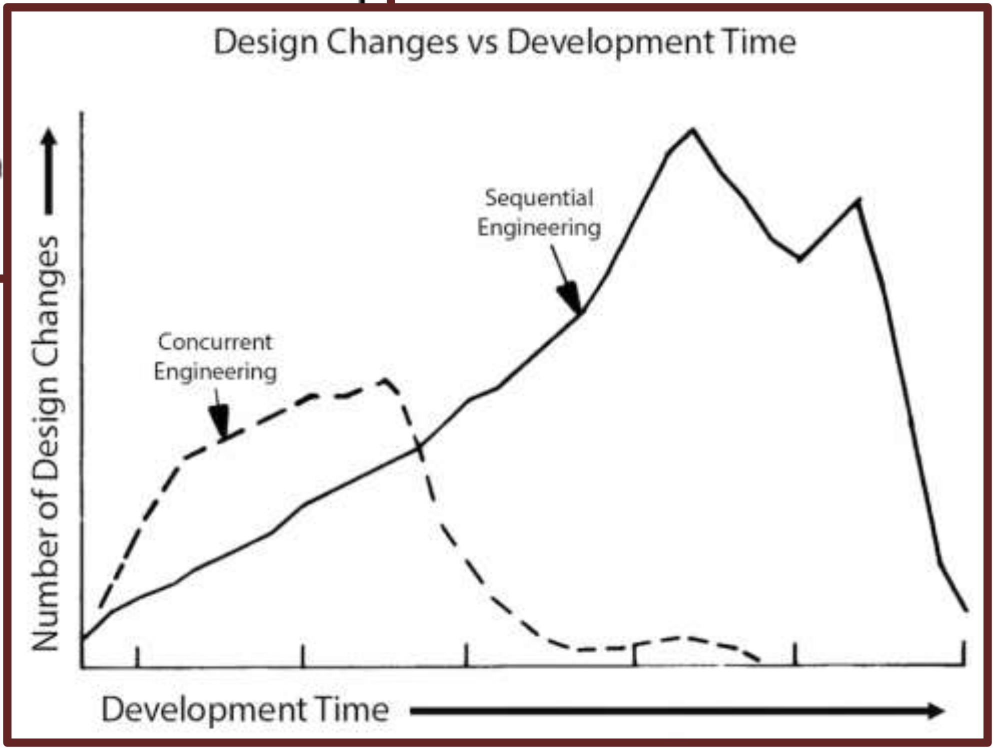


CAD/CAM Tools Based on Their Implementation in Manufacturing



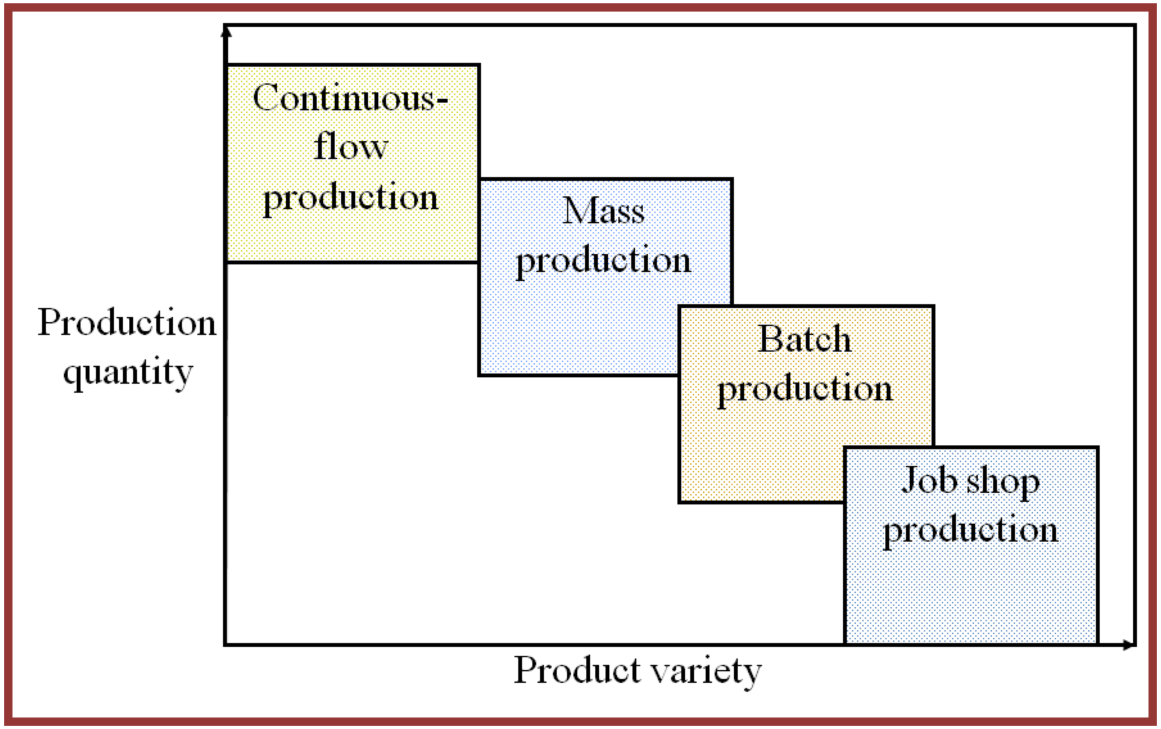
Fundamentals of CAD/CAM



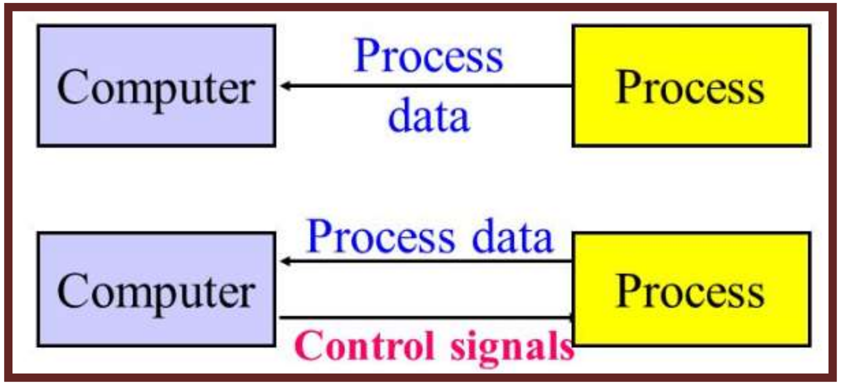


Types of Manufacturing Systems

- **Continuous-flow processes**. Continuous dedicated production of large amount of bulk product.
  Example: chemicals, plastics, petroleum, and food industries.
- **Mass production of discrete products**. Dedicated production of large quantities of one product (with perhaps limited model variations).
  Example: automobiles, appliances and engine blocks.
- **Batch production.** Production of medium lot sizes of the same product. The lot may be produced once or repeated periodically.
  Example: books, clothing and certain industrial machinery.
- **Job-shop production**. Production of low quantities, often one of a kind, of specialized products. The products are often customized and technologically complex.
  Example: prototypes, aircraft, machine tools and other equipment.

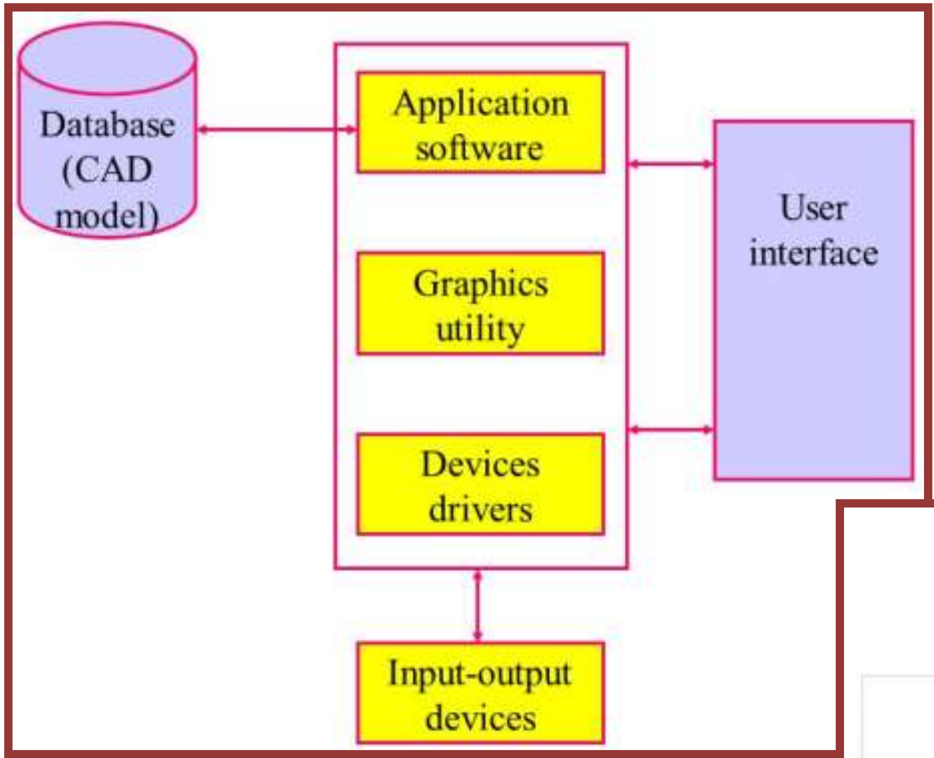


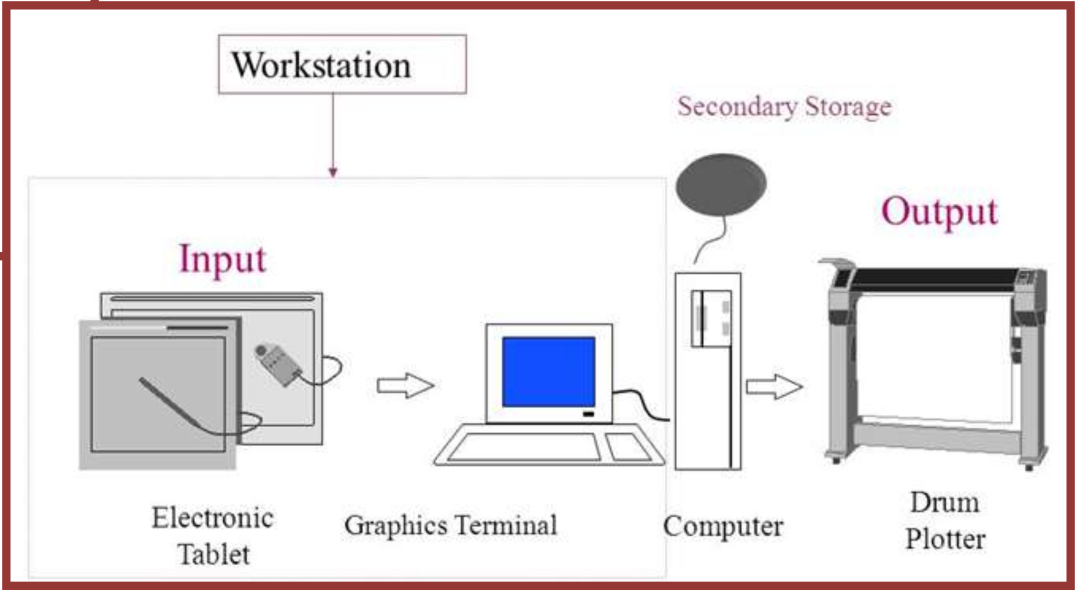
Computer Aided Process and Process Monitoring Control system



Fundamentals of CAD

Computer - Aided Design (CAD) is the technology concerned with the use of computer systems to assist in the creation, modification, analysis, and optimization of a design. [Groover and Zimmers, 1984]





Fundamentals of CAD

Hardware - Input Devices

- Input devices are what is used to put data into the computer. Without them you could not tell the computer what to do.

The input devices you need to know about are:

- **Keyboard**: The most commonly used input device. Some keyboards are specially designed to help people with disabilities.

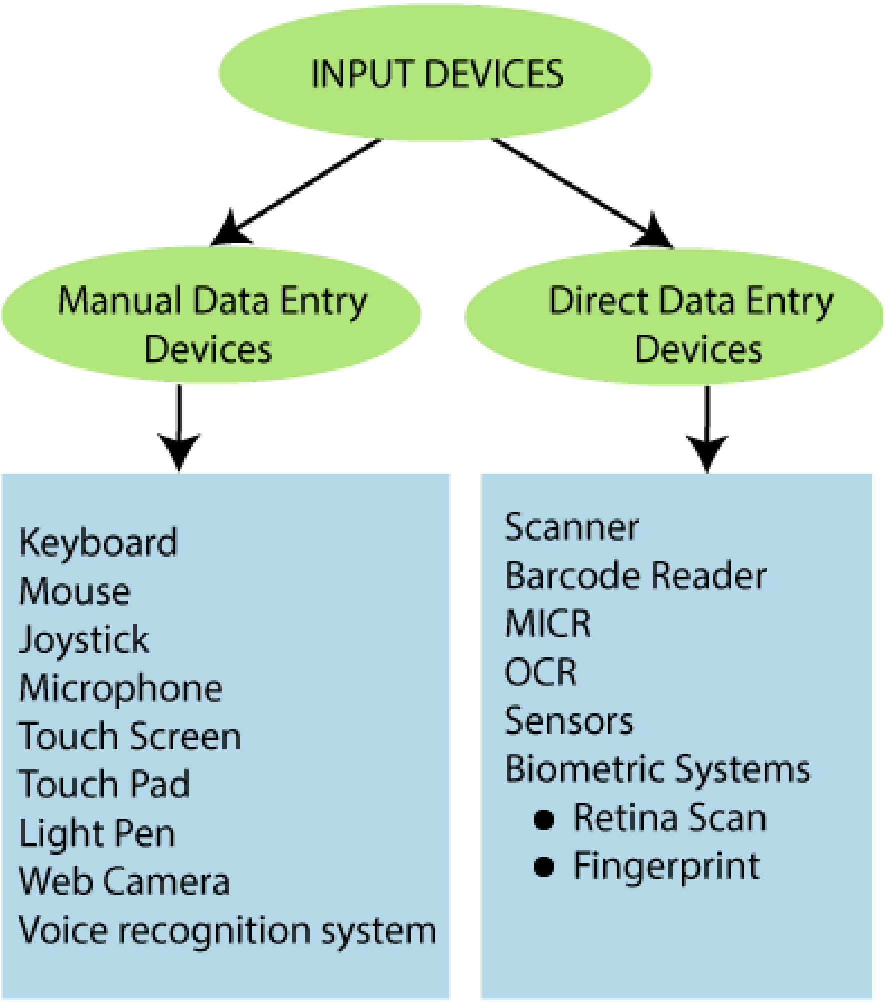
- **Mouse**: Used to control a pointer and to select items. A very *user-friendly* device.

- **Trackball**: This is like an upside-down mouse where the user rolls the wheel in the direction they want the pointer to go. This is useful when there is no flat surface to use a mouse on. They are often used with video games and information kiosks.

- **Trackpad**: Used instead of a mouse on most laptop computers. It is a touch sensitive pad that the user moves their finger along in the direction they wish the pointer move.

- **Joystick**: Often used for playing games and for simulators. They can move in 8 directions and often have buttons attached for extra functionality.

- **Graphics Tablet**: Used for *Computer Aided Design* (*CAD*) and other graphics work. It is a flat, pressure sensitive board that you press on with a special pen. It makes it easier to draw, just like using a pen or pencil.



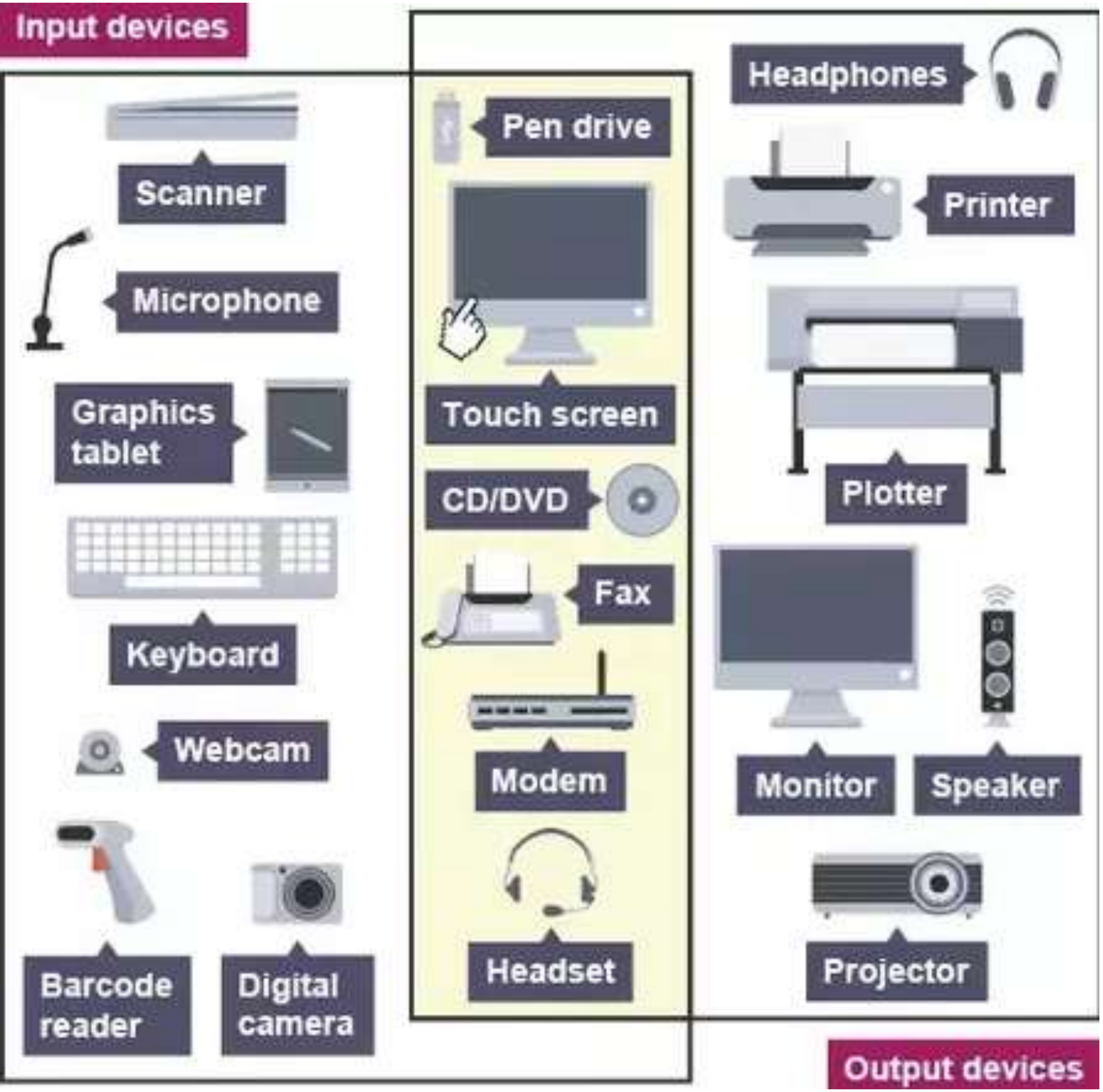
Magnetic Ink Card Reader (MICR)

MICR input device is generally used in banks as there are large number of cheques to be processed every day. The bank's code number and cheque number are printed on the cheques with a special type of ink that contains particles of magnetic material that are machine readable

Optical Character Reader (OCR)

OCR is an **input** device used to read a printed text. **OCR** scans the text optically, character by character, converts them into a machine readable code, and stores the text on the system memory

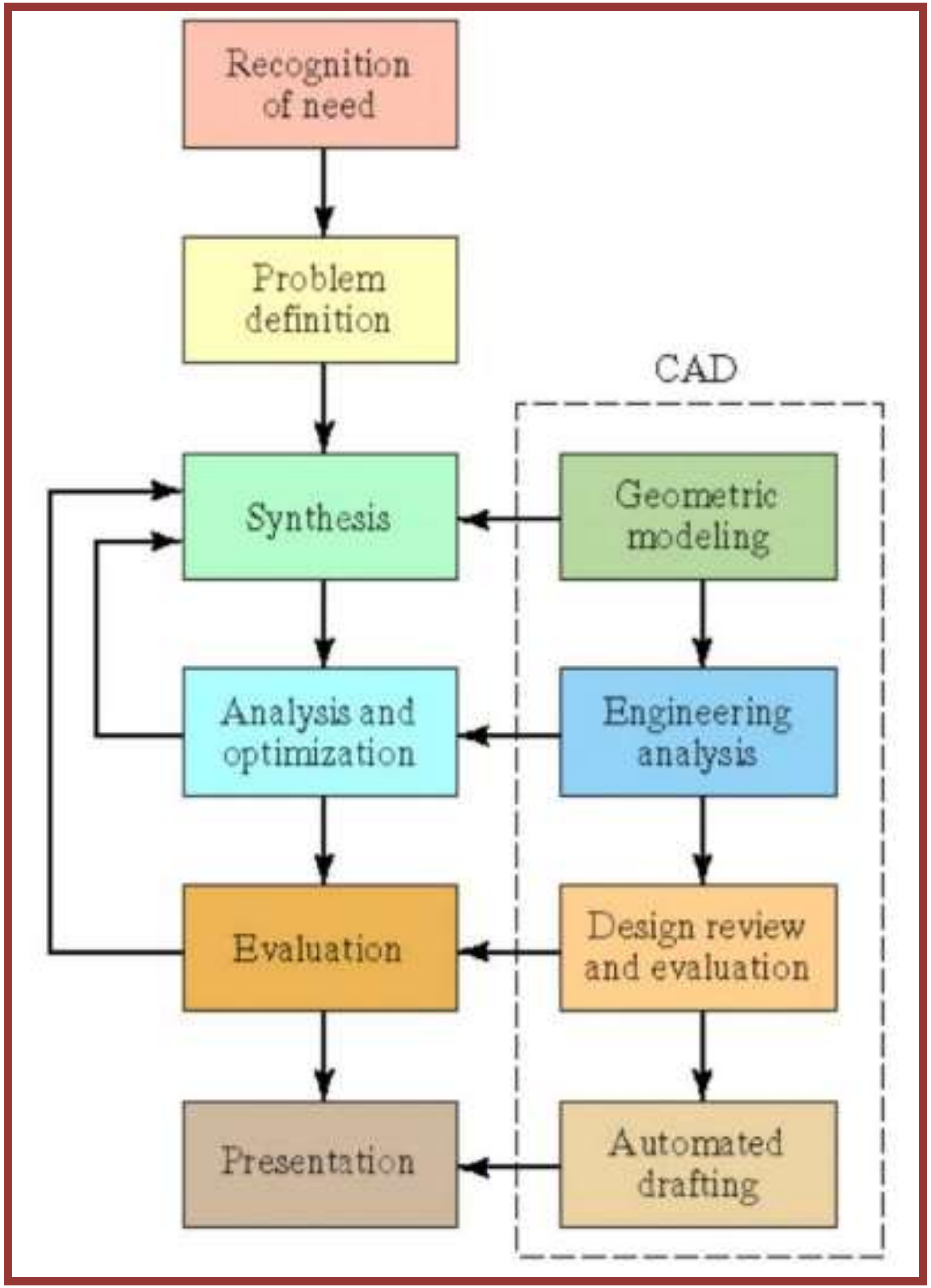
Fundamentals of CAD



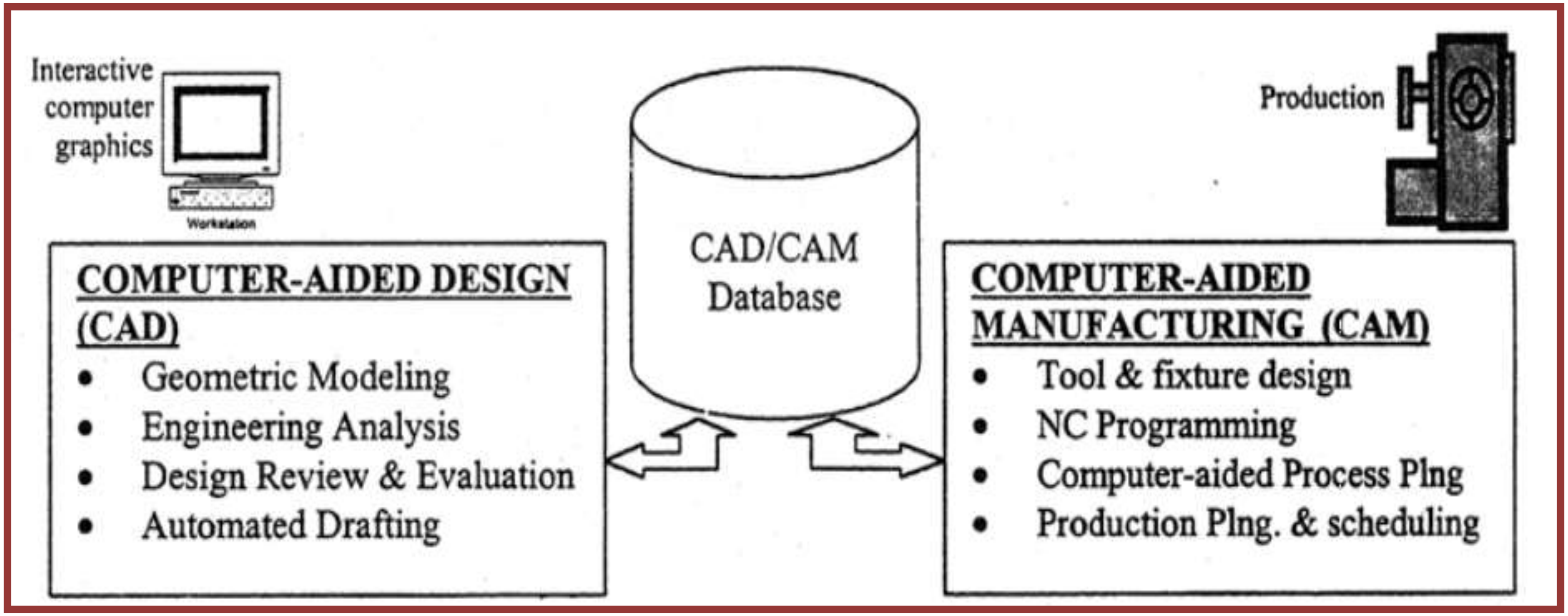
Graphics Output Devices

- Most commonly used computer output devices that are capable of producing graphical output are:
  - Raster-scan Cathode Ray Tube (CRT)
  - Plasma Display
  - Liquid Crystal Display
  - 3D Viewing using Stereoscopic Systems
  - Plotters and Printers

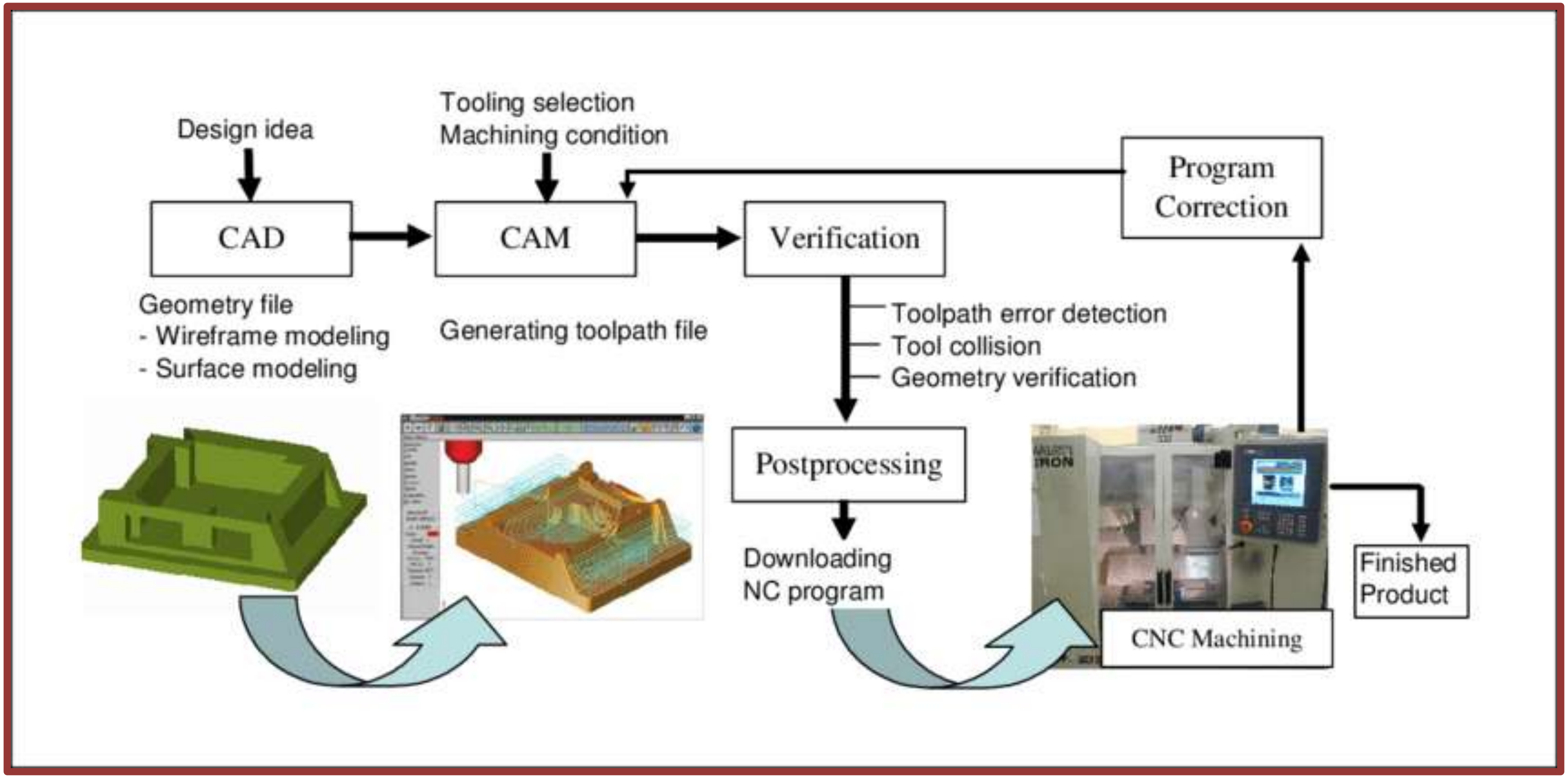
Stages in Design Process with CAD



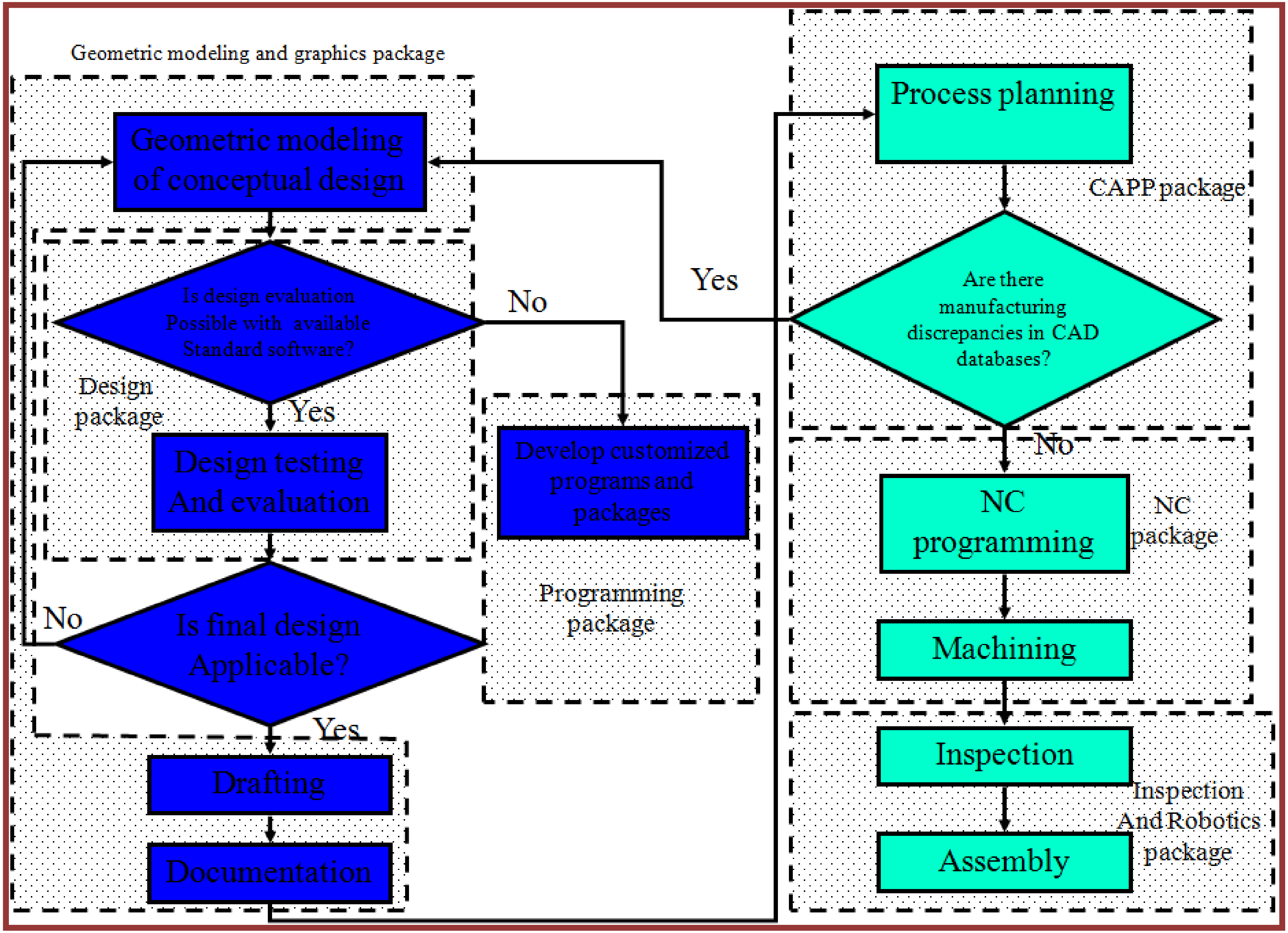
CAD/CAM DATA BASE



CAD/CAM DATA BASE



Typical Utilization of CAD/CAM Systems in an Industrial Environment

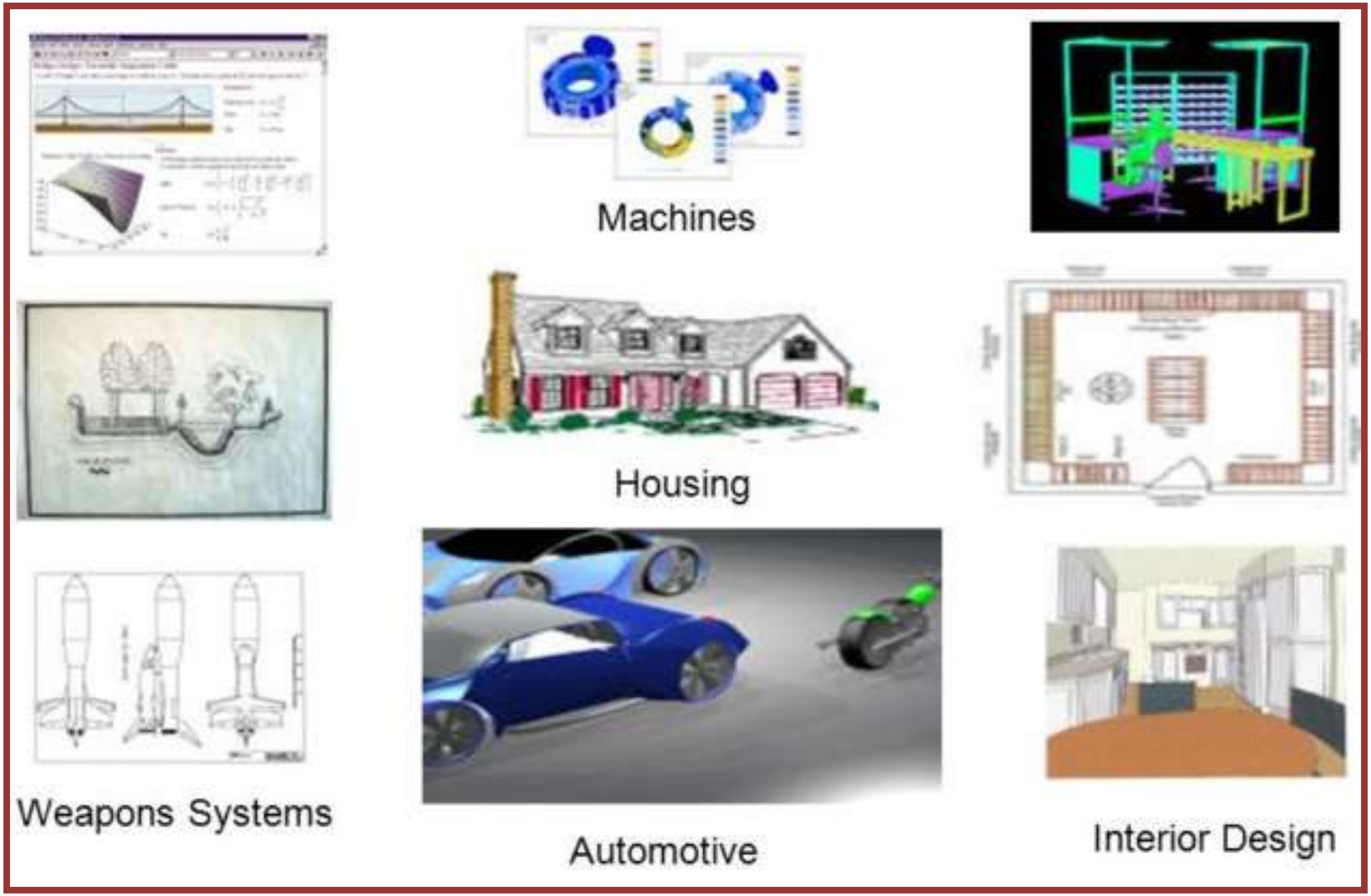


Advantages of CAD /CAM

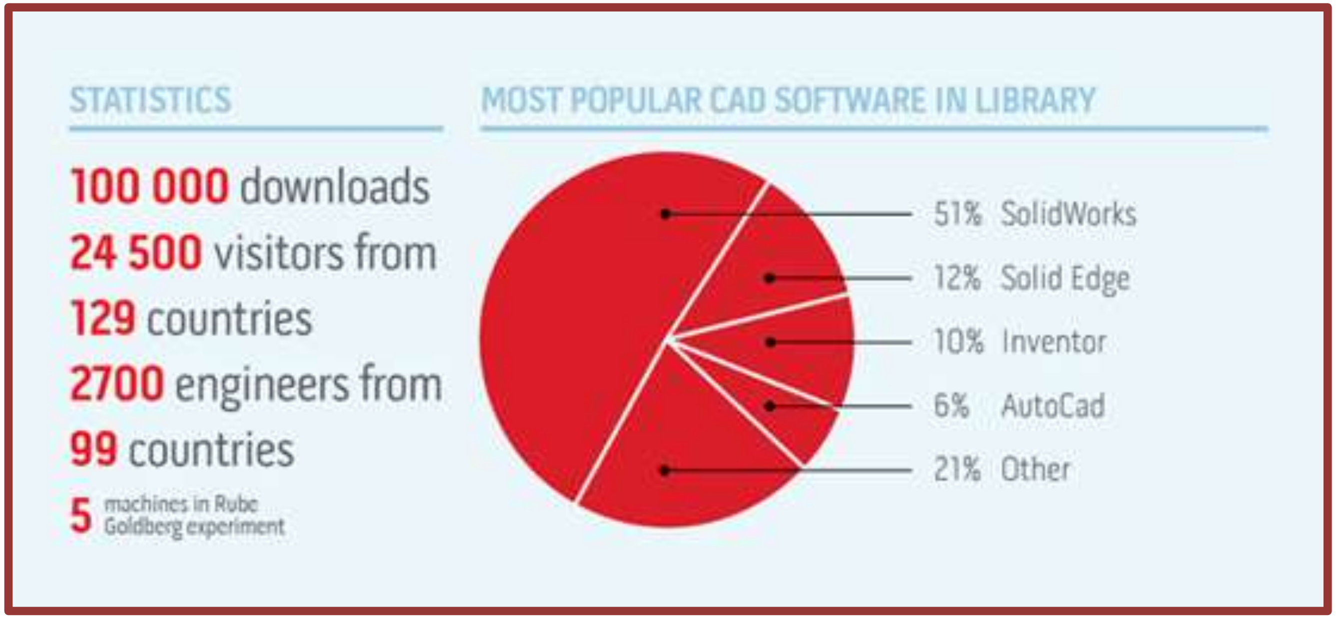
- **Greater flexibility.**
- **Reduced lead times.**
- **Reduced inventories.**
- **Increased Productivity.**
- **Improved customer service.**
- **Improved quality.**
- **Improved communications with suppliers.**

- **Better product design.**
- **Greater manufacturing control.**
- **Supported integration.**
- **Reduced costs.**
- **Increased utilization.**
- **Reduction of machine tools.**
- **Less floor space.**

Applications of CAD/CAM



CAD/CAM Software's

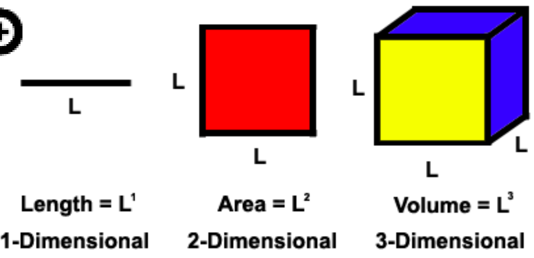


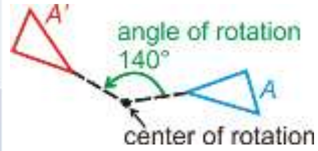
Application Area	Software	Integrated System
CAD—2D drafting	CADAM, AutoCAD, MicroCADAM, VersaCAD	Pro/ENGINEER Unigraphics
CAD—Solid modeling	Solid Edge, SolidWorks, SolidDesigner, Mechanical Desktop	CATIA I-DEAS
CAM	BravoNCG, VERICUT, DUCT, Camand, Mastercam, PowerMILL	I/EMS EUCLID-IS
CAE	MSC/NASTRAN, ANSYS, PATRAN, DADS, ADAMS, C-MOLD, MOLDFLOW, DesignWorks	

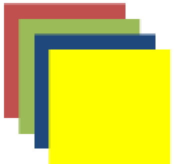
CAD/CAM Software's

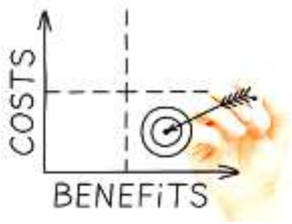
Features of CAD/CAM Software

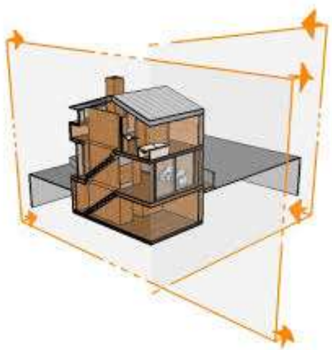
Feature	Use
Zoom	The ability to zoom in and out of a design
2D and 3D	The ability to change the surface of the models from 2D to 3D
Rotation	The ability to rotate a 3D design so you can see the design from all angles
Shading	Can add shading to a diagram to aid visualisation
No need for Prototyping	You can create a design without having to build a model
Layering	Layers can be used with each layer adding more detail, i.e. Layer of walls, electric circuits and plumbing
Walkthrough	Internal view in 3D / visit rooms in 3D. Allows a supermarket to visualise what the building will be like by testing out various layouts
Costings	Allows a database of prices of materials to be created. The program can explore the cost of different options in a kitchen plan.
Hatching/Rendering	Can use different finishes or materials. Can do what if investigation to see the effect of different finishes.
Stress/strain	Allows design features to be checked against requirements. By working out the weights of materials can avoid a later disaster.

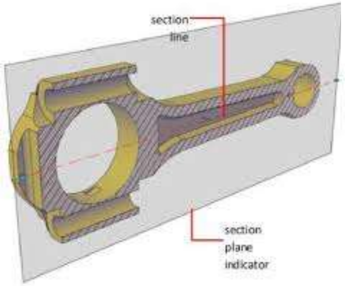


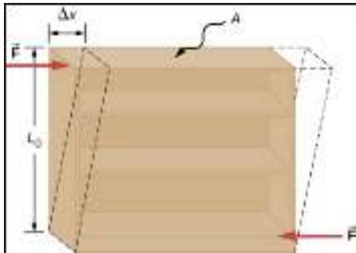












GRAPHIC PRIMITIVES

A drawing is created by an assembly of points, lines, arcs, circles. For example, drawing shown in Fig 3.1 consists of several entities. In computer graphics also drawings are created in a similar manner. Each of these is called an entity. The drawing entities that a user may find in a typical CAD package include :

point

line

construction line, multi-line, polyline

circle

spline

arc

ellipse

polygon

rectangle

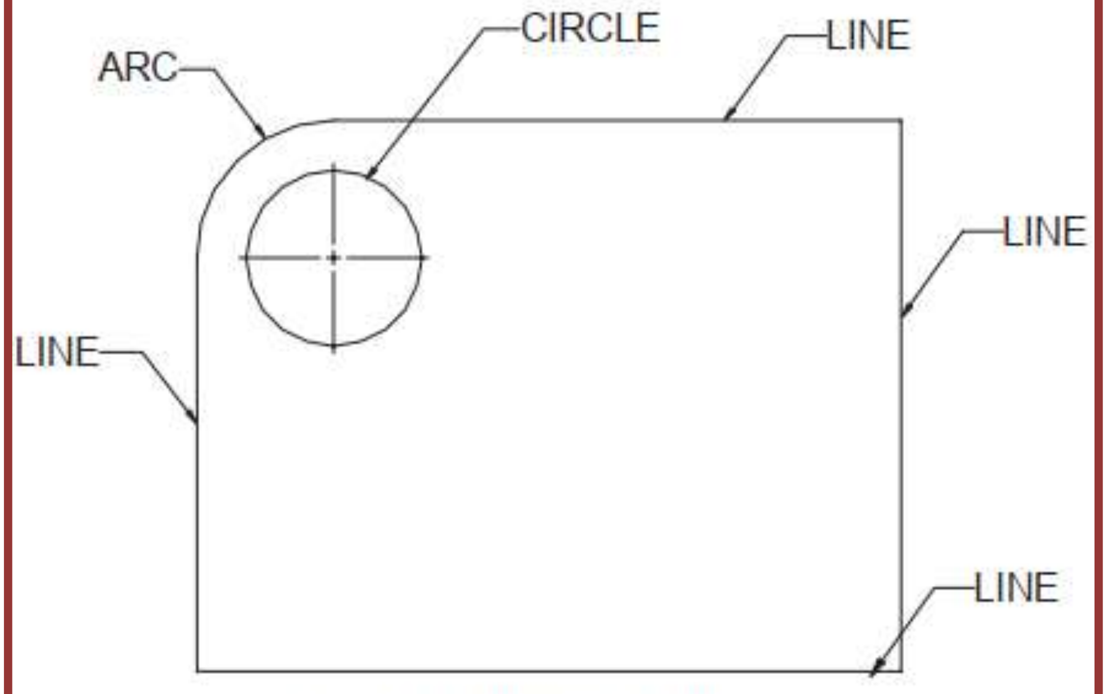


Fig. 3.1 A Simple Drawing

GRAPHIC PRIMITIVES

POINT PLOTTING

- The frame buffer display is an example of a point plotting device.
- The smallest unit accepted by such displays is a single pixel.
- To construct a useful picture on a point plotting device, a picture must be built out of several hundreds of pixels.

DRAWING OF LINES

- Straight line segments are used a great deal in computer generated pictures. The following criteria have been stipulated for line drawing displays :
- Lines should appear straight
- Lines should terminate accurately
- Lines should have constant density
- Line density should be independent of length and angle
- Line should be drawn rapidly

- The process of turning on the pixels for a line segment is called vector generation. If the end points of the line segment are known, there are several schemes for selecting the pixels between the end pixels. One method of generating a line segment is a symmetrical digital differential analyzer (DDA)

TRANSFORMATION IN GRAPHICS

Geometric transformations provide a means by which an image can be enlarged in size, or reduced, rotated, or moved. These changes are brought about by changing the co-ordinates of the picture to a new set of values depending upon the requirements.

Transformations can be carried out either in **Viewing, 2-dimensions** or **3-dimensions**.

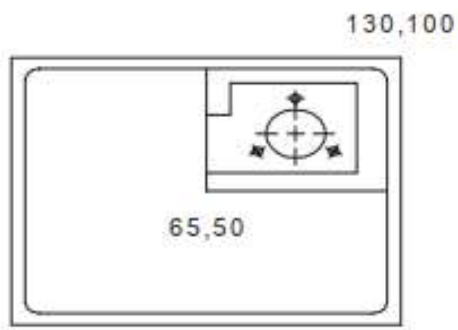


Fig. 3.8 View Port

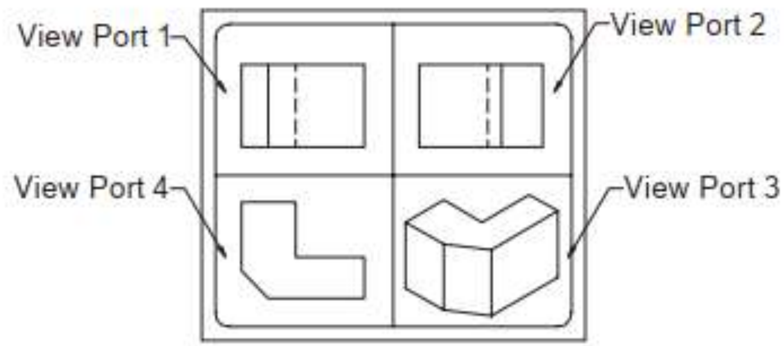
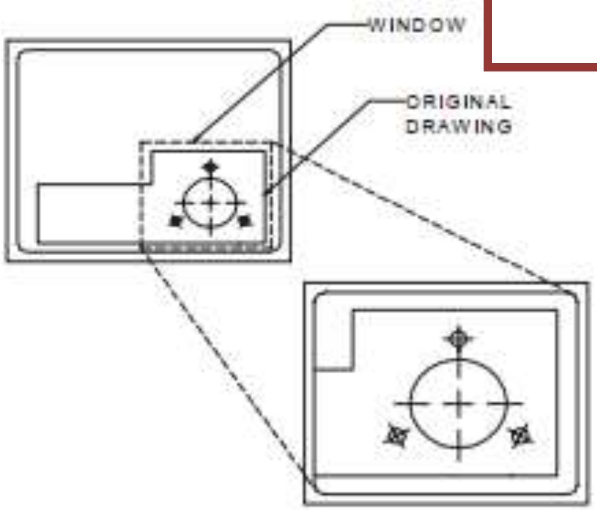


Fig. 3.9 Use of Multiple View Ports



Use of Window to Enlarge a Portion of the Drawing

SCALING

Changing the dimensions of window and view port, it is possible to alter the size of drawings. This technique is not satisfactory in all cases. A drawing can be made bigger by increasing the distance between the points of the drawing. In general, this can be done by multiplying the co-ordinates of the drawing by an enlargement or reduction factor called scaling factor, and the operation is called scaling. Referring to Fig. 3.10, P1 (30, 20) represents a point in the XY plane. In matrix form, P1 can be represented as:

$$P1 = [30, 20]$$

If we multiply this by a matrix

$$\begin{bmatrix} 2 & 0 \\ 0 & 3 \end{bmatrix}$$

we get a new point P2 (60, 60). The matrix is called the scaling matrix. In general, the scaling matrix can be represented as:

$$\begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix}$$

where S_x and S_y are scaling factors in X and Y directions.

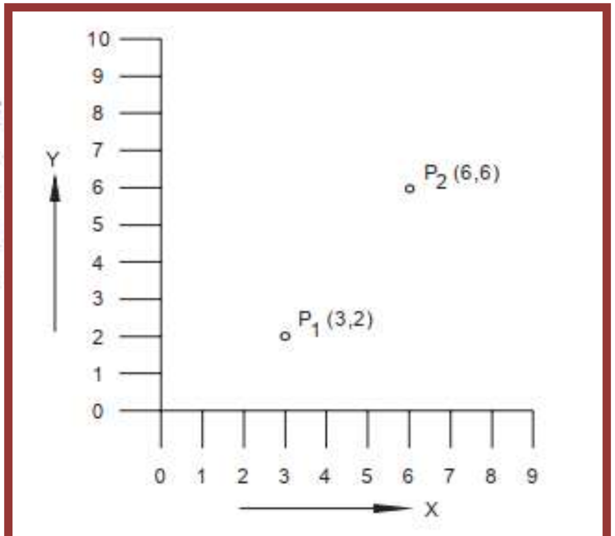


Fig. 3.10 Scaling a Point

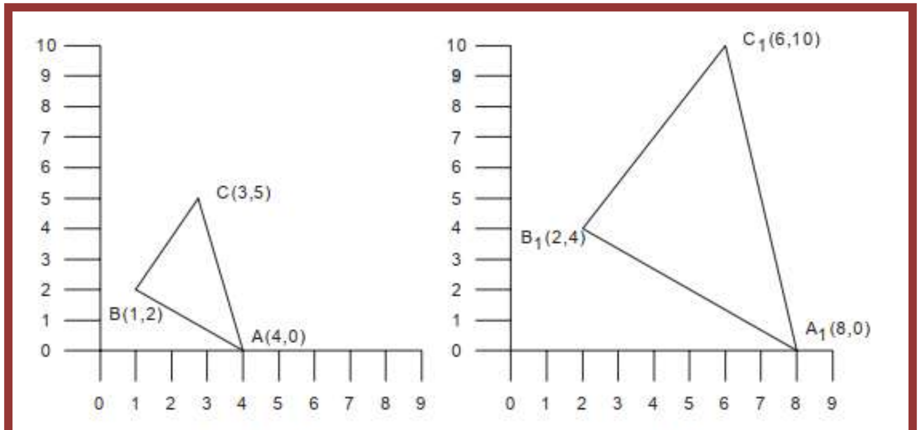


Fig. 3.11 (a)

Fig. 3.11 (b)

Fig. 3.11 Scaling a Triangle

An example of scaling in the case of a triangle is shown in Fig. 3.11. Fig. 3.11 (a) shows the original picture before scaling. Fig. 3.11 (b) shows the triangle after the co-ordinates are multiplied by the scaling matrix.

TRANSLATION

Moving drawing or model across the screen is called translation. This is accomplished by adding to the co-ordinates of each corner point the distance through which the drawing is to be moved (translated). Fig. 3.12 shows a rectangle (Fig. 3.12 (a)) being moved to a new position (Fig. 3.12 (b)) by adding 40 units to X co-ordinate values and 30 units to Y co-ordinate values. In general, in order to translate drawing by (T_X , T_Y) every point X, Y will be replaced by a point X1 , Y1 where

$$X1 = X + T_X$$

$$Y = Y + T_Y$$

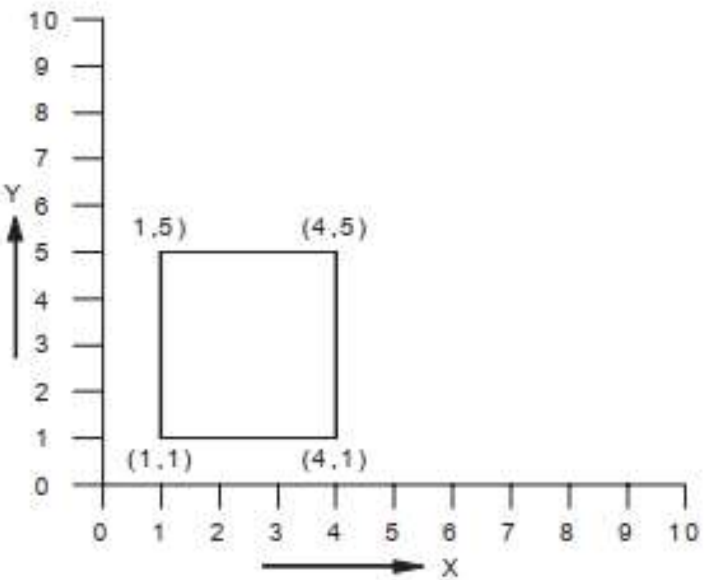


Fig. 3.12(a) Original Rectangle

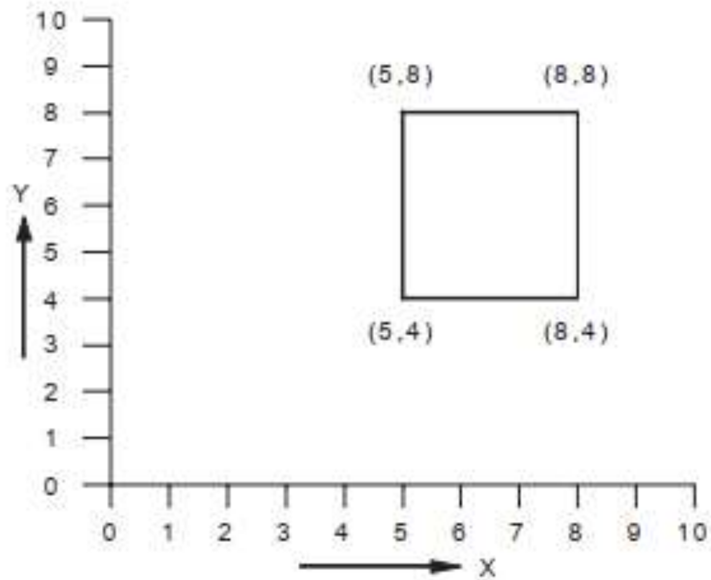


Fig. 3.12 (b) Rectangle After Translation

ROTATION

Another useful transformation is the rotation of a drawing about a pivot point. Consider Fig. 3.13. Point P1 (40, 20) can be seen being rotated about the origin through an angle, θ = 45°, in the anti-clockwise direction to position P2. The co-ordinates of P2 can be obtained by multiplying the co-ordinates of P1 by the matrix:

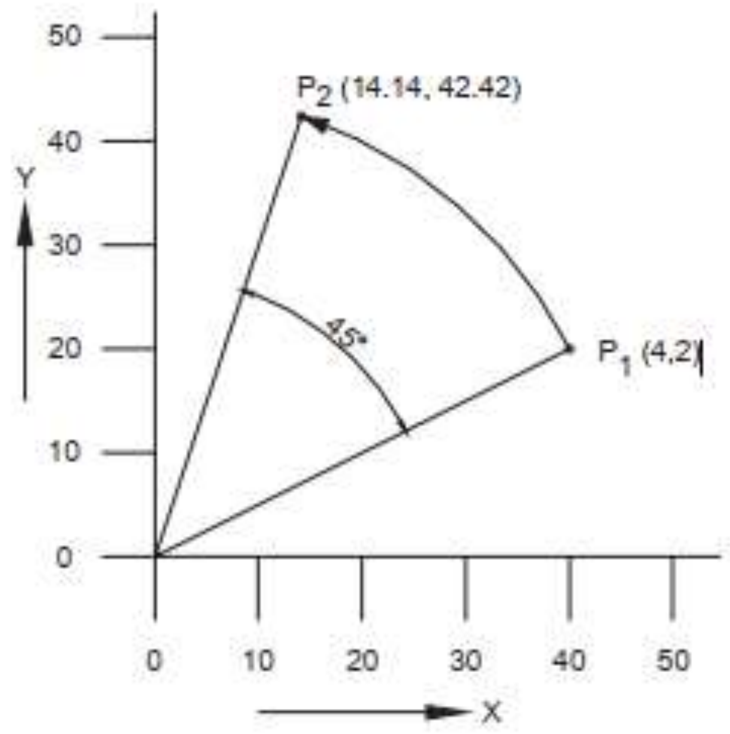


Fig. 3.13 Rotation

$$\begin{bmatrix} Cos\theta & Sin\theta \\ -Sin\theta & Cos\theta \end{bmatrix}$$

The new co-ordinates are

$$= [40 \quad 20]\begin{bmatrix} Cos\,45° & Sin\,45° \\ -Sin\,45° & Cos\,45° \end{bmatrix}$$

$$= [40 \quad 20]\begin{bmatrix} 0.707 & 0.707 \\ -0.707 & 0.707 \end{bmatrix}$$

$$= [14.14 \quad 42.42]$$

For rotating drawings in anticlockwise direction positive angles are used.

SHEARING

A shearing transformation produces distortion of an object or an entire image. There are two types of shears: X-shear and Y-shear. A Y-shear transforms the point (X, Y) to the point (X_1, Y_1) by a factor Sh_1, where

$$X_1 = X$$

$$Y_1 = Sh1.X + Y$$

Fig. 3.14 shows Y shear applied to a drawing.

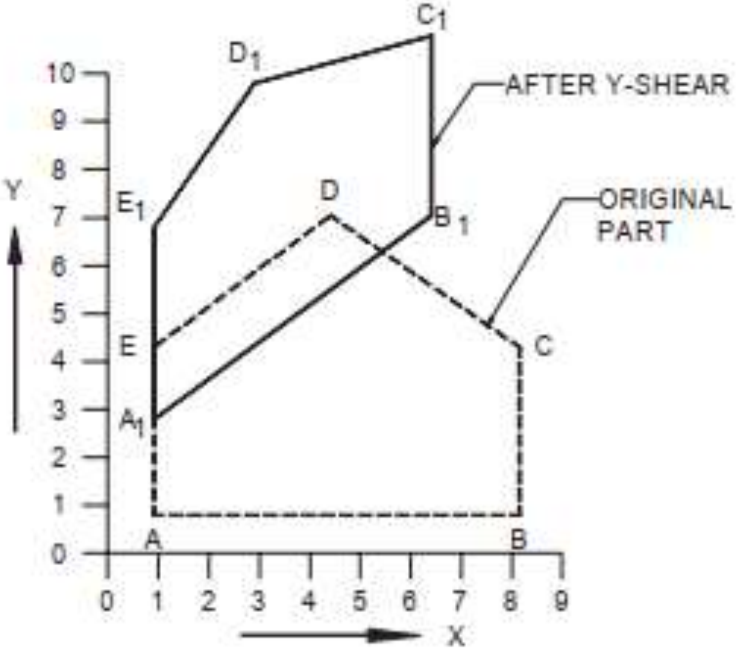


Fig. 3.14 Shearing

An X-shear transforms the point (X, Y) to $(X_1, Y1)$, where

$$X_1 = X + Sh2.Y$$

$$Y_1 = Y$$

Sh2 is the shear factor.

Fig. 3.15 shows the effect of X-shear.

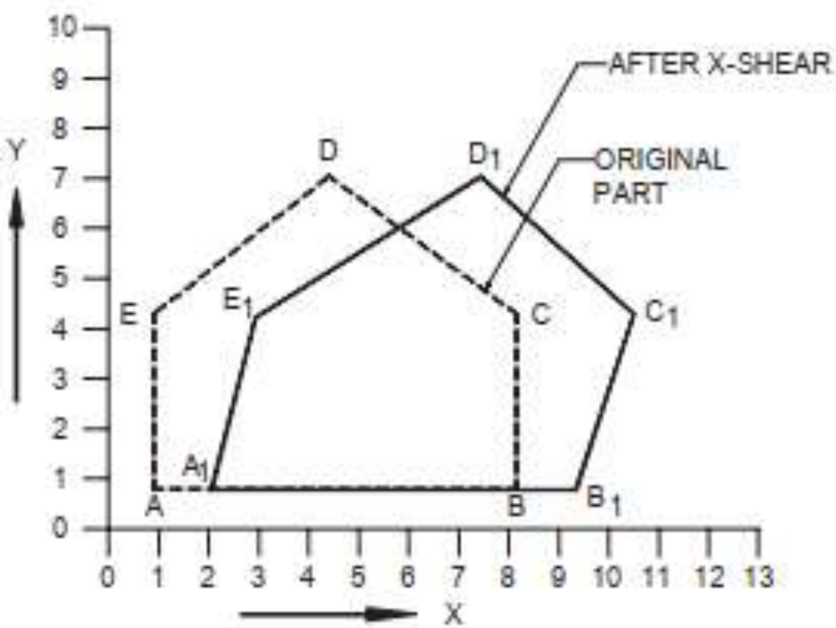


Fig. 3.15 X-Shear

HOMOGENEOUS TRANSFORMATIONS

Each of the above transformations with the exception of translation can be represented as a row vector X, Y and a 2 X 2 matrix. However, all the four transformations discussed above can be represented as a product of a 1 X 3 row vector and an appropriate 3 X 3 matrix. The conversion of a two-dimensional co-ordinate pair (X, Y) into a 3-dimensional vector can be achieved by representing the point as [X Y 1]. After multiplying this vector by a 3 X 3 matrix, another homogeneous row vector is obtained [X1 Y1 1]. The first two terms in this vector are the co-ordinate pair which is the transform of (X, Y). This three dimensional representation of a two dimensional plane is called homogeneous co-ordinates and the transformation using the homogeneous co-ordinates is called homogeneous transformation. The matrix representations of the four basic transformations are given below.

HOMOGENEOUS TRANSFORMATIONS

Translation:

$$[X1\ Y1\ 1] = [X\ Y\ 1]\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

Rotation

$$[X1\ Y1\ 1] = [X\ Y\ 1]\begin{bmatrix} Cos\theta & Sin\theta & 0 \\ -Sin\theta & Cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Scaling

$$[X1\ Y1\ 1] = [X\ Y\ 1]\begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

X-shear

$$[X1\ Y1\ 1] = [X\ Y\ 1]\begin{bmatrix} 1 & 0 & 0 \\ Sh_x & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Y-shear

$$[X1\ Y1\ 1] = [X\ Y\ 1]\begin{bmatrix} 1 & Sh_y & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

COMBINATION TRANSFORMATIONS

Sequences of transformations can be combined into a single transformation using the concatenation process. For example, consider the rotation of a line about an arbitrary point. Line AB is to be rotated through 45° in anticlockwise direction about point A (Fig 3.16(a)). Fig. 3.16(b) shows an inverse translation of AB to A_1B_1. A_1B_1 is then rotated through 45° to A_2B_2. The line A_2B_2 is then translated to A_3B_3.

The respective transformation matrices are:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -T_x & -T_y & 1 \end{bmatrix}$$

$$\begin{bmatrix} Cos\theta & Sin\theta & 0 \\ -Sin\theta & Cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

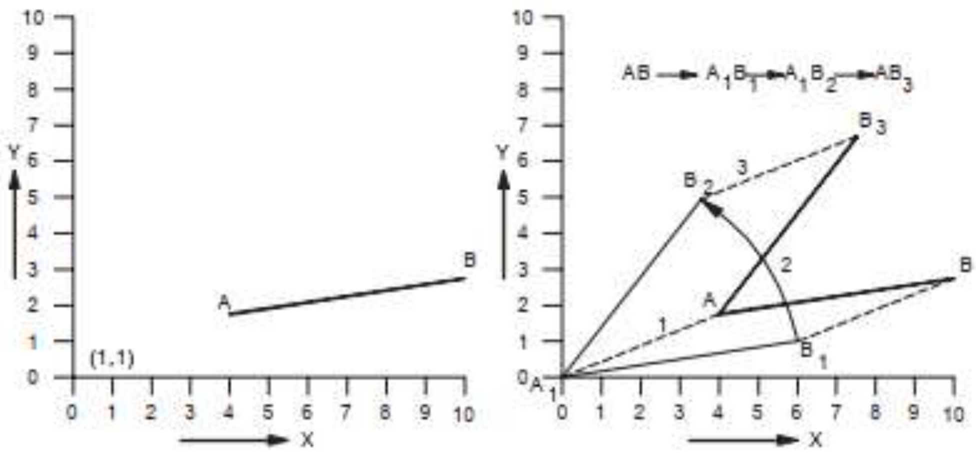


Fig. 3.16 (a) *Fig. 3.16 (b)*

Fig. 3.16 Rotation about an Arbitrary Point

The same effect can be achieved using the concatenated (combined) matrix given below:

$$[X1\ Y1\ 1] = [X\ Y\ 1] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -T_x & -T_y & 1 \end{bmatrix} \begin{bmatrix} Cos\theta & Sin\theta & 0 \\ -Sin\theta & Cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} X$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

Since matrix operations are not commutative, care must be taken to preserve the order in which they are performed while combining the matrices.

CLIPPING

Clipping is the process of determining the visible portions of a drawing lying within a window. In clipping each graphic element of the display is examined to determine whether or not it is completely inside the window, completely outside the window or crosses a window boundary. Portions outside the boundary are not drawn. If the element of a drawing crosses the boundary the point of inter-section is determined and only portions which lie inside are drawn. Readers are advised to refer to books on computer graphics for typical clipping algorithms like Cohen-Sutherland clipping algorithm. Fig. 3.17 shows an example of clipping.

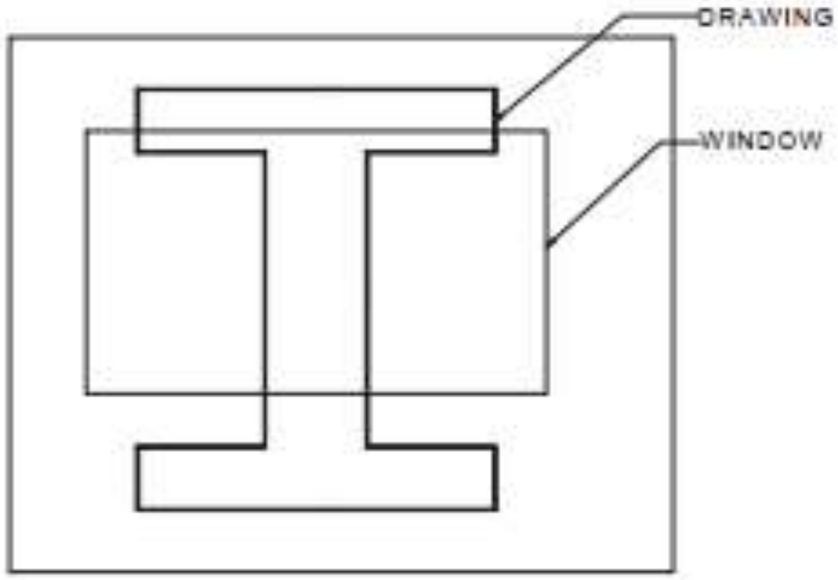


Fig. 3.17 Example of Clipping

3-DIMENSIONAL TRANSFORMATIONS

It is often necessary to display objects in 3-D on the graphics screen. The transformation matrices developed for 2-dimensions can be extended to 3-D.

Scaling: The scaling matrix in 3-D is:

$$\begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Translation: The translation matrix is:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix}$$

Rotation: Rotation in 3-D can be about X - , Y - or Z axis.

Rotation about Z axis: $R_z = \begin{bmatrix} Cos\theta & Sin\theta & 0 & 0 \\ -Sin\theta & Cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Similarly $R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & Cos\phi & -Sin\phi & 0 \\ 0 & Sin\phi & Cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

similarly

and $R_y = \begin{bmatrix} Cos\varphi & 0 & Sin\varphi & 0 \\ 0 & 1 & 0 & 0 \\ -Sin\varphi & 0 & Cos\varphi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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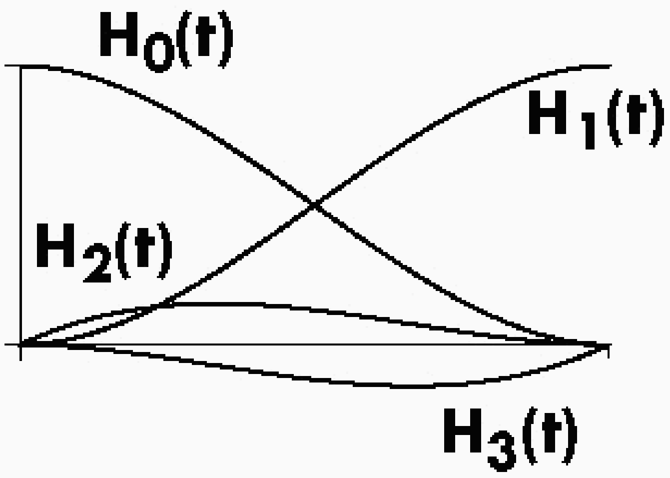
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 2 – GEOMETRIC MODELING – I - SMEA1501

2.1. HERMITE CURVE



$$H_0(t) = 2t^3 - 3t^2 + 1$$
$$H_1(t) = -2t^3 + 3t^2$$
$$H_2(t) = t^3 - 2t^2 + t$$
$$H_3(t) = t^3 - t^2$$

$$\mathbf{M}_H = \begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix}$$

Fig 2.1. Blending functions of Hermite cubic curve

2.1.1. Bezier curve

A quadratic Bezier curve is a Bezier curve of degree 2 and is defined through 3 points (P0, P1 and P2) is show in the fig (A). A cubic Bezier curve is a Bezier curve of degree 3 and is defined by 4 points (P0, P1, P2 and P3). The curve starts at P0 and stops at P3. The line P0P1 is the tangent of the curve in point P0. And so it is the line P2P3 in point P3. In general, the curve will not pass through P1 or P2; the only function of these points is providing directional information. The distance between P0 and P1 determines "how long" the curve moves into direction P1 before turning towards P3 is shows in the fig (B).

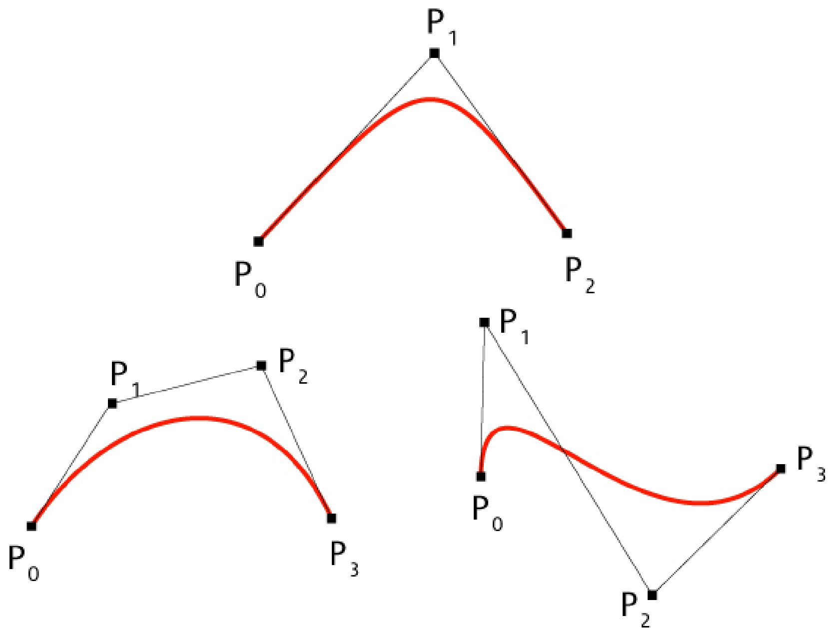


Fig 2.2. Bazier curves

2.1.2. B-Spline curve

The B-Spline curve Tool draws smooth curves when you create open or closed shapes. B-spline, also known as Basis spline, uses a mathematical formula. It is this calculation that produces really nice elegant curves. When you use the B-Spline Tool, control points are connected together as you draw and a polygon is constructed. The polygon controls the position and direction and calculates the smoothest possible curve between two points on the page.

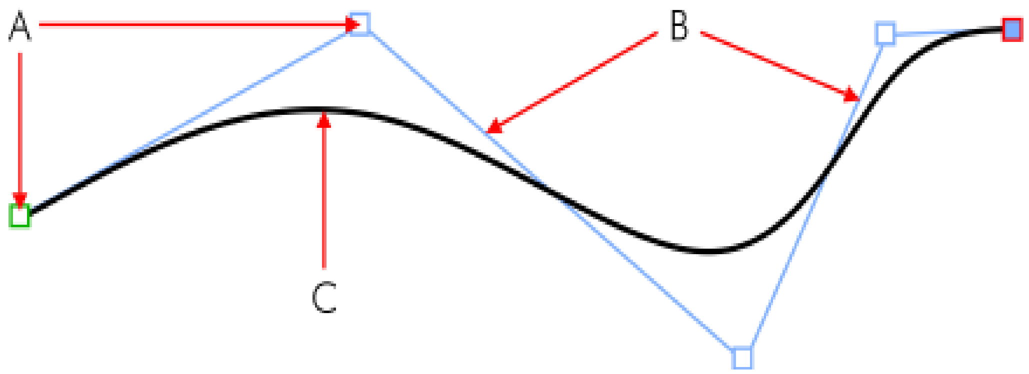


Fig 2.3. B-spline curve

2.1.3. Rational Curve

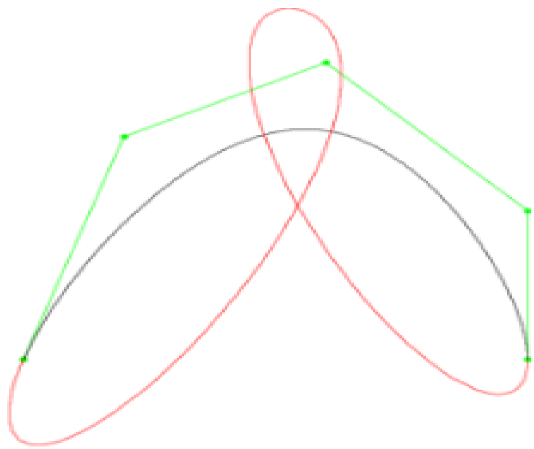


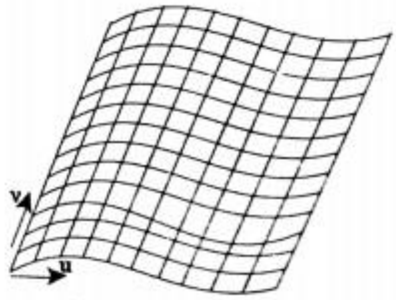
Fig 2.4: Rational normal curve

The rational normal curve is a smooth, rational curve C of degree n in projective n-space Pn. It is a simple example of a projective variety; formally, it is the Veronese variety when the domain is the projective line. For n = 2 it is the flat conic Z0Z2 = Z2 1, and for n = 3 it is the twisted cubic. The term "normal" refers to projective normality, not normal schemes. The intersection of the rational normal curve with an affine space is called the moment curve.

2.2. TECHNIQUES FOR SURFACE MODELING

2.2.1. Surface Patch

The patch is the fundamental building block for surfaces. The two variables *u* and *v* vary across the patch; the patch may be termed *biparametric.* The parametric variables often lie in the range 0 to 1. Fixing the value of one of the parametric variables results in a curve on the patch in terms of the other variable (*Isoperimetric curve*). Figure shows a surface with curves at intervals of u and v of 0 to 1.



Surface patch.

Fig 2.5: Surface patch

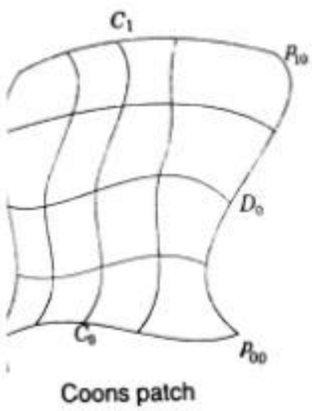
2.2.2. Coons Patch

The sculptured surface often involve interpolation across an intersecting mesh of curves that in effect comprise a rectangular grid of patches, each bounded by four boundary curves. The linearly blended coons patch is the simplest for interpolating between such boundary curves. This patch definition technique blends for four boundary curves $C_i(u)$ and $D_j(v)$ and the corner points p_{ij} of the patch with the linear blending functions,

$$f(t) = 1 - t$$
$$g(t) = t$$

using the expression

$$\vec{p}(u, v) = \vec{C}_0(u)\, f(v) + \vec{C}_1(u)\, g(v) + \vec{D}_0(v)\, f(u) + \vec{D}_1(v)\, g(u) - \vec{p}_{00}\, f(u)\, f(v) - \vec{p}_{01}\, f(u)\, g(u) - \vec{p}_{10}\, g(u)\, f(v) - \vec{p}_{11}\, g(u)\, g(v)$$



Coons patch

Fig 2.6: Coon's patch

2.2.3. Bicubic Patch

The bi-cubic patch is used for surface descriptions defined in terms of point and tangent vector information. The general form of the expressions for a bi-cubic patch is given by:

$$\vec{p}(u, v) = \sum_{i=0}^{3} \sum_{j=0}^{3} \vec{k_{ij}} u^i v^j$$

This is a vector equation with 16 unknown parameters *kij* which can be found by Lagrange interpolation through 4 x 4 grid.

GEOMETRIC MODELS

There are three types of geometric models

- Wireframes,
- Surfaces
- Solids

WIREFRAME MODELS

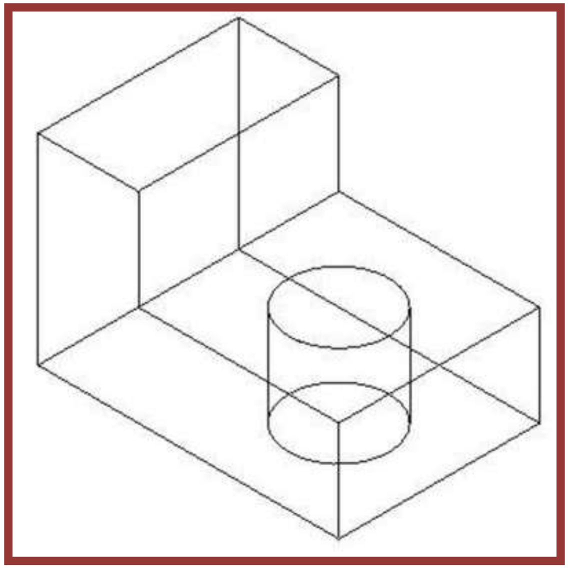
A wireframe representation is a 3-D line drawing of an object showing only the edges without any side surface in between.

A frame constructed from thin wires representing the edges and projected lines and curves

A wireframe model of an object is the simplest and represents mathematically in the computers.

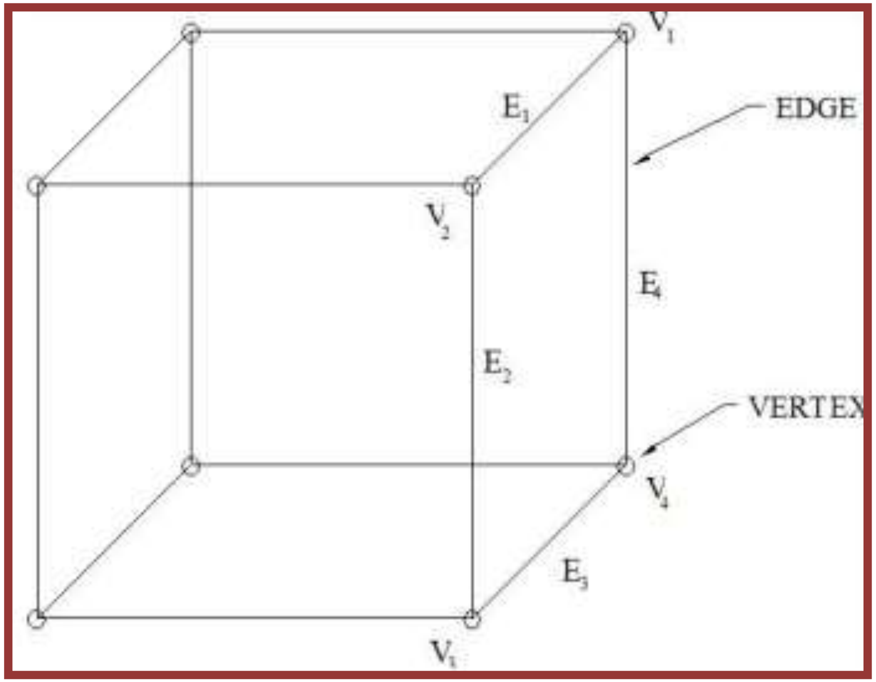
It is most commonly used technique and all commercial CAD/CAM systems are wire-frame based.

Basic wire-frame entities can be divided into analytic and synthetic entities.



Wireframe Model

- Contains information about the locations of all the points (vertices) and edges in space coordinates.
- Each vertex is defined by x, y, z coordinate.
- Edges are defined by a pair of vertices.
- Faces are defined as three or more edges.
- Wireframe is a collection of edges, there is no skin defining the area between the edges.



Advantages

- Can quickly and efficiently convey information than multiview drawings.
- The only lines seen are the intersections of surfaces.
- Can be used for finite element analysis.
- Can be used as input for CNC machines to generate simple parts.
- Contain most of the information needed to create surface, solid and higher order models

Disadvantages

- Geometric entities are lines and curves in 3D
- Volume or surfaces of object not defined
- Easy to store and display
- Hard to interpret – ambiguous
- Hidden lines are not removed
- For complex items, the result can be a jumble of lines that is impossible to determine.
- No ability to determine computationally information such as the line of intersect between two faces of intersecting models.

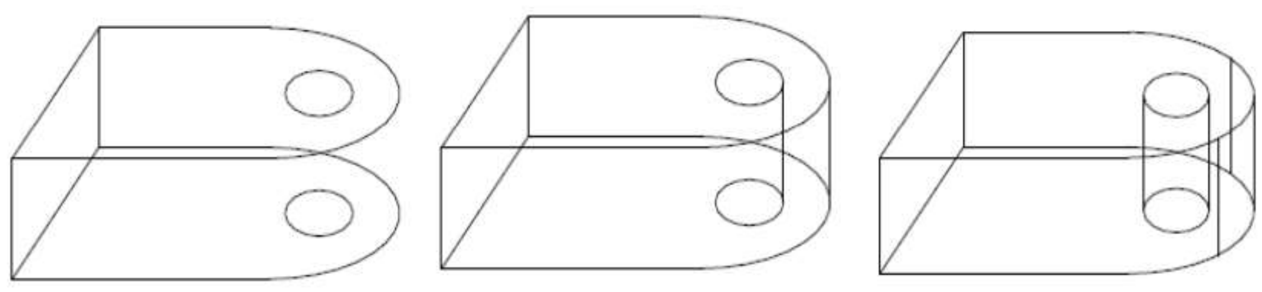
WIREFRAME MODELS

•Typically, a wireframe model consists of a finite set of points (vertices), connected in pairs by straight lines (edges), or arcs, circles, conics, and curves, so that the three dimensional form of a solid object can be visualized.

• The major advantage of wireframe modeling is its simplicity to construct. It does not require as much computer time and memory as does surface or solid modeling. Wireframe modeling is considered a natural extension of traditional methods of drafting.

• The disadvantages of wireframe models are manifolds. Primarily, wireframe models are usually ambiguous representations of real objects and rely heavily on human interpretation.

•Models of complex designs having many edges become very confusing and perhaps even impossible to interpret. Moreover, as shown in Figure , it is often difficult to display objects with curve surfaces using wireframe



Displaying holes and curved ends in wireframe models

Curve representation

PARAMETRIC CURVES

Curves can be classified in number of ways:

- Plane curves & Space curves

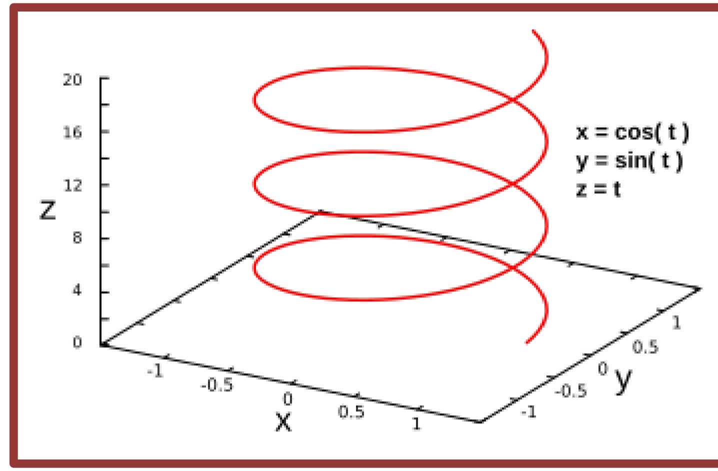
  Example: Circle & Helix

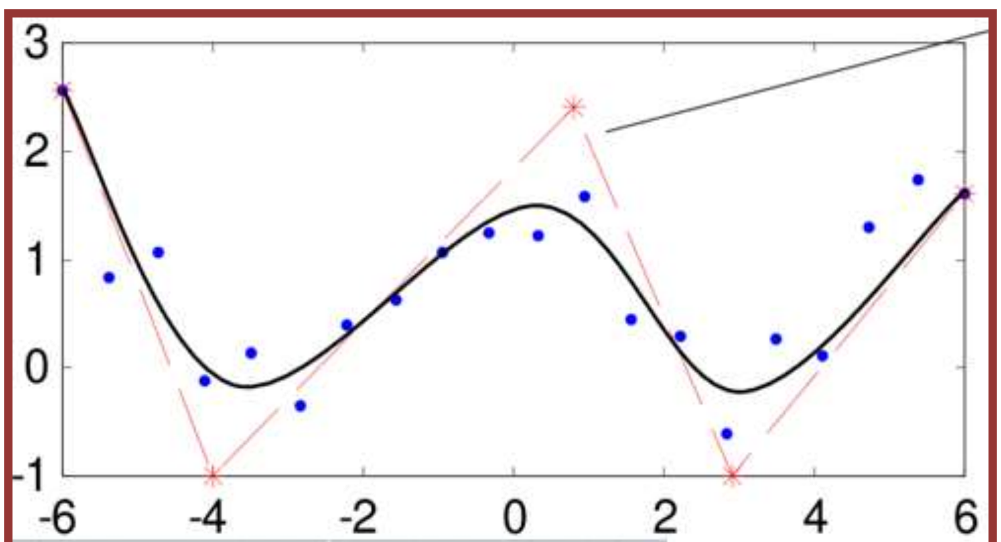
- Curves of known forms & Free-form curves

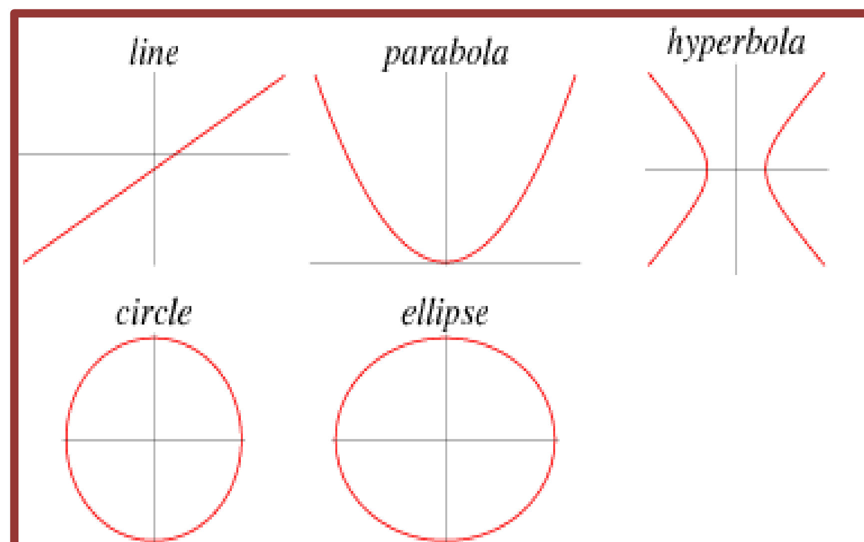
  Example: Circle vs. Bezier Curve

- Interpolation curves and Approximation curves

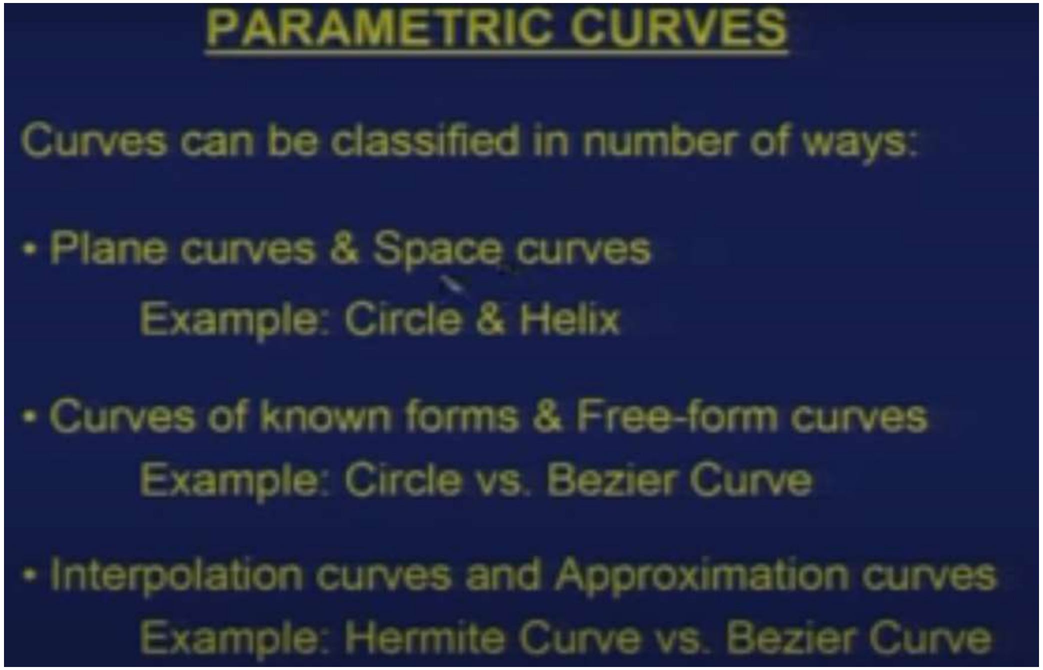
  Example: Hermite Curve vs. Bezier Curve

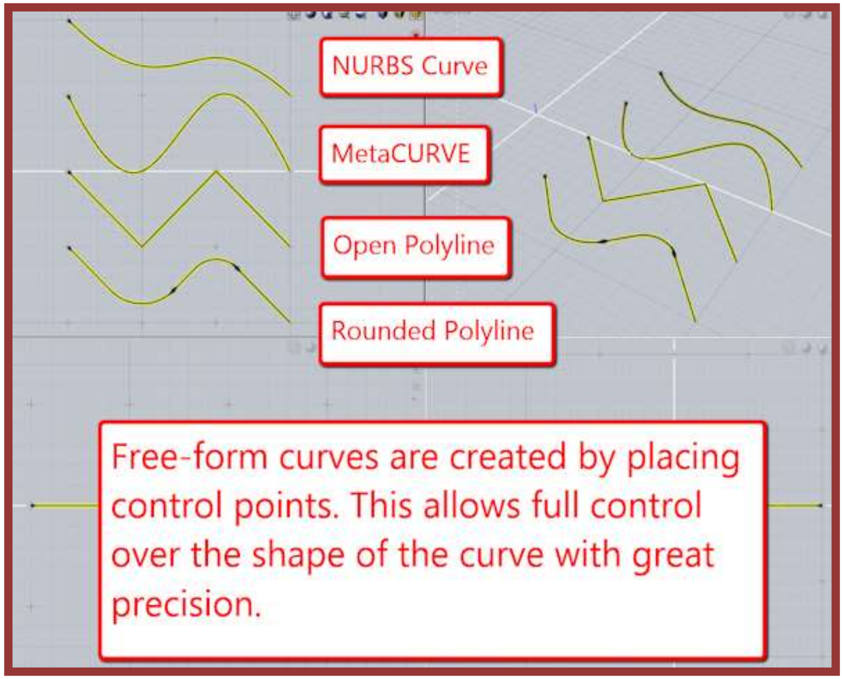


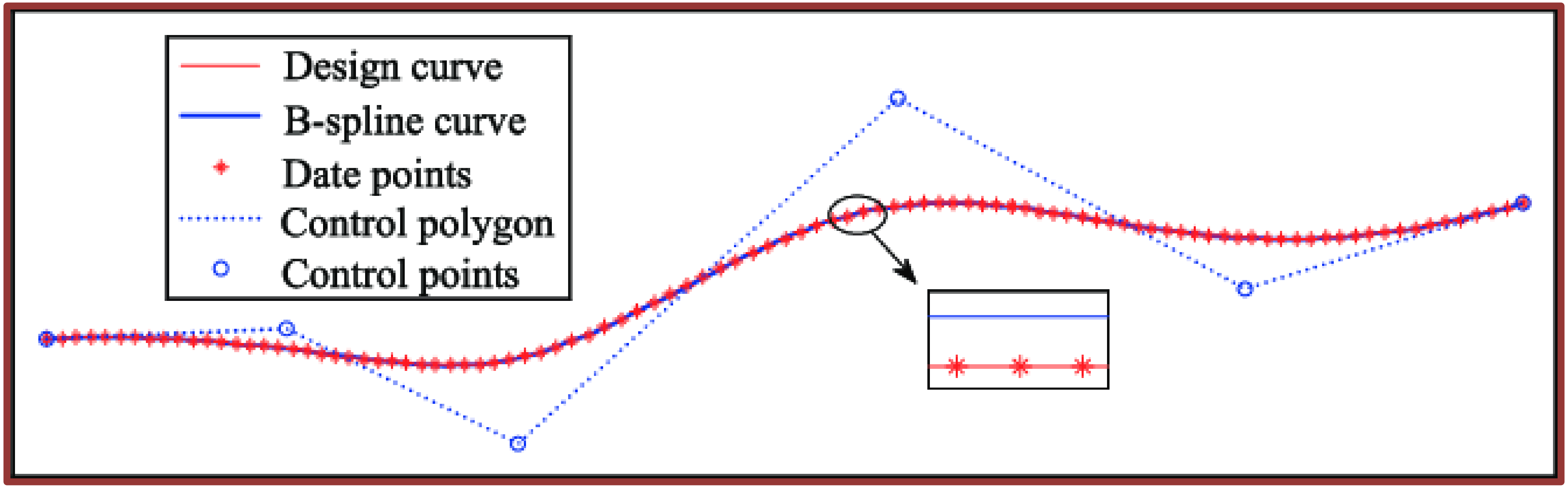




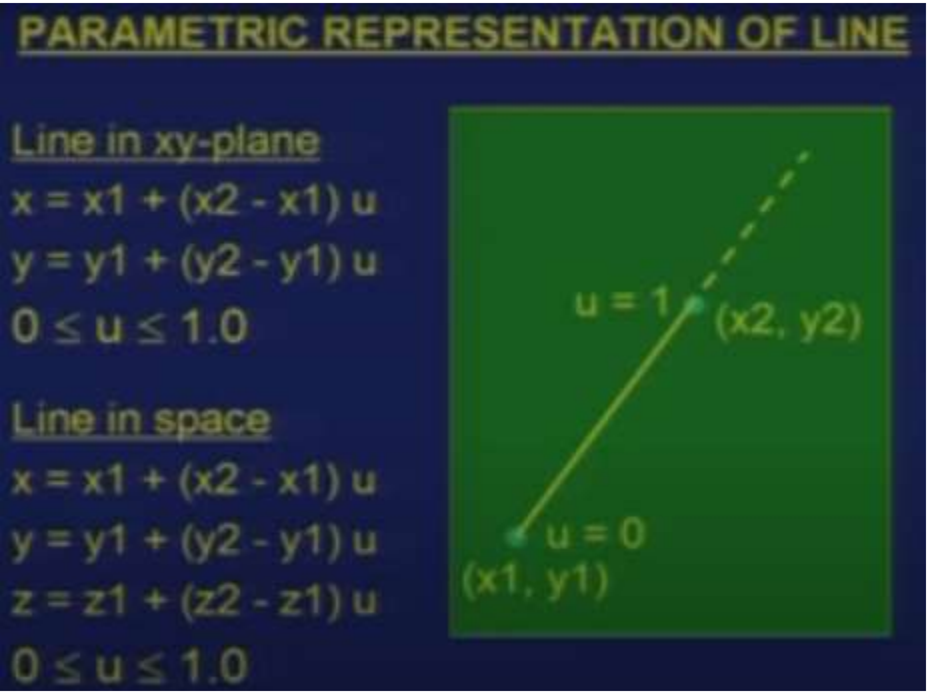
Curve representation

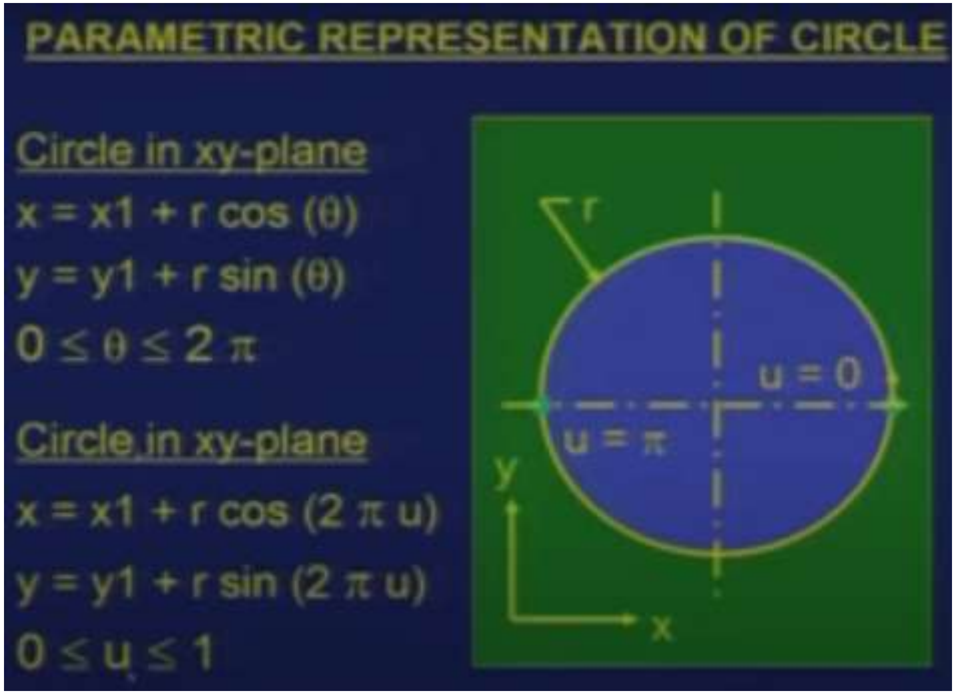






Curve representation





Curve representation

PARAMETRIC REPRESENTATION OF CONICS

Ellipse

$x = a\cos(\theta);\ y = b\sin(\theta)$ $\quad 0 \le \theta \le 2\pi$

Parabola

$x = a u^2;\ y = 2au$ $\quad 0 \le u \le 1$

Hyperbola

$x = a\sec(\theta);\ y = b\tan(\theta)$ $\quad 0 \le \theta \le 2\pi$

$x = a\cosh(\theta);\ y = b\sinh(\theta)$

PARAMETRIC REPRESENTATION OF FREE-FORM CURVES

Interpolation Curves

- Parametric Cubic Curve

Approximation Curves

- Bezier Curve
- B-Spline Curve
- NURBS Curve

PARAMETRIC CUBIC CURVE

- It is also known as Hermite Curve
- It is an Interpolation Curve
- It has three different forms

  Algebraic Form (12 algebraic coefficients)
  Geometric Form (End points & tangent vectors)
  Four - Point Form (Four points)

Curve representation

PARAMETRIC CUBIC CURVE

Algebraic Form

$$x = a_{3x} u^3 + a_{2x} u^2 + a_{1x} u + a_{0x}$$
$$y = a_{3y} u^3 + a_{2y} u^2 + a_{1y} u + a_{0y}$$
$$z = a_{3z} u^3 + a_{2z} u^2 + a_{1z} u + a_{0z}$$
$$0 \le u \le 1$$

12 unknowns

$$\mathbf{p}(u) = \mathbf{a}_3 u^3 + \mathbf{a}_2 u^2 + \mathbf{a}_1 u + \mathbf{a}_0$$

(Vector Form)

PARAMETRIC CUBIC CURVE

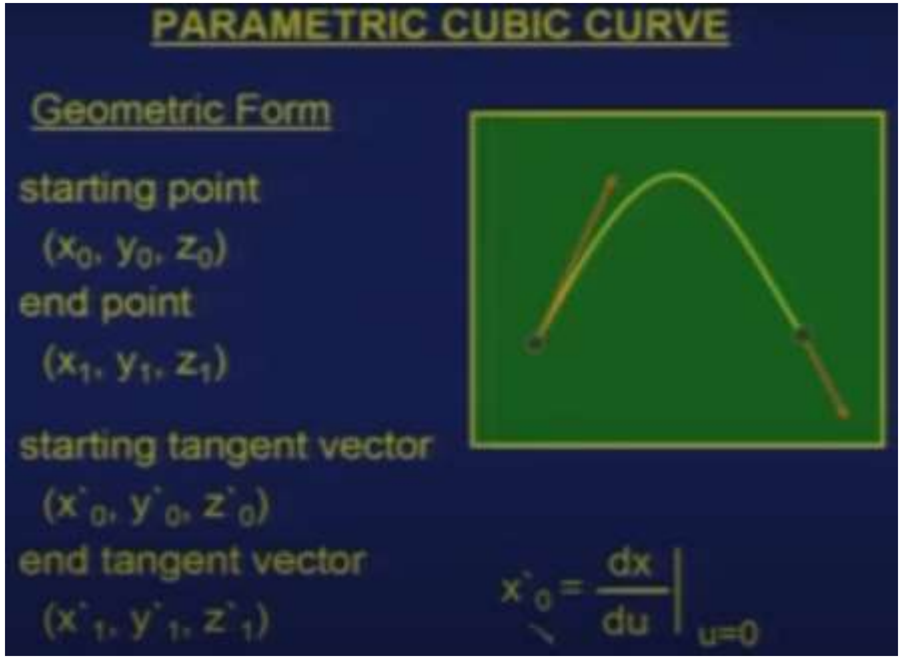
Algebraic to Geometric Form

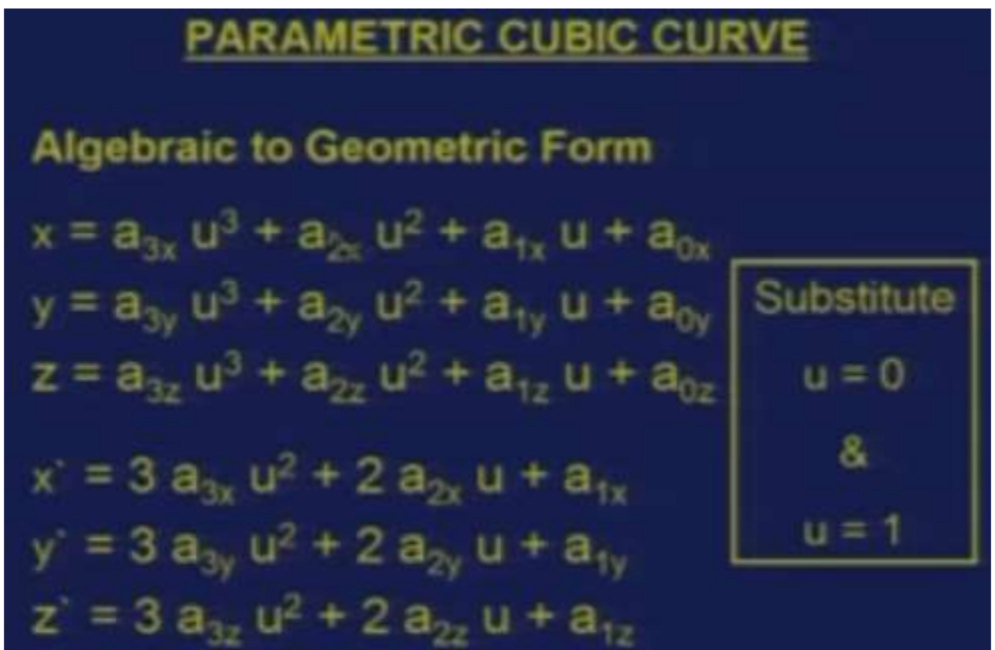
$$x = a_{3x} u^3 + a_{2x} u^2 + a_{1x} u + a_{0x}$$
$$y = a_{3y} u^3 + a_{2y} u^2 + a_{1y} u + a_{0y} \quad 0 \le u \le 1$$
$$z = a_{3z} u^3 + a_{2z} u^2 + a_{1z} u + a_{0z}$$

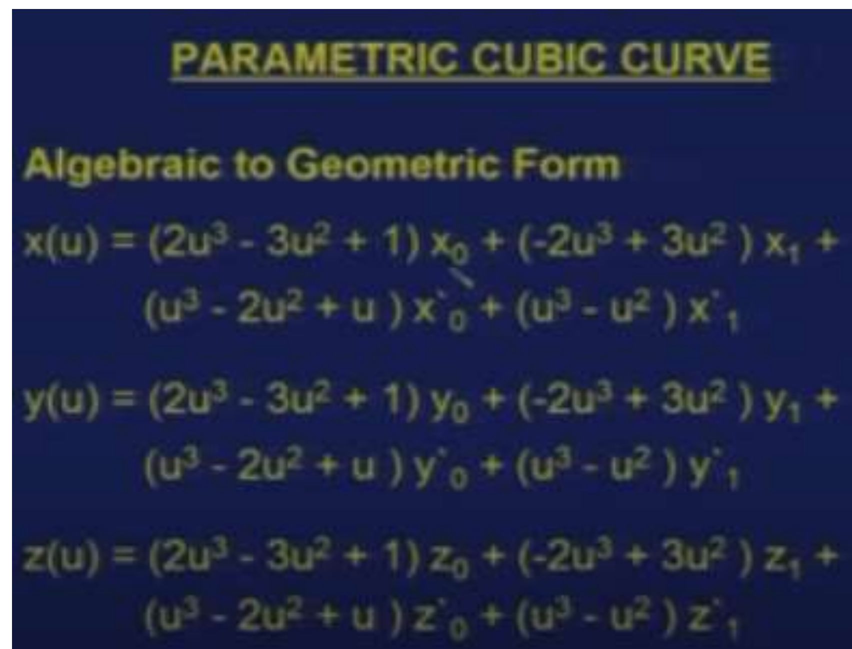
$$x' = 3 a_{3x} u^2 + 2 a_{2x} u + a_{1x}$$
$$y' = 3 a_{3y} u^2 + 2 a_{2y} u + a_{1y}$$
$$z' = 3 a_{3z} u^2 + 2 a_{2z} u + a_{1z}$$

Tangent Vector

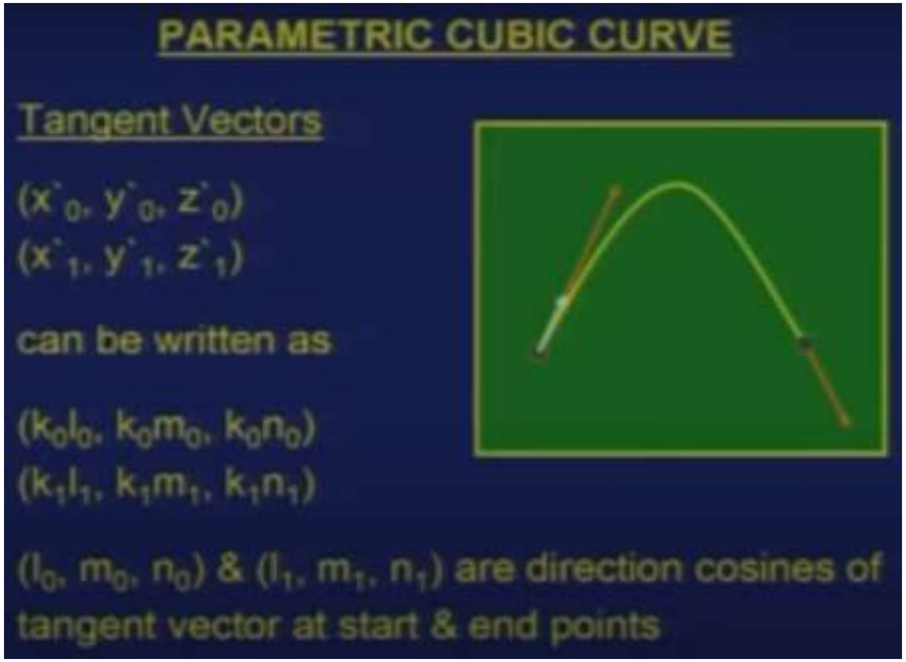
Curve representation

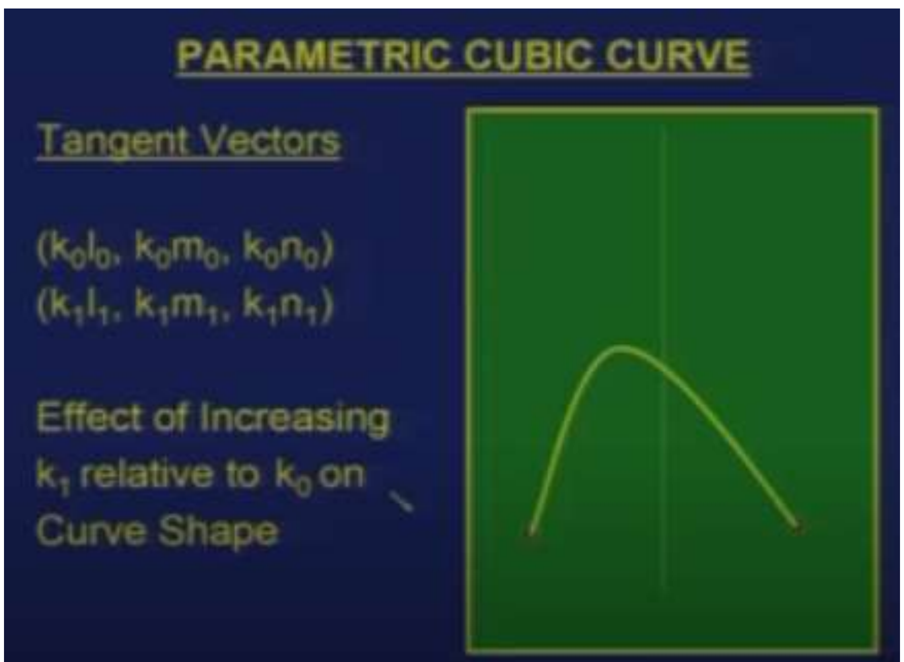


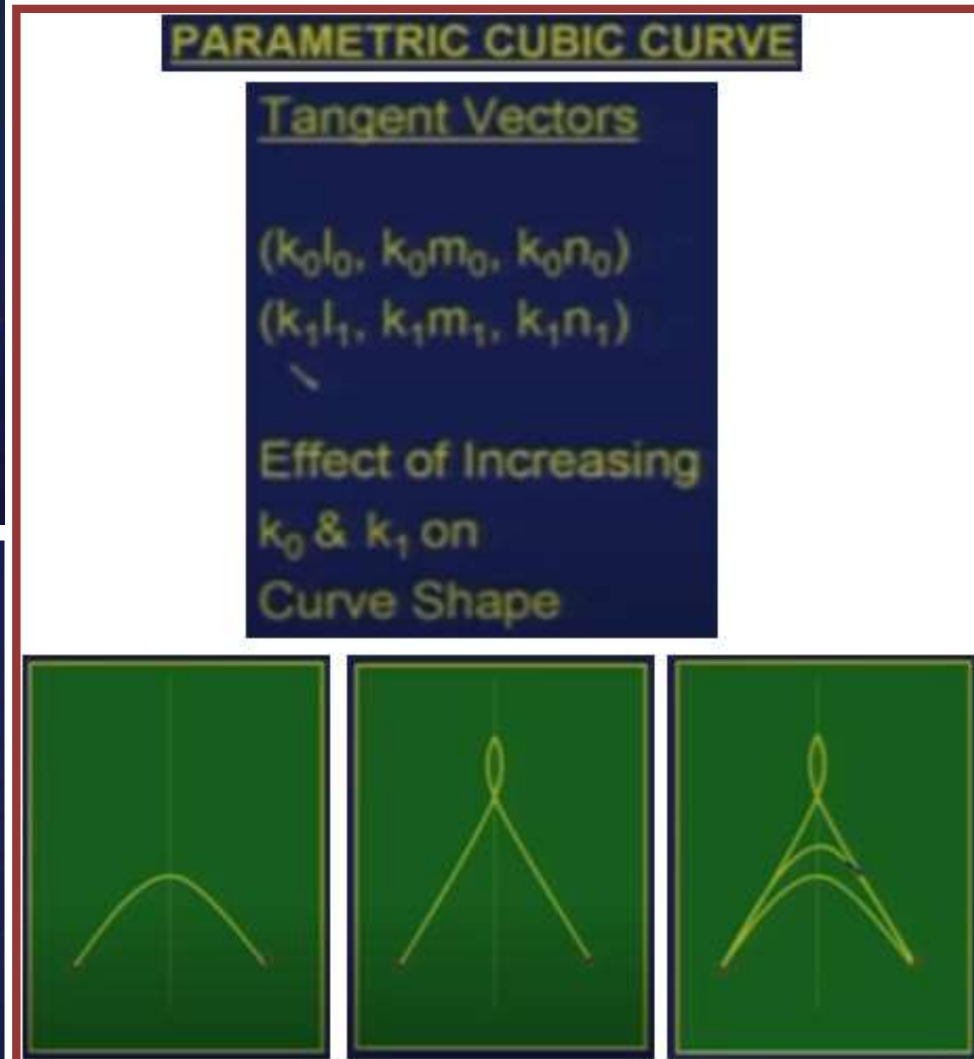




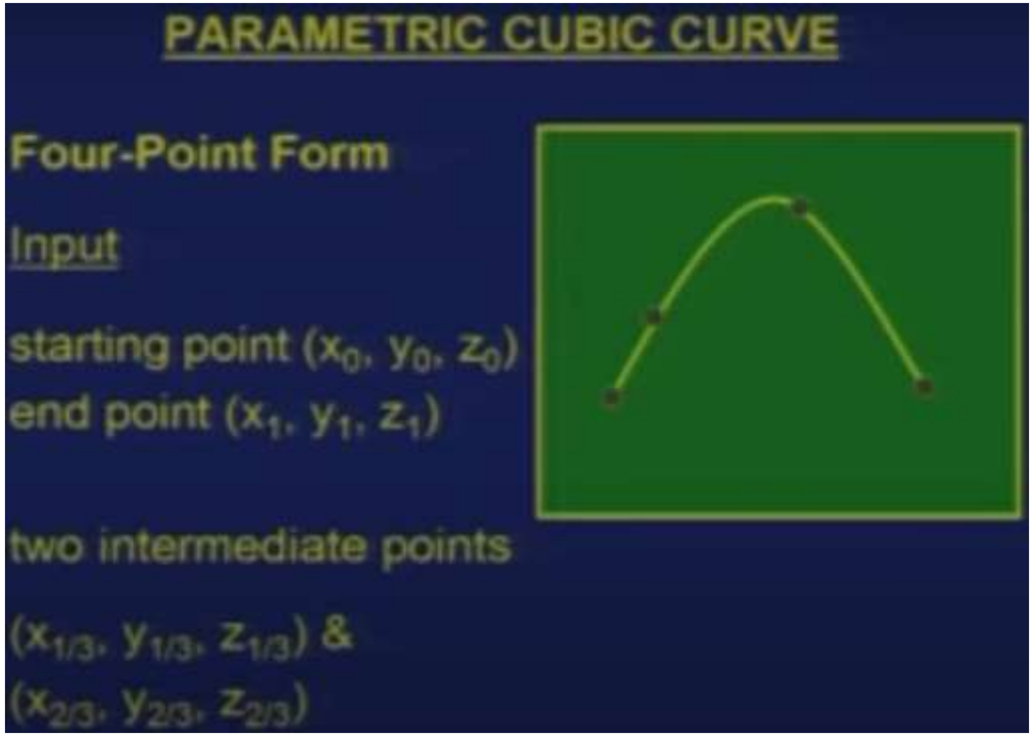
Curve representation

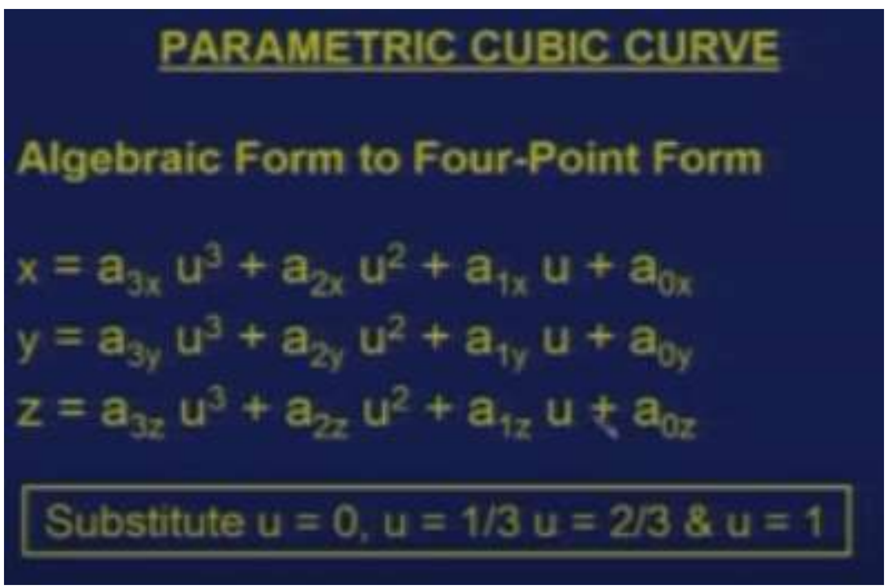


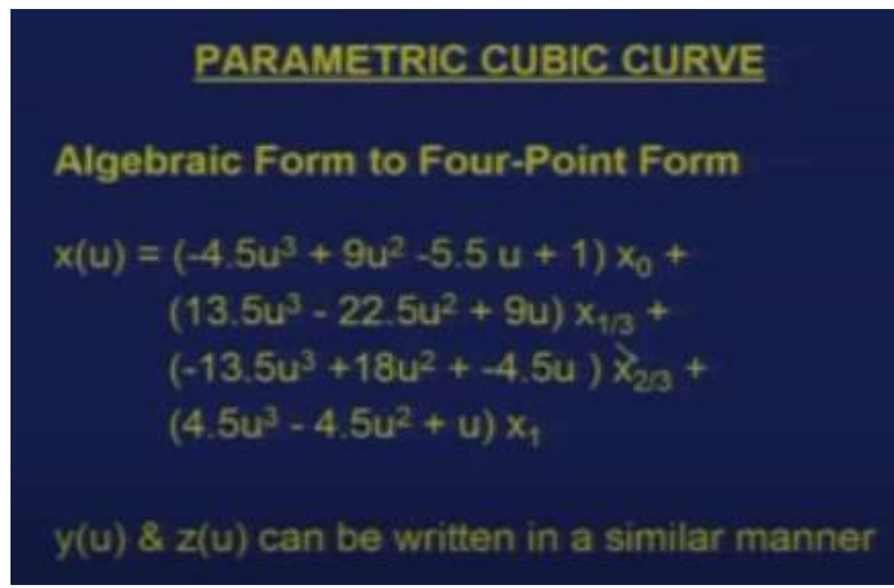




Curve representation

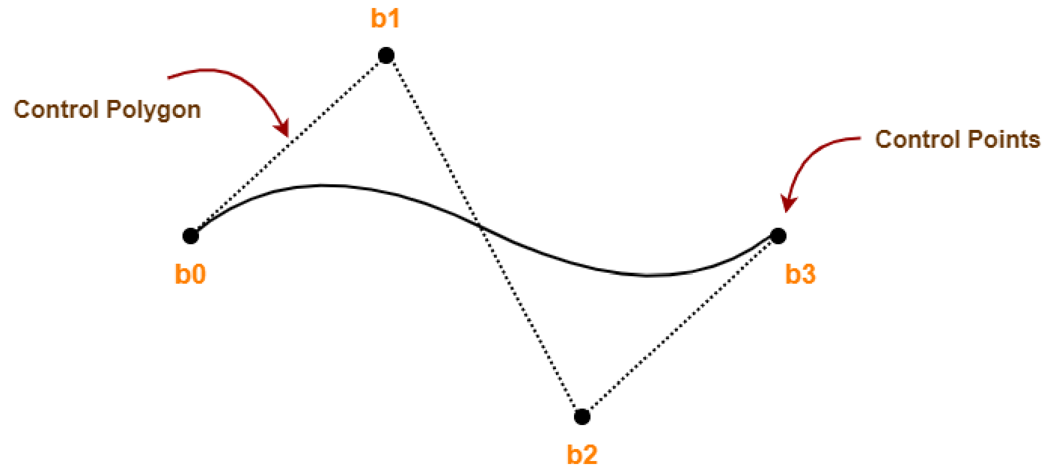






PARAMETRIC BEZIER CURVE

- Bezier curve is an approximation curve
- The curve was first proposed in 60's by P. Bezier
- The curve was first used to define sculptured surfaces of automobile bodies
- A cubic Bezier curve is defined by four control points



Input to Cubic Bezier Curve

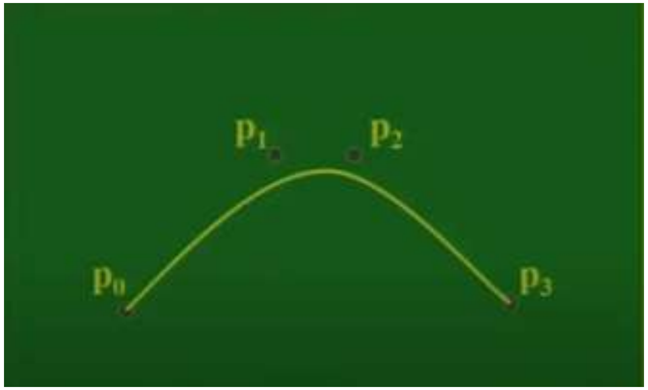
first point, $p_0 = (x_0, y_0, z_0)$

second point, $p_1 = (x_1, y_1, z_1)$

third point, $p_2 = (x_2, y_2, z_2)$

fourth point, $p_3 = (x_3, y_3, z_3)$

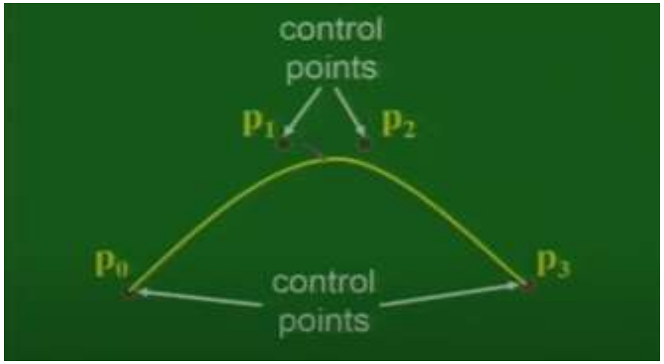
- *First point is starting point*
- *Fourth point is end point*
- *Order of points is important.*

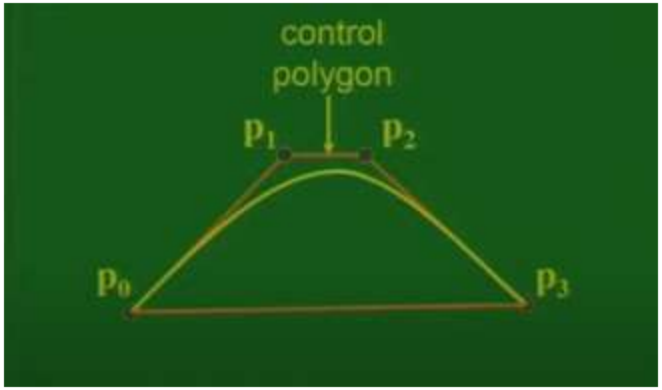


$$x(u) = (1-u)^3 x_0 + 3(1-u)^2 u\, x_1 + 3(1-u) u^2 x_2 + u^3 x_3$$

$$0 \le u \le 1$$

Bezier Curve Example





Curve representation

$$x(u) = (1-u)^3 x_0 + 3(1-u)^2 u\, x_1 + 3(1-u) u^2 x_2 + u^3 x_3$$

$$y(u) = (1-u)^3 y_0 + 3(1-u)^2 u\, y_1 + 3(1-u) u^2 y_2 + u^3 y_3$$

$$z(u) = (1-u)^3 z_0 + 3(1-u)^2 u\, z_1 + 3(1-u) u^2 z_2 + u^3 z_3$$

$$0 \le u \le 1$$

$$x(u) = (1-u)^3 x_0 + 3(1-u)^2 u\, x_1 + 3(1-u) u^2 x_2 + u^3 x_3$$

$$x(u) = {}^3c_0 (1-u)^3 x_0 + {}^3c_1 (1-u)^2 u\, x_1 + {}^3c_2 (1-u) u^2 x_2 + {}^3c_3 u^3 x_3$$

$$x(u) = \sum_{i=0}^{i=3} {}^3c_i (1-u)^{3-i} u^i x_i$$

Curve representation

Cubic Bezier Curve

$$x(u) = \sum_{i=0}^{i=3} {}^{3}c_i\,(1-u)^{3-i}\,u^i\,x_i$$

Quartic Bezier Curve

$$x(u) = \sum_{i=0}^{i=4} {}^{4}c_i\,(1-u)^{4-i}\,u^i\,x_i$$

Quintic Bezier Curve

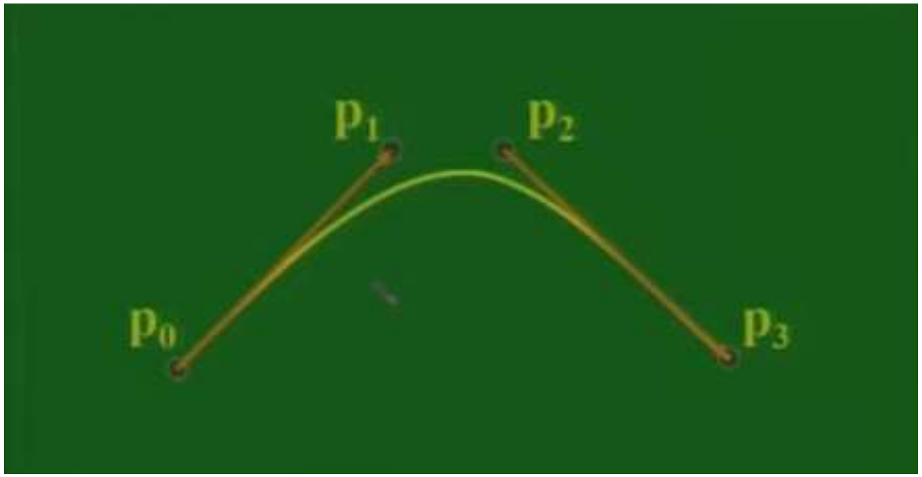
$$x(u) = \sum_{i=0}^{i=5} {}^{5}c_i\,(1-u)^{5-i}\,u^i\,x_i$$

Generic Bezier Curve

$$x(u) = \sum_{i=0}^{i=n} {}^{n}c_i\,(1-u)^{n-i}\,u^i\,x_i$$

Curve representation

PROPERTIES OF BEZIER CURVE



Tangents at end points are defined by end points and their adjacent points

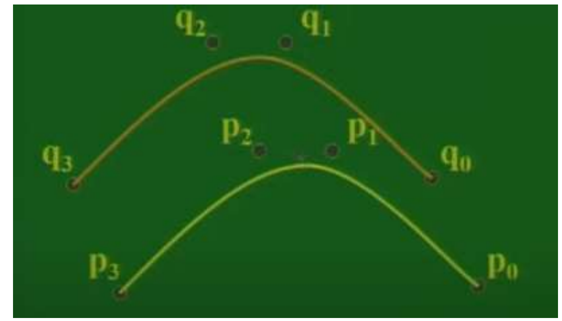
Reversing the sequence of control points does not change the shape of curve.

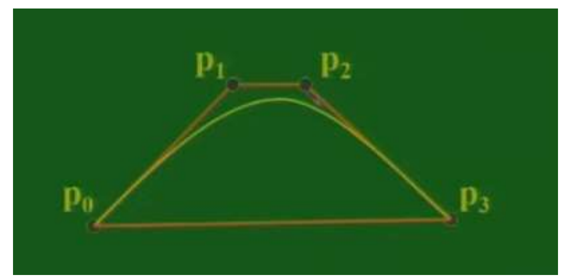
The curve is invariant under an affine transformation

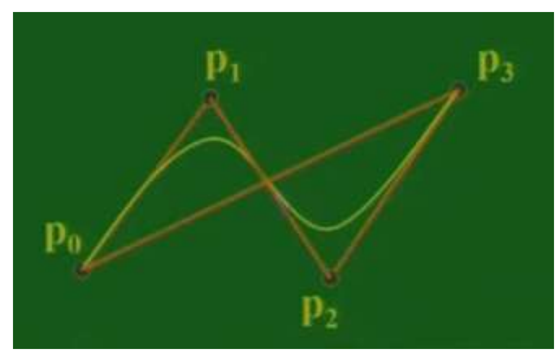
Convex Hull Property

$$\kappa_0 = \frac{2|(p_1-p_0) \times (p_2-p_1)|}{3|p_1-p_0|^3}$$

$$\kappa_1 = \frac{2|(p_{n-1}-p_{n-2}) \times (p_n-p_{n-1})|}{3|p_n-p_{n-1}|^3}$$







Curve representation

PROPERTIES OF BEZIER CURVE

Partition of Unity Property

$$\sum_{i=0}^{i=n} {}^{n}c_i \,(1-u)^{n-i} u^i = 1$$

For i = 3,

$$(1-u)^3 + 3\,(1-u)^2\,u + 3\,(1-u)\,u^2 + u^3 = 1$$

For i = 3,

$$(1-u)^3 + 3\,(1-u)^2\,u + 3\,(1-u)\,u^2 + u^3 = 1$$

when u = 0.6

$$0.064 + 3 * 0.16 * 0.6 + 3 * 0.4 * 0.36 + 0.216$$

$$0.064 + 0.288 + 0.432 + 0.216$$

$$1.0$$

Curve representation

Curve definition in matrix form

$$x(u) = (1-u)^3 x_0 + 3(1-u)^2 u\, x_1 + 3(1-u) u^2 x_2 + u^3 x_3$$

$$x(u) = (1 - 3u + 3u^2 - u^3)\, x_0 + (3u - 6u^2 + 3u^3)\, x_1 + (3u^2 - 3u^3)\, x_2 + u^3 x_3$$

Curve definition in matrix form

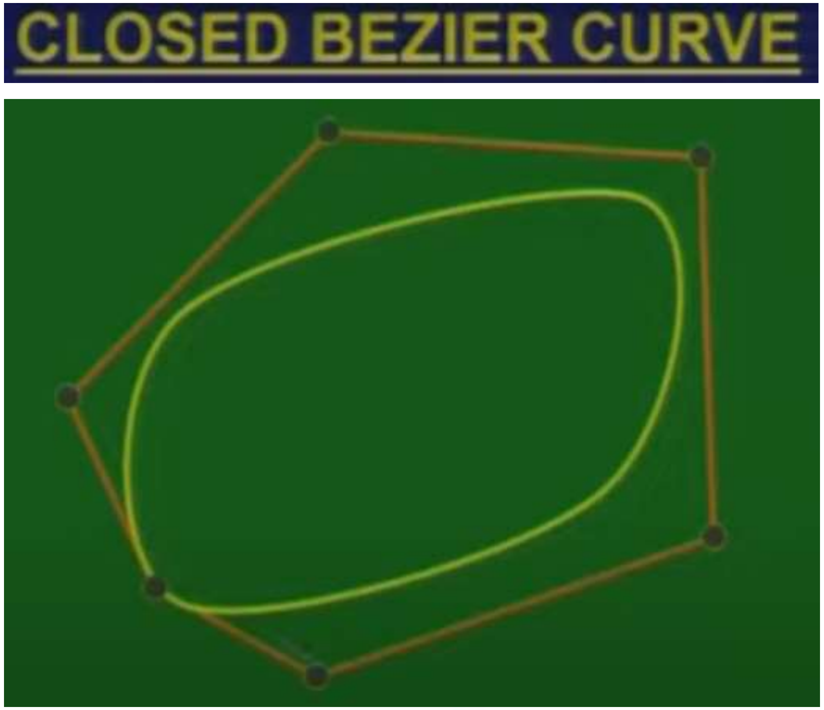
$$x(u) = (1 - 3u + 3u^2 - u^3)\, x_0 + (3u - 6u^2 + 3u^3)\, x_1 + (3u^2 - 3u^3)\, x_2 + u^3 x_3$$

$$x(u) = (-x_0 + 3x_1 - 3x_2 + x_3)\, u^3 + (3x_0 - 6x_1 + 3x_2)\, u^2 + (-3x_0 + 3x_1)\, u + x_0$$

Curve definition in matrix form

$$x(u) = [u^3\ u^2\ u\ 1] \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Curve representation

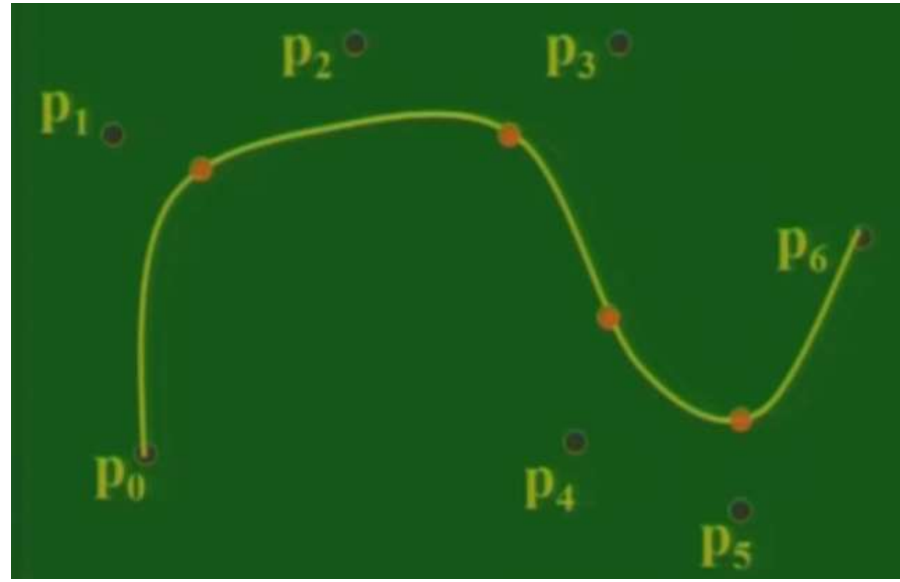


The Bézier representation has two main disadvantages. First, the number of control points is directly related to the degree. Therefore, to increase the complexity of the shape of the curve by adding control points requires increasing the degree of the curve or satisfying the continuity conditions between consecutive segments of a composite curve. Second, changing any control point affects the entire curve or surface, making design of specific sections very difficult. These disadvantages are remedied with the introduction of the *B-spline (basis-spline)* representation.

IN BEZIER CURVES, CHANGING ONE POINT MEANS CHANGING THE FULL CURVE [GLOBAL CONTOROL / PROPAGATION OF CHANGE]

B-SPLINE CURVE

- Curve is defined by n+1 control points and the order (k) of the curve
- The curve has an advantage that it has local propagation unlike global propagation properties of Bezier curve.
- The curve can be used to define both open and closed curves.



Non-Uniform B-Spline Curve
(n = 6, k = 3)

Bezier Curve

$$x(u) = \sum_{i=0}^{i=n} {}^{n}c_i \,(1-u)^{n-i} u^i x_i \qquad 0 \le u \le 1$$

B-Spline Curve

$$x(u) = \sum_{i=0}^{i=n} N_{i,k}(u)\, x_i \qquad 0 \le u \le n-k+2$$

Curve representation

B-SPLINE CURVE

Bezier Curve (n = 5)

$$x = (1\text{-}u)^5\, x_0 + 5\,(1\text{-}u)^4\, u\, x_1 + 10\,(1\text{-}u)^3\, u^2\, x_2 +$$
$$10\,(1\text{-}u)^2\, u^3\, x_3 + 5\,(1\text{-}u)\, u^4\, x_4 + u^5\, x_5$$
$$0 \le u \le 1$$

Non-Uniform B-Spine Curve (n = 5, k = 3)

$$x\,(u) = N_{0,3}\,(u)\, x_0 + N_{1,3}\,(u)\, x_1 + N_{2,3}\,(u)\, x_2 +$$
$$N_{3,3}\,(u)\, x_3 + N_{4,3}\,(u)\, x_4 + N_{5,3}\,(u)\, x_5$$
$$0 \le u \le 4$$

Non-Uniform B-Spline Curve (n = 5, k = 3)

$$x = (1\text{-}u)^2\, x_0 + 0.5\, u\,(4\text{-}3u)\, x_1 + 0.5\, u^2\, x_2$$
$$0 \le u < 1$$
$$x = 0.5\,(2\text{-}u)^2\, x_1 + 0.5\, u\,(\text{-}2u^2 + 6u\text{-}3)\, x_2 + 0.5\,(u\text{-}1)^2\, x_3$$
$$1 \le u < 2$$
$$x = 0.5\,(3\text{-}u)^2\, x_2 + 0.5\, u\,(\text{-}2u^2 + 10u\text{-}11)\, x_3 + 0.5\,(u\text{-}2)^2\, x_4$$
$$2 \le u < 3$$
$$x = 0.5\,(4\text{-}u)^2\, x_3 + 0.5\, u\,(\text{-}3u^2 + 20u\text{-}32)\, x_4 + 0.5\,(u\text{-}3)^2\, x_5$$
$$3 \le u < 4$$

Curve representation

B-SPLINE CURVE

Non-Uniform B-Spline Curve Properties

- The curve is $C^{(k-2)}$ Continuous
- The curve is made up of (n-k+2) segments
- Only k control points affect any segment of the curve
- A given control point affects 1 or 2 or …k curve segments.

Curve representation

PARAMETRIC REPRESENTATION OF ANALYTIC CURVES

•There are two categories of curves that can be represented parametrically: Analytic curves and synthetic curves.

• Analytic curves are defined as those that can be described by analytic equations such as lines, circles, and conics.

•Synthetic curves are the ones that are described by a set of data points (control points) such as splines and Bezier curves.

•Lines and circles are often expressed in analytic equations.

The parametric equation of the line becomes

$$\mathbf{P} = \mathbf{P}_1 + u(\mathbf{P}_2 - \mathbf{P}_1), \quad 0 \le u \le 1$$

In scalar form, this equation can be written as

$$\left.\begin{aligned} x &= x_1 + u(x_2 - x_1) \\ y &= y_1 + u(y_2 - y_1) \\ z &= z_1 + u(z_2 - z_1) \end{aligned}\right\} \quad 0 \le u \le 1$$

Circles and circular arcs are among the most common entities used in wireframe modeling

The parametric equation of a circle can be written as

$$\left.\begin{aligned} x &= x_c + R\cos u \\ y &= y_c + R\sin u \\ z &= z_c \end{aligned}\right\}, \quad 0 \le u \le 2\pi$$

Incremental form

$$\begin{aligned} x_n &= x_c + R\cos u \\ y_n &= y_c + R\sin u \\ x_{n+1} &= x_c + R\cos(u + \Delta u) \\ y_{n+1} &= y_c + R\sin(u + \Delta u) \\ z_{n+1} &= z_n \end{aligned}$$

Synthetic curves

The need for synthetic curves in design arises on two occasions:

- **When a curve is represented by a collection of measured data points**
- **When an existing curve must change to meet new design requirements**

- **Analytic curves are usually not sufficient to meet geometric design requirements of mechanical parts.**

- **Synthetic curves provide designers with greater flexibility and control of a curve shape by changing the positions of the control points.**

- **Products such as car bodies, ship hulls, airplane fuselage and wings, propeller blades, shoe insoles, and bottles are a few examples that require free-form, or synthetic, curves and surfaces**

Synthetic curves

- A spline curve is defined by giving a set of coordinate positions, call control points, which indicate the general shape of the curve. These control points are then fitted with piecewise continuous parametric polynomial functions.
- When polynomial sections are fitted so that the curve passes through each control point, the resulting curve is said to interpolate the set of control points.
- On the other hand, when the polynomials are fitted to the general control point path without necessarily passing through any control point, the resulting curve is said to approximate the set of control points.

- Mathematically, synthetic curves represent a curve-fitting problem to construct a smooth curve that passes through given data points. Zero-order continuity C^0 *yields* a position continuous curve.
- First C^1 - *and second* C^2 *-order continuities imply slope* and curvature continuous curves respectively. A C^1 *curve is the minimum acceptable* curve for engineering design. A cubic polynomial is the minimum-order polynomial that can guarantee the generation of C^0, C^1 or C^2 curves.
- Also, the designer may prefer to control the shape of the curve locally instead of globally by changing the control points.

Hermite Cubic Splines

•The Hermite form of a cubic spline is determined by defining positions and tangent vectors at the data points

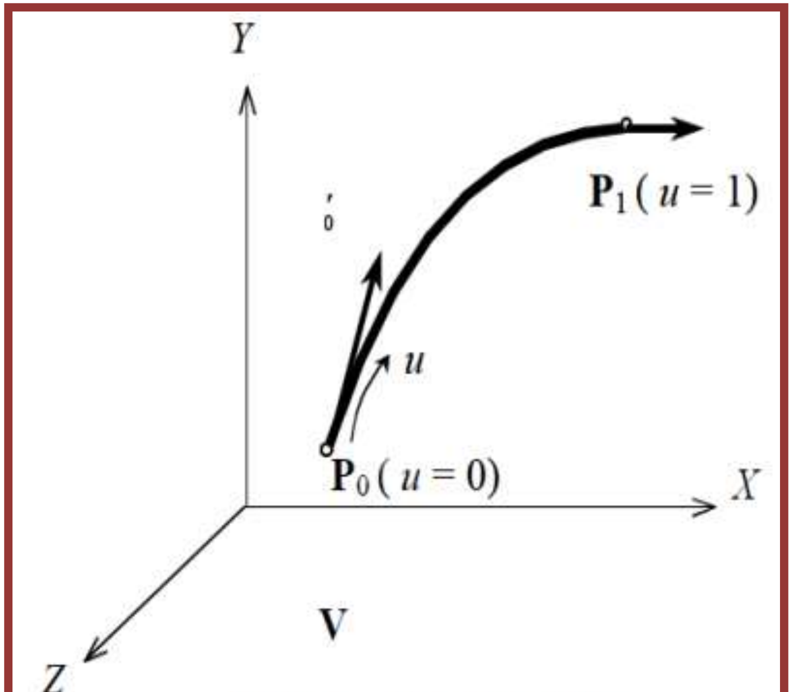
•The parametric cubic spline curve (or cubic spline for short) connects two data (end) points and utilizes a cubic equation.

•Therefore, four conditions are required to determine the coefficients of the equation.

The parametric equation of a cubic spline segment is given By:

$$\mathbf{P}(u) = \sum_{i=0}^{3} \mathbf{C}_i u^i, \quad 0 \le u \le 1$$

where u is the parameter and C_i are the polynomial (also called algebraic) coefficients



Hermite cubic spline curve

Curve representation

Scalar form this equation is written as

$$x(u) = C_{3x}u^3 + C_{2x}u^2 + C_{1x}u + C_{0x}$$
$$y(u) = C_{3y}u^3 + C_{2y}u^2 + C_{1y}u + C_{0y}$$
$$z(u) = C_{3z}u^3 + C_{2z}u^2 + C_{1z}u + C_{0z}$$

In an expanded vector form

$$\mathbf{P}(u) = \mathbf{C}_3u^3 + \mathbf{C}_2u^2 + \mathbf{C}_1u + \mathbf{C}_0 \qquad (1)$$

Matrix form

$$\mathbf{P}(u) = \mathbf{U}^T\mathbf{C}$$

where $\mathbf{U} = [u^3 \quad u^2 \quad u \quad 1]^T$ and $\mathbf{C} = [\mathbf{C}_3 \quad \mathbf{C}_2 \quad \mathbf{C}_1 \quad \mathbf{C}_0]^T$, and $\mathbf{C}$ is called the coefficients vector. The tangent vector is

$$\mathbf{P}'(u) = \sum_{i=0}^{3} \mathbf{C}_i i u^{i-1}, \quad 0 \le u \le 1$$

Curve representation

Now the problem is how to relate the parametric equations to the designers' input, namely, the two end points and tangent vectors.

Applying the boundary conditions (P0, P'0 at u=0 and P1, P'1 at u=1)

$$\mathbf{P}_0 = \mathbf{C}_0 \qquad\qquad \mathbf{C}_0 = \mathbf{P}_0$$

$$\mathbf{P}'_0 = \mathbf{C}_1 \qquad\qquad \mathbf{C}_1 = \mathbf{P}'_0$$

$$\mathbf{P}_1 = \mathbf{C}_3 + \mathbf{C}_2 + \mathbf{C}_1 + \mathbf{C}_0 \qquad\qquad \mathbf{C}_2 = 3(\mathbf{P}_1 - \mathbf{P}_0) - 2(\mathbf{P}'_0 - \mathbf{P}'_1)$$

$$\mathbf{P}'_1 = 3\mathbf{C}_3 + 2\mathbf{C}_2 + \mathbf{C}_1 \qquad\qquad \mathbf{C}_3 = 2(\mathbf{P}_0 - \mathbf{P}_1) + \mathbf{P}'_0 + \mathbf{P}'_1$$

Substituting, C_i into equation 1

$$\mathbf{P}(u) = (2u^3 - 3u^2 + 1)\mathbf{P}_0 + (-2u^3 + 3u^2)\mathbf{P}_1 + (u^3 - 2u^2 + u)\mathbf{P}'_0 + (u^3 - u^2)\mathbf{P}'_1 \qquad 0 \le u \le 1$$

$$\mathbf{P}(u) = \mathbf{U}^T[\mathbf{M}_H]\mathbf{V}, \quad 0 \le u \le 1 \qquad (2)$$

where [$\mathbf{M}_H$] **is the Hermite matrix and V is the geometry (or boundary conditions) vector.**

Both are given by

$$[\mathbf{M}_H] = \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

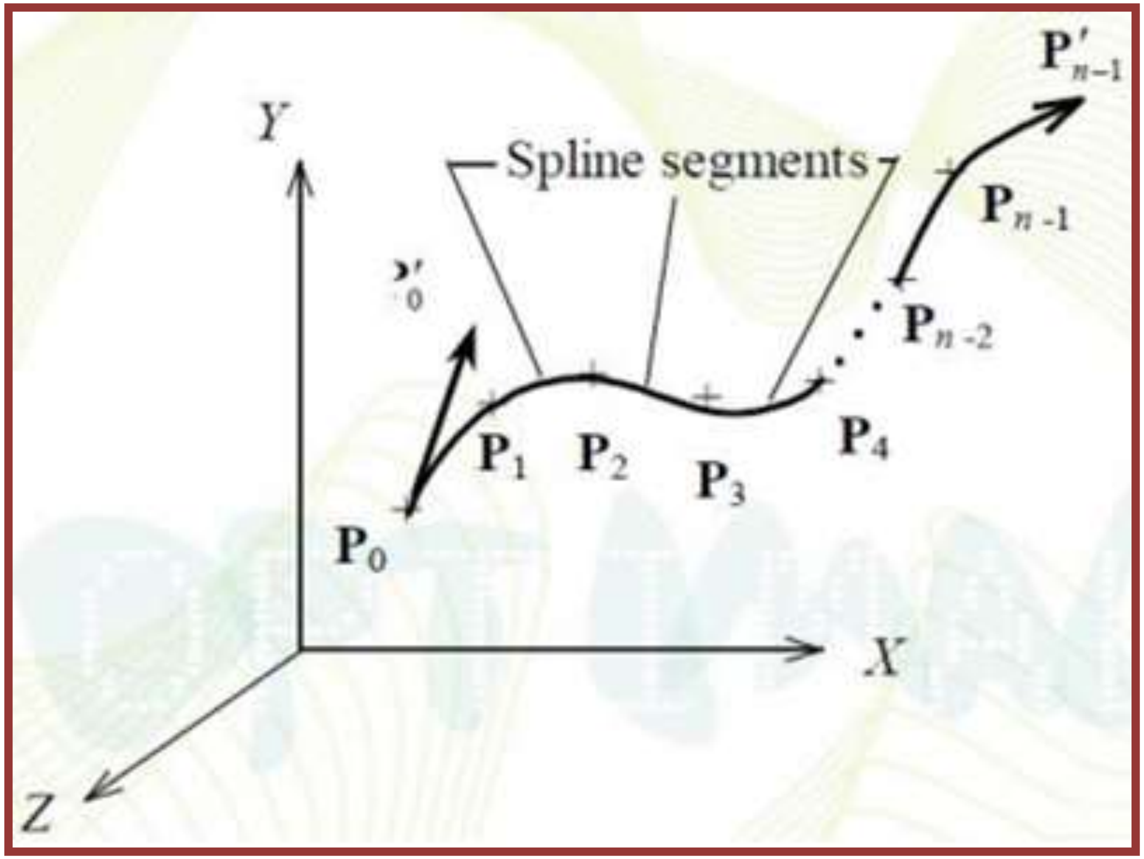
$$\mathbf{V} = [\mathbf{P}_0 \quad \mathbf{P}_1 \quad \mathbf{P}'_0 \quad \mathbf{P}'_1]^T$$

Curve representation

Equation (2) is for one cubic spline segment. It can be generalized for any two adjacent spline segments of a spline curve that are to fit a given number of data points.

This introduces the problem of blending or joining cubic spline segments which can be stated as follows:

given a set of n points P_0, P_1, …, P_{n-1} and the two end tangent vectors P'0 and P'n-1 (as shown in Figure), connect the points with a cubic spline curve.



Curve representation

Let's start from connecting two curves. To connect two Hermite spline curves to form a C2 continuous curve, the second derivative at the end of the first curve must be equal to the second derivative at the beginning of the first curve. Thus we have:

$$\mathbf{P}''(u_1 = 1) = \mathbf{P}''(u_2 = 0)$$

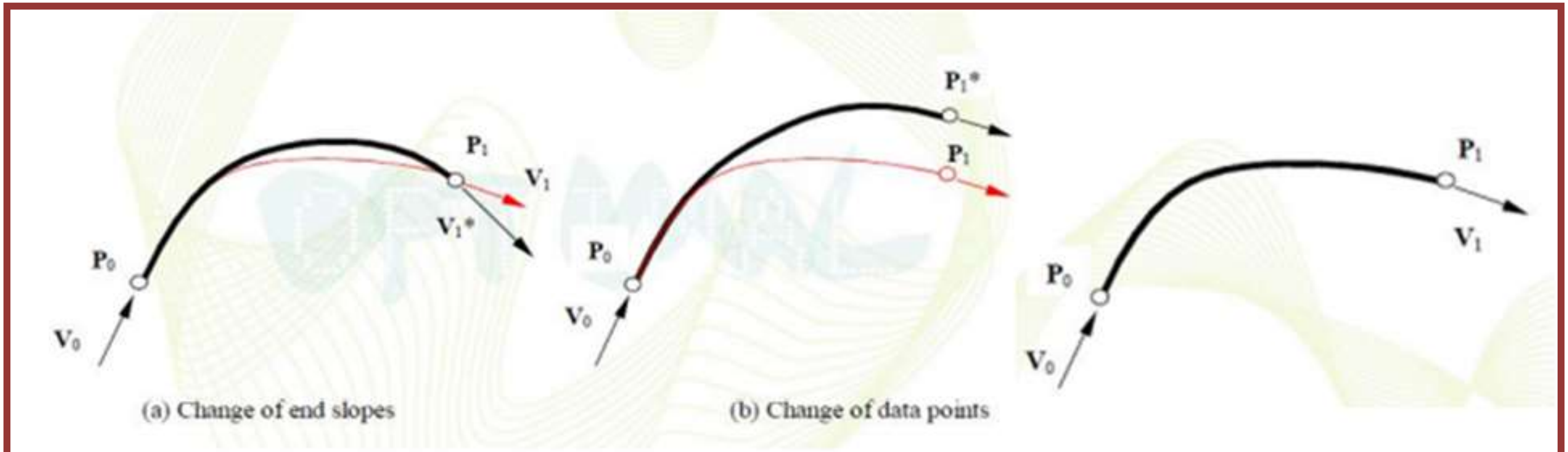
Using this relation, we can further derive the tangent vector at the end of the second curve, which is also the tangent vector at the beginning of the second curve:

$$\mathbf{P}'_1 = -\frac{1}{4}\left(3\mathbf{P}_0 + \mathbf{P}'_0 - 3\mathbf{P}_2 + \mathbf{P}'_2\right)$$

Using this information, we can construct a C2 continuous curve that passes through the three given data points by blending two Hermite curves together

Curve representation

The use of the cubic splines in design applications is not very popular compared to Bezier or B-spline curves. The control of the curve is not very obvious from the input data due to its global control characteristics. As shown in Figure , changing the position of a data point or an end slope changes the entiire shape of the spline, which does not provide the intuitive feel required for design. In addition, the order of the curve is always constant (cubic) regardless of the number of data points.



Control of cubic spline curve

CAD - CAM

UNIT 2 GEOMETRIC MODELLING - I **9 Hrs.**

Wireframe modelling of analytical curves, such as line, circle and conics, and synthetic curves, such as Hermite cubic spline, Bezier curve and B-Spline curve. Surface modelling of analytical surfaces, such as plane surface, ruled surface, surface of revolution and tabulated cylinder, and synthetic surfaces, such as Hermite cubic surface, Bezier surface and B-Spline surface.

Lecture series on Computer Aided Design by
Dr.P.V.Madhusudhan,
Department of Mechanical Engineering, IIT Delhi
https://www.youtube.com/watch?v=KTn2LVhQmf0

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 3 – GEOMETRIC MODELING – II - SMEA1501

3.1. GRAPHICS SOFTWARE

The most important characteristic of CAD/CAM software is its fully three-dimensional, associative, centralized, and integrated database. Such a database is always rich in information needed for both the design and manufacturing processes. The centralized concept implies that any change in or addition to a geometric model in one of its views is automatically reflected in the existing views or any views. Users of CAD/CAM software can be classified into three groups: software operators, applications programmers, and system programmers. The majority of users including engineers and designers fall into the operator’s category. The main concern of this group is to master using the software so that the anticipated productivity increases are achieved.

The needs for graphics standards were obvious and were acknowledged by the CAD'CAM community—both vendors and users. The following are some of these needs:

1. Application program portability. This avoids hardware dependence of the program. For example, if the program is written originally for a DVST display, it can be transported to support a raster display with minimal effort.

2. Picture data portability. Description and storage of pictures should be independent of different graphics devices.

3. Text portability. This ensures that text associated with graphics can be presented in an independent form of hardware.

4. Object database portability. While the above needs concern CAD/CAM vendors, transporting design and manufacturing (product specification) data from one system to another is of interest to CAD/CAM users. In some cases, a company might need to ship a CAD database of a specific design to an outside vendor to manufacture and produce the product.

3.1.1. Standard functioning at various level of the graphics system

1. GKS is an ANSI and ISO standard. It is device independent, host system independent and application-independent. It supports both two-dimensional and three-dimensional data and viewing. It interfaces the application program with the graphics support package.

2. PHIGS (programmer's hierarchical interactive graphics system) is intended to support high function workstations and their related CAD'CAM applications. The significant extensions it offers beyond GKS-3D. are in supporting segmentation used to display graphics and the dynamic ability to modify segment contents and relationships. PHIGS operates at the same level as GKS (interface A).

3. VDM (virtual device metafile) defines the functions needed to describe a picture. Such description can be stored or transmitted from one graphics device to another. It functions at the level just above device drivers. VDM is now called CGM (computer graphics metafile).

4. VDI (virtual device interface) lies between GKS or PHIGS .

5. IGES enables an exchange of model databases on CAD/CAM systems. It functions at object database and application data structures.

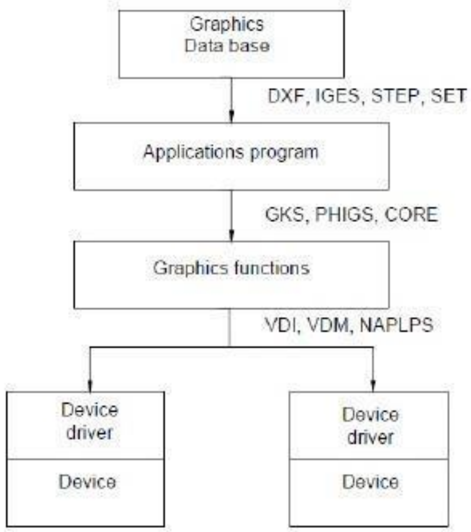


Fig 3.1. Graphics functions

Computer databases are now replacing paper blueprints in defining product geometry and non-geometry for all phases of product design and manufacturing. It becomes increasingly important to find effective procedures for exchanging these databases. Transferring data between dissimilar CAD/CAM systems must embrace the complete product description stored in its database. Four types of modeling data make up this description. These are shape, non-shape, design, and manufacturing data. Shape data consists of both geometrical and topological information as well as part or form features. Features allow high-level concept communication about parts. Examples are hole, flange, web, pocket, chamfer, etc. Non-shape data includes graphics data such as shaded images, and model global data as measuring units of the database and the resolution of storing the database numerical values.

Early attempts to design data formats, e.g., IGES, focused on CAD -to-CAD exchange where primarily shape and non-shape data were to be transferred from one system to another. Soon it became apparent that new data formats need to be designed or the scope of existing ones must be extended to include CAD-to-CAD and CAM-to-CAM exchanges, that is, exchange of complete product descriptions.

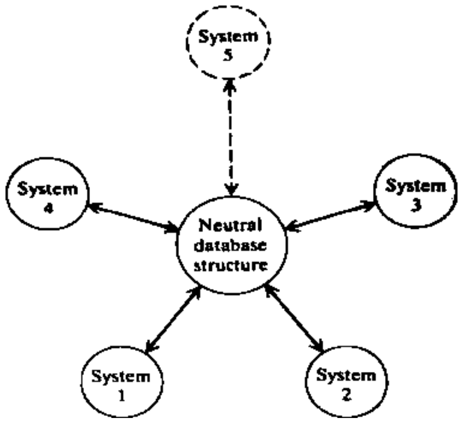


Fig 3.2 Neutral database

3.1.2. Requirements for the Exchange

- *Shape data:* both geometric and topological information, part and form features. Fonts, color, annotation are considered part of the geometric information.

- *Non-shape data:* graphics data such as shaded images, and model global data as measuring units of the database and the resolution of storing the database numerical values.

- *Design data:* information that designers generate from geometric models for analysis purposes. Mass property and finite element mesh data belong to this type of data.
- *Manufacturing data*: information as tooling, NC tool paths, tolerance, process planning, tool design, and bill of materials (BOM).

3.1.3. Standard neutral data formats:

- Initial Graphics Exchange Specification (IGES) - the most popular format of the Neutral file, supported by all CAD/CAE/CAM systems and defined by the international standard organization (ISO).

- Drawing Interchange Format (DXF) - a format originated by Auto Desk and used mainly for the exchange of drawing data.

A number of other neutral data formats for CAD/GAE/CAM systems were used in the past. These include PHIGS, NAPLPS and GKS. Currently, CAD systems, which used to support IGES format, are moving toward the use of STEP.

3.2 GRAPHICAL KERNEL SYSTEM

Graphical Kernel System (GKS) provides a set of functions for the purpose of generating 2D pictures on vector graphics and/or raster devices. It also supports operator input and interaction by supplying basic functions for graphical input, picture segmentation and subsequent storage, retrieval and dynamic modification of graphical information.

GKS provides a functional interface between an application program and a configuration of graphical input and output devices. The functional interface contains all basic functions for interactive and non-interactive graphics on a wide variety of graphical equipment.

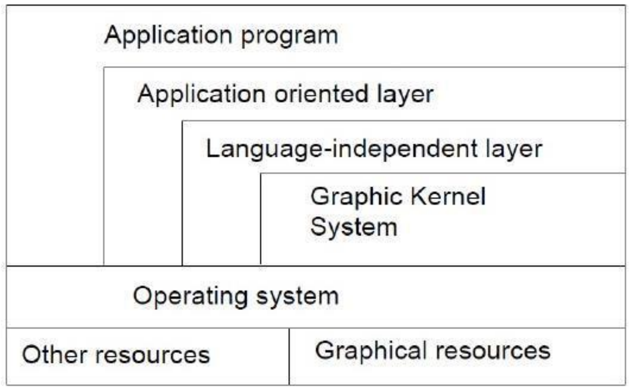


Fig 3.3. Layers of GKS

The geometric information (coordinates) contained in the output primitives, attributes and logical input values can be subjected to transformations. These transformations perform mapping between three coordinate systems, namely:

(a) World Coordinates (WC) used by the application programmer to describe graphical information to GKS.

(b) Normalized Device Coordinates (NDC) used to define a uniform coordinate system for all workstations.

(c) Device Coordinates (DC), one coordinate system per workstation, representing its display surface coordinates. Input containing coordinates are expressed to GKS by the device using DC values.

Output primitives and attributes are mapped from WC to NDC by normalization transformation, from NDC to NDC by segment transformation (as indicated by a transformation matrix defining rotation, scaling and shift factors) and from NDC to DC by workstation transformation. Input from the display surface (expressed in DC) is mapped by an inverse workstation transformation from DC to NDC and by one of the inverse normalization transformation from NDC to WC.

Output primitives and primitive attributes may be grouped together in a segment. Segments are units for manipulation and change. Manipulation includes creation, deletion, and renaming while change includes transforming a segment, changing its visibility and also highlighting segments, i.e., causing segments to "flash". Segments also form the basis for workstation independent storage of pictures at run time. Via this storage, a special workstation called Workstation Independent Segment Storage (WISS), segments can be inserted into other existing ones or transferred to other workstations.

3.3. INITIAL GRAPHICS EXCHANGE SPECIFICATION (IGES)

First developed by National Institute of Standards and Technology (NIST) in 1980. Then adopted by the American National Standards Institute (ANSI) in the same year. Exchanges primarily shape (both geometric and topological) and non-shape data, which is referred as CAD-to-CAD exchange.

File is composed of 80-character ASCII records, a record length derived from the punched card era. Text strings are represented in "Hollerith" format, the number of characters in the string, followed by the letter "H", followed by the text string, e.g., "4HSLOT" (this is the text string format used in early versions of the Fortran language). Early IGES translators had problems with IBM mainframe computers because the mainframes used EBCDIC encoding for text, and some EBCDIC-ASCII translators would either substitute the wrong character, or improperly set the parity bit, causing a misread.

The file is divided into 5 sections: Start, Global, Directory Entry, Parameter Data, and Terminate indicated by the characters S, G, D, P, or T in column 73. The characteristics and geometric information for an entity is split between two sections; one in a two record, fixed-length format (the Directory Entry, or DE Section), the other in a multiple record, comma delimited format (the Parameter Data, or PD Section), as can be seen in a more human-readable representation of the file.

```
                                                                        S      1
1H,,1H;,4HSLOT,37H$1$DUA2:[IGESLIB.BDRAFT.B2I]SLOT.IGS;,                G      1
17HBravo3 BravoDRAFT,31HBravo3->IGES V3.002 (02-Oct-87),32,38,6,38,15,  G      2
4HSLOT,1.,1,4HINCH,8,0.08,13H871006.192927,1.E-06,6.,                   G      3
31HD. A. Harrod, Tel. 313/995-6333,24HAPPLICON - Ann Arbor, MI,4,0;     G      4
     116       1       0       1       0       0       0       0       1D      1
     116       1       5       1       0                               0D      2
     116       2       0       1       0       0       0       0       1D      3
     116       1       5       1       0                               0D      4
     100       3       0       1       0       0       0       0       1D      5
     100       1       2       1       0                               0D      6
     100       4       0       1       0       0       0       0       1D      7
     100       1       2       1       0                               0D      8
     110       5       0       1       0       0       0       0       1D      9
     110       1       3       1       0                               0D     10
     110       6       0       1       0       0       0       0       1D     11
     110       1       3       1       0                               0D     12
116,0.,0.,0.,0,0,0;                                                    1P      1
116,5.,0.,0.,0,0,0;                                                    3P      2
100,0.,0.,0.,0.,1.,0.,-1.,0,0;                                         5P      3
100,0.,5.,0.,5.,-1.,5.,1.,0,0;                                         7P      4
110,0.,-1.,0.,5.,-1.,0.,0,0;                                           9P      5
110,0.,1.,0.,5.,1.,0.,0,0;                                            11P      6
S      1G      4D      12P      6                                       T      1
```

Fig 3.4 An example of IGES File

3.4. GEOMENTRIC MODELLING

Geometric modeling deals with the mathematical representation of curves, surfaces, and solids necessary in the definition of complex physical or engineering objects. The associated field of computational geometry is concerned with the development, analysis, and computer implementation of algorithms encountered in geometric modeling. The objects we are concerned with in engineering range from the simple mechanical parts (machine elements) to complex sculptured objects such as ships, automobiles, airplanes, turbine and propeller blades, etc.

Geometric modeling attempts to provide a complete, flexible, and unambiguous representation of the object, so that the shape of the object can be:

- Easily visualized (rendered)
- Easily modified (manipulated)
- Increased in complexity
- Converted to a model that can be analyzed computationally
- Manufactured and tested

3.4.1 Wireframe modeling

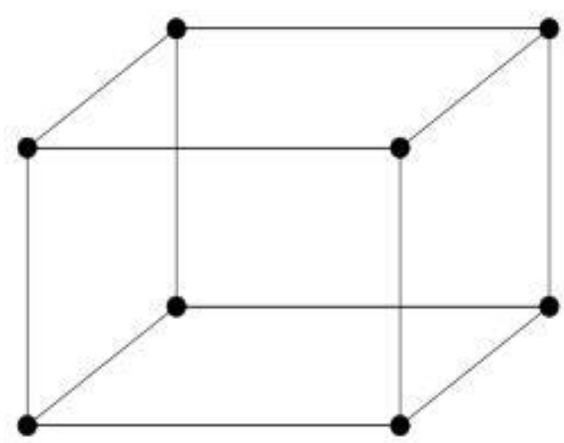


Fig 3.5. Wireframe model

Wireframe modeling, developed in the early 1960's, is one of the earliest geometric modeling techniques. It represents objects by edge curves and vertices on the surface of the object, including the geometric equations of these entities. It is created by intersecting the hull surface with three sets of orthogonal planes. Usually the hull surface is taken as the molded hull surface which is the inner side of the hull plating. Intersections of the hull surface with vertical planes (from bow to stern) are called buttock lines. Intersections of the hull surface with horizontal planes (parallel to keel) are the waterlines, while intersections with transverse vertical planes are called sections. Wireframes are rather incomplete and possibly ambiguous representations that were superseded by surface models.

3.4.2 Surface modeling

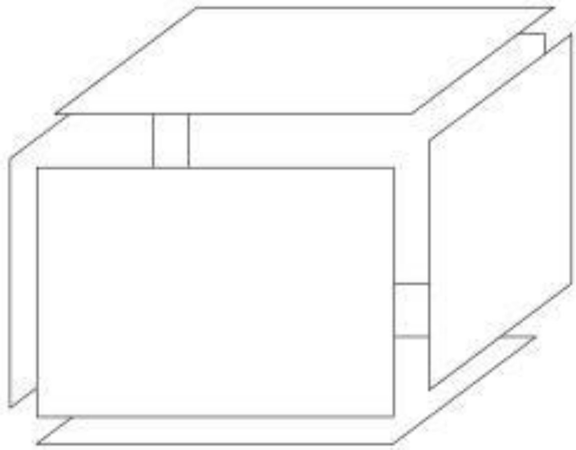


Fig 3.6. Surface model

Surface modeling techniques, developed in the late 1960's, go one step further than wireframe representations by also providing mathematical descriptions of the shape of the surfaces of objects. Surface modeling techniques allow graphic display and numerical control machining of carefully constructed models, but usually offer few integrity checking features (e.g. closed volumes). The surfaces are not necessarily properly connected and there is no explicit connectivity information stored. These techniques are still used in areas where only the visual display is required, e.g. flight simulators.

3.4.3. Solid modeling

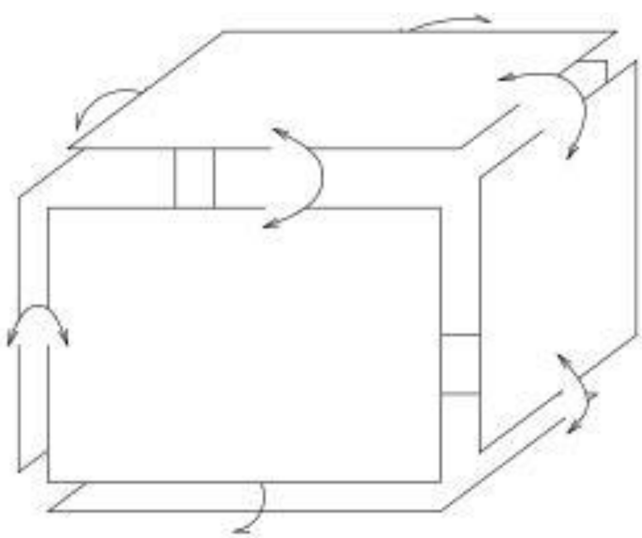


Fig 3.7. Solid model

Solid modeling, first introduced in the early 1970's, explicitly or implicitly contains information about the closure and connectivity of the volumes of solid shapes. Solid modeling offers a number of advantages over previous wireframe and surface modeling techniques. In principle, it guarantees closed and bounded objects and provides a fairly complete description of an object modeled as a rigid solid in 3D space illustrates that for a boundary based solid model of a single homogeneous object, every surface boundary is always directly adjacent to one other surface boundary, guaranteeing a closed volume. Solid models, unlike surface models, enable a modeling system to distinguish the outside of a volume from the inside. This capability, in turn, allows integral property analysis for the determination of volume, center of volume or gravity, moments of inertia, etc

3.5. SOLID MODELING TECHNIQUES

Solid modeling techniques are based on informational complete, valid and unambiguous representations of objects. Simply stated, a complete geometric data representation of an object is one that enables points in space to be classified relative to the object, if it is inside, outside, or on the object. This classification is sometimes called spatial addressability. Both wireframe and surface models are incapable of handling spatial addressability as well as verifying that the model is well formed. The latter meanings that these models cannot verify whether two objects occupy the same space.

User input required to create solid models on existing CAD/CAM systems depends on both the internal representation scheme used by each system as well as the user interface. It is crucial to distinguish between the user interface and the internal data representation of a given CAD/CAM system. The two are quite separate aspects of the systems and can be linked together by software that is transparent to the user. For example, a system that has a B-rep (boundary representation) internal data representation may use a CSG (constructive solid geometry)-oriented user interface; that is, input a solid model by its primitives. Most systems use the building-block approach (CSG oriented) and sweep operations as the basis for user interface.

Solid modelers store more information (geometry and topology) than wireframe or surface modelers (geometry only). Geometry (sometimes called metric information) is the actual dimensions that define the entities of the object. The geometry that defines the object shown in Figure1 is the lengths of lines $L1$, $L2$ and $L3$, the angles between the lines, and the radius R *and* the center P1 of the half-circle. Topology (sometimes called combinatorial structure), on the other hand, is the connectivity and associatively of the object entities. It has to do with the notion of neighborhood; that is, it determines the relational information between object entities.

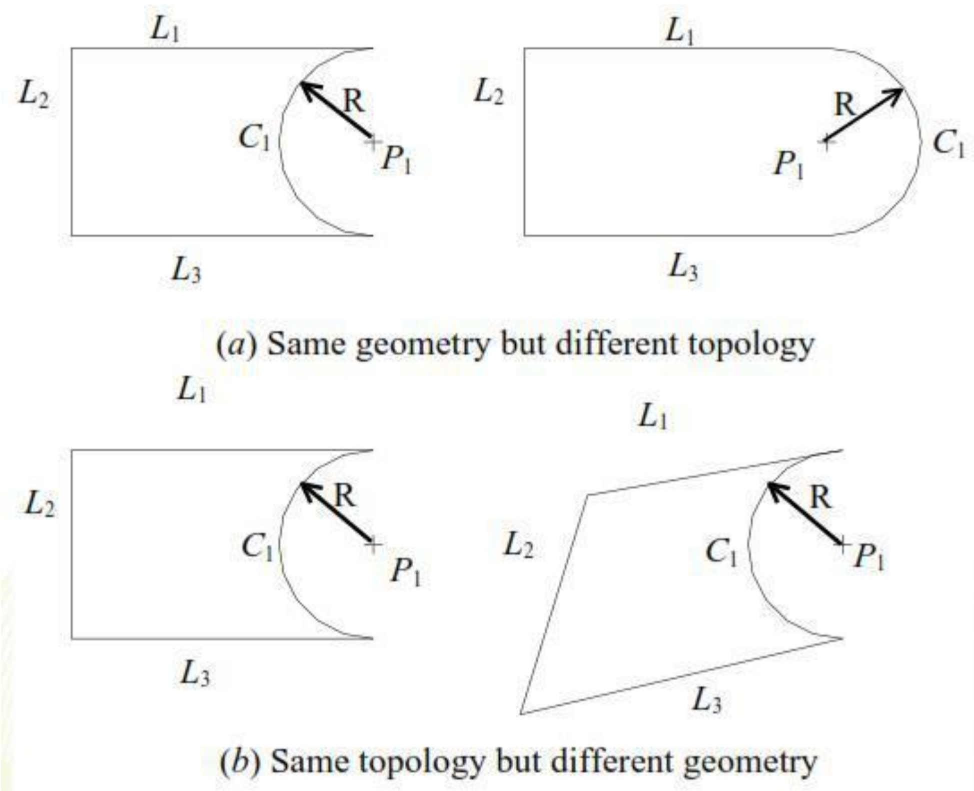


Fig. 3.8. Geometry and topology

Based on these definitions, neither geometry nor topology alone can completely model objects. Wireframe and surface models deal only with geometrical information of objects, and are therefore considered incomplete and ambiguous. From a user point of view, geometry is visible, and topology is considered to be no graphical relational information that is stored in solid model databases and is not visible to users.

3.6. BOUNDARY REPRESENTATION (B-REP)

Boundary representation is one of the two most popular and widely used schemes to create solid models of physical objects. A B-rep model or boundary model is based on the topological notion that a physical object is bounded by a set of faces. These faces are regions or subsets of closed and orient able surfaces. A closed surface is one that is continuous without breaks. An orient able surface is one in which it is possible to distinguish two sides by using the direction of the surface normal to point to the inside or outside of the solid model under construction. Each face is bounded by edges and each edge is bounded by vertices. Thus, topologically, a boundary model of an object is comprised of faces, edges, and vertices of the object linked together in such a way as to ensure the topological consistency of the model. The database of boundary model contains both its topology and geometry. Topology is created by performing Euler operations and geometry is created by operators; ensure the integrity (closeness, no dangling faces or edges, etc.) of boundary models. They offer a mechanism to check the validity of these models. Geometry includes coordinates of vertices, rigid motion and transformation (translation, rotation, etc.), and metric information such as distances, angles, areas, volumes, and inertia tensors. It should be noted that topology and geometry are interrelated and cannot be separated entirely. Both must be compatible otherwise nonsense objects may result. Figure3 shows a square which, after dividing its top edges by introducing a new vertex, is still valid. Topologically but produces a nonsense object depending on the geometry of the new vertex.

3.6.1 Primitives of B-rep

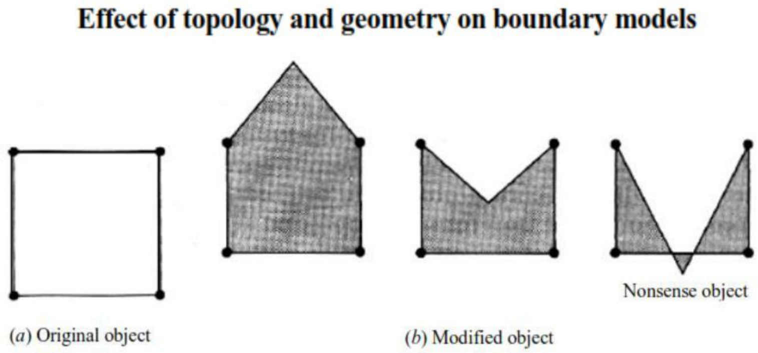


Fig. 3.9. Topology models

If a solid modeling system is to be designed, the domain of its representation scheme (objects that can be modeled) must be defined, the basic elements (primitives) needed to cover such modeling domain must be identified, the proper operators that enable the system users to build complex objects by combining the primitives must be developed, and finally a suitable data structure must be designed to store all relevant data and information of the solid model. Objects that are often encountered in engineering applications can be classified as either polyhedral or curved objects. A polyhedral object (plane-faced polyhedron) consists of planar faces (or sides) connected at straight (linear) edges which, in turn, are connected at vertices. A cube or a tetrahedron is an obvious example. A curved objects (curved polyhedron) is similar to a polyhedral object but with curved faces and edges instead.

3.6.2 Advantages and disadvantages of B-rep

The B-rep scheme is very popular and has a strong history in computer graphics because it is closely related to traditional drafting. Its main advantage is that it is very appropriate to construct solid models of unusual shapes that are difficult to build using primitives.

Another major advantage is that it is relatively simple to convert a B-rep model into a wireframe model because the model's boundary definition is similar to the wireframe definition. One of the major disadvantages of the boundary model is that it requires large amounts of storage because it stores the explicit definition of the model boundaries. It is also a verbose scheme more verbose than CSG. The model is defined by its faces, edges, and vertices which tend to grow fairly fast for complex models. If B-rep systems do not have a CSG-compatible user interface, then it becomes slow and inconvenient to use Euler operators in a design and production environment.

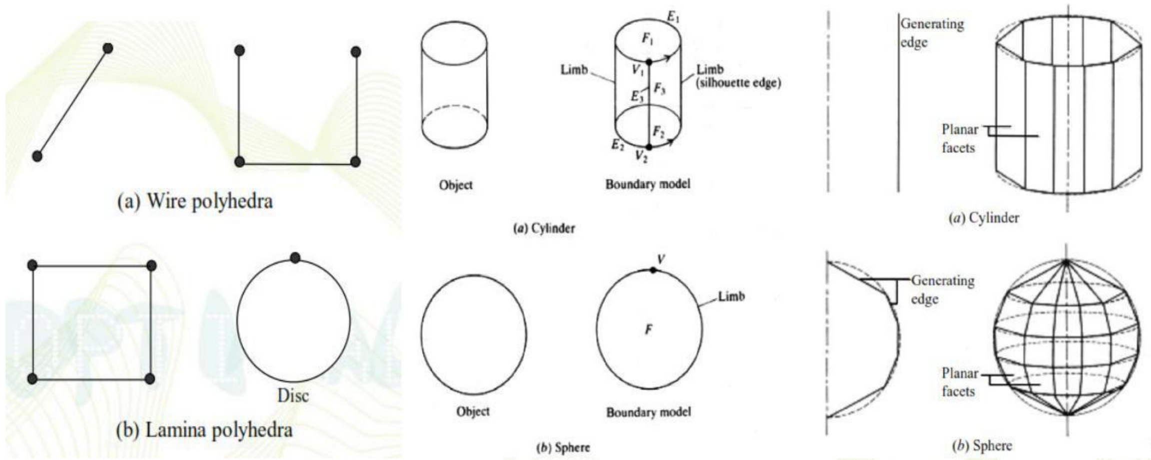


Fig 3.10. B-Rep models

3.7 CONSTRUCTIVE SOLID GEOMETRY (CSG)

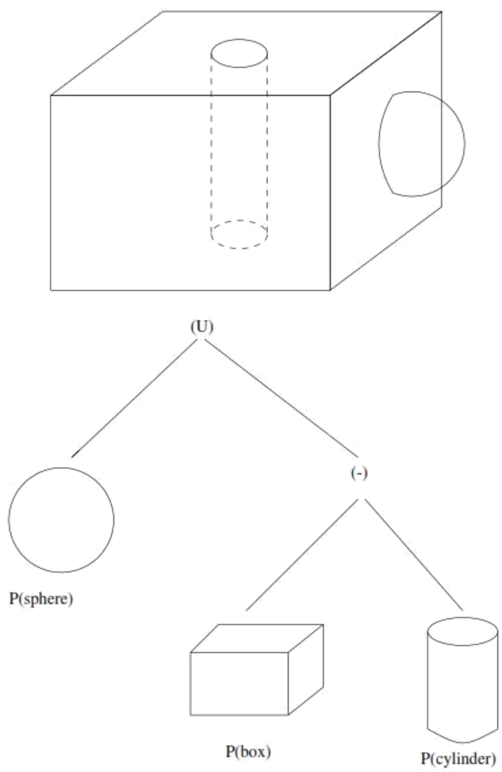


Fig 3.11. CSG Model

Constructive Solid Geometry (CSG) is the Boolean combination of primitive volumes that include the surface and the interior. For example, primitives including rectangular box, sphere, cylinder, cone and torus can be combined using intersection, union and difference operators to form complex solids. Positioning operators (position, orientation) and size operators are applied to the primitives before the Boolean operators are invoked. Terminal nodes on the binary tree are primitive volumes; other nodes are Boolean operators. This representation has a direct manufacturing analogue, where difference indicates drilling or machining and union indicates for example welding. Another example of a related representation is sweeps, where more general primitives are obtained by sweeping a solid along a space curve or sweeping a planar curve through a revolution about an axis in its plane. Sweeps are useful in the representation of blends, volumes swept by machine tools, and in robotics. In a survey of machine elements, 90 to 95% of parts could be represented accurately using the CSG method with the above simple primitive solid

GEOMETRIC MODELS

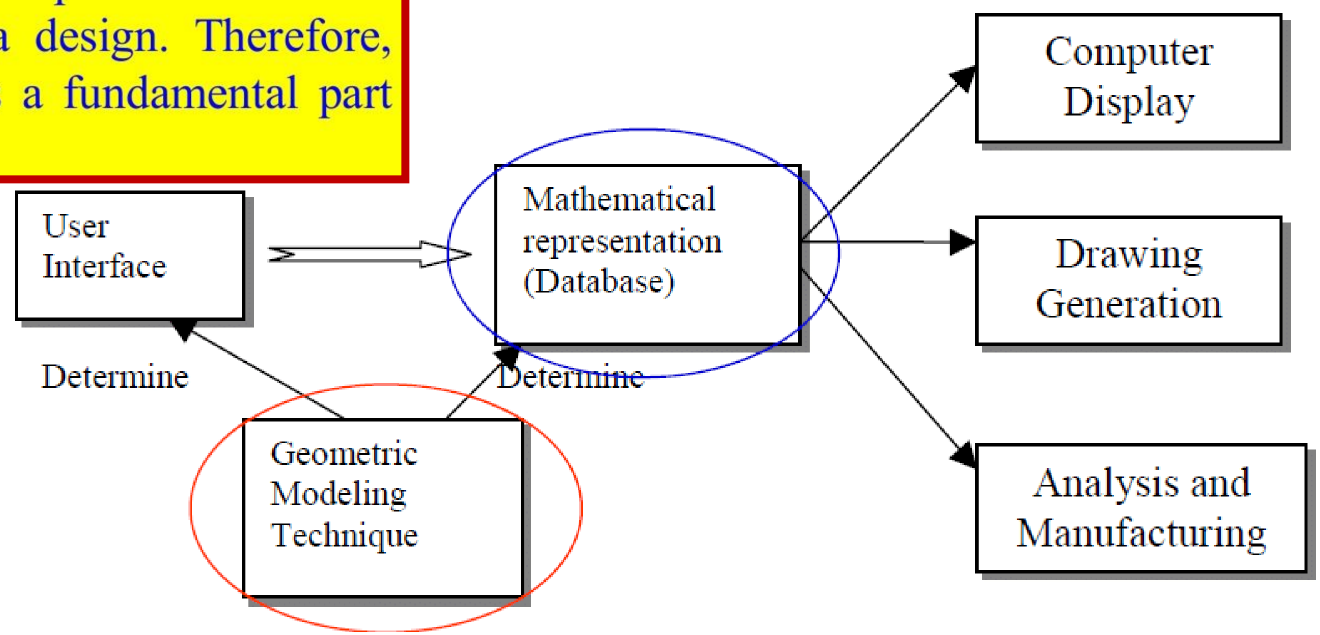
Geometric modeling is the process of capturing the properties of an object or a system using mathematical formulae.

Computer geometric modeling is the field that discusses the mathematical methods behind the modeling of realistic objects for computer graphics and computer aided design

What is Geometric modeling

Geometric modelling refers to a set of techniques concerned mainly with developing efficient representations of geometric aspects of a design. Therefore, geometric modelling is a fundamental part of all CAD tools.

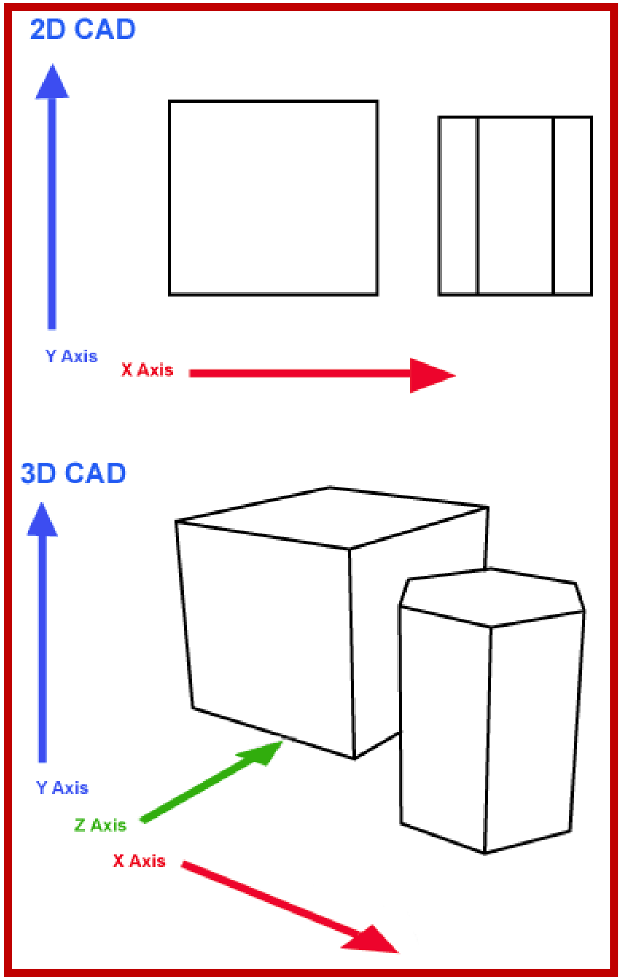
Role of Geometric modeling in CAD

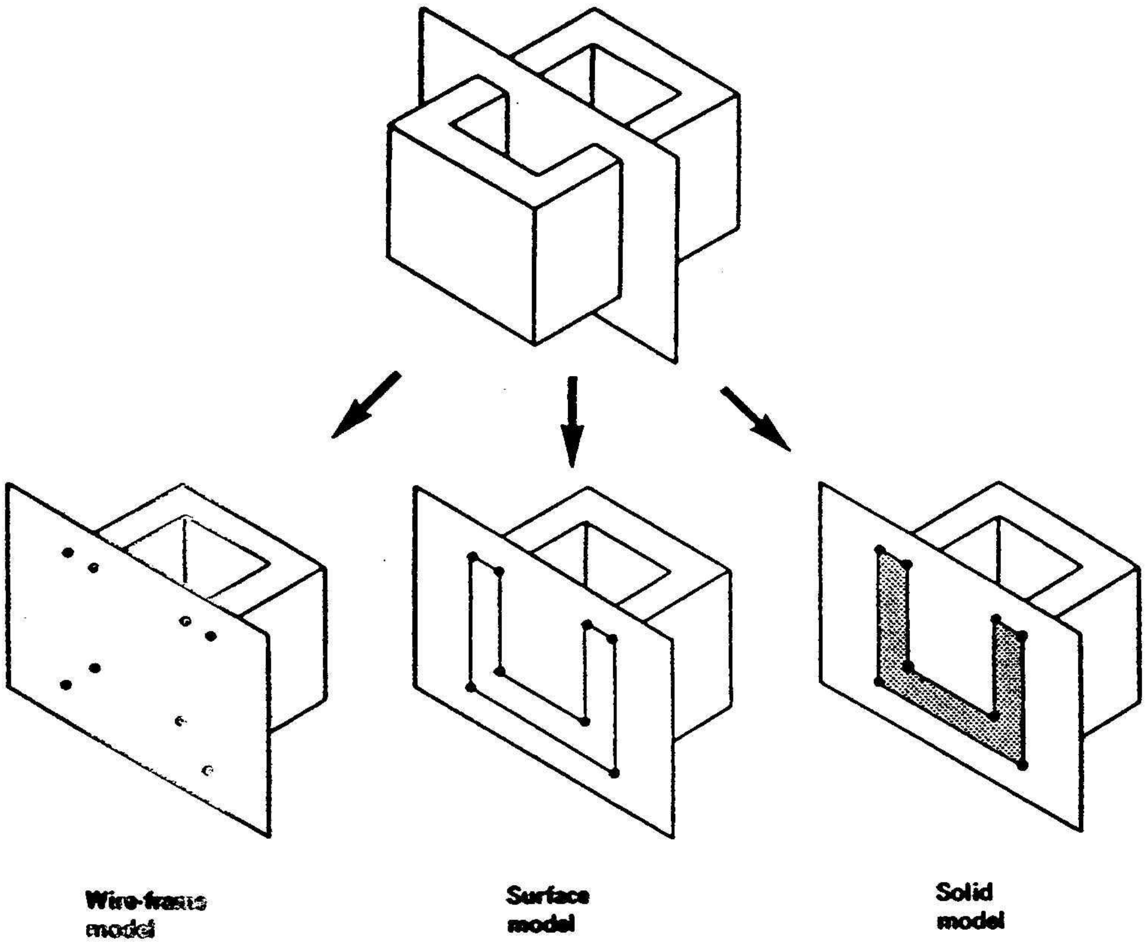


GEOMETRIC MODELS

The basic geometric modelling approaches available to designers on CAD/CAM systems are:

1. Wire-frame modeling.
2. Surface modeling.
3. Solid modeling.





GEOMETRIC MODELS

Applications of Geometric modeling

- Mass property calculations.
- Mechanism analysis.
- Finite-element modelling.
- NC programming.

Need for Geometric modeling

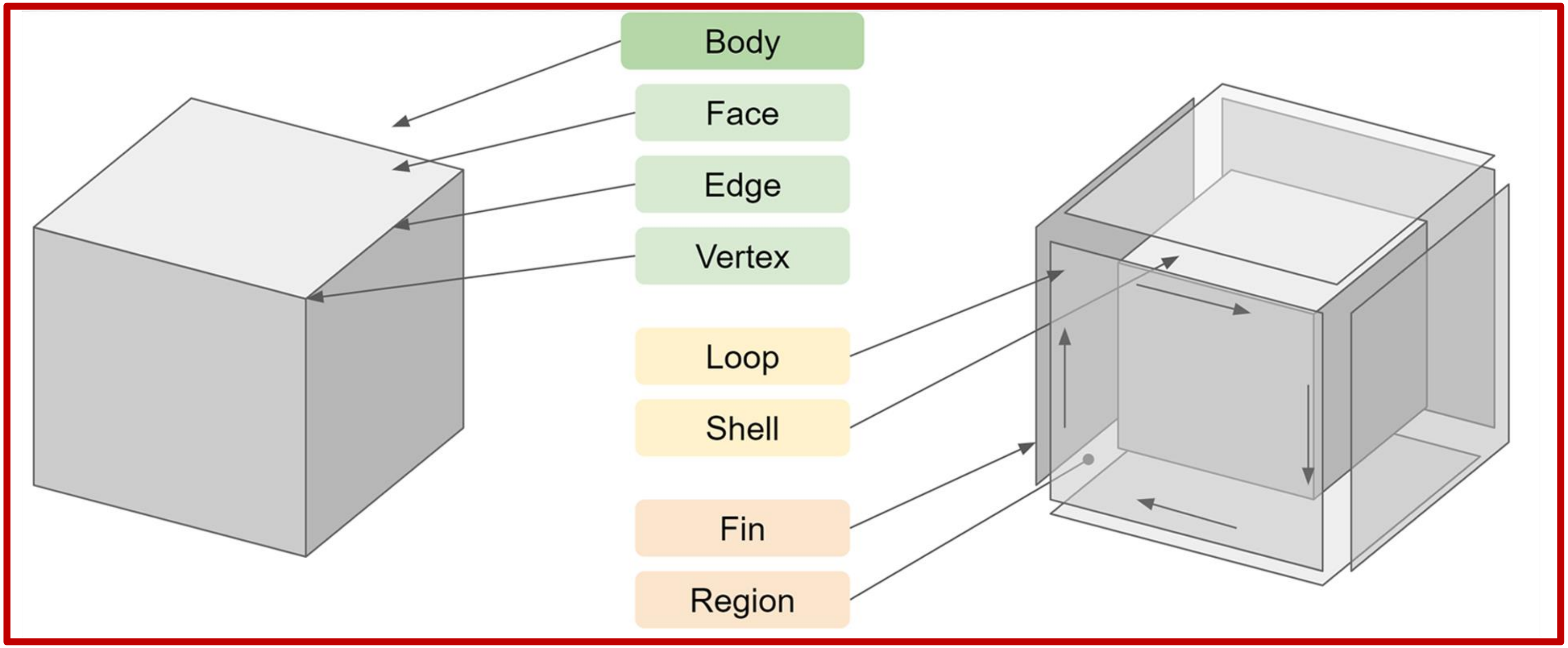
- Geometric (3D) models are easier to interpret.
- Simulation under real-life conditions.
- Less expensive than building a physical model.
- 3D models can be used to perform finite element analysis (stress, deflection, thermal)
- 3D models can be used directly in manufacturing, Computer Numerical Control (CNC).
- Can be used for presentations and marketing.

Requirements of Geometric modeling

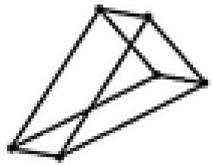
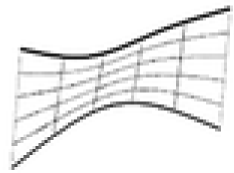
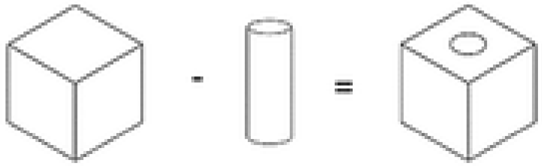
- Completeness of the part representation.
- The modelling method should be easy to use by designers.
- Rendering capabilities (which means how fast the entities can be accessed and displayed by the computer).

GEOMETRIC MODELS

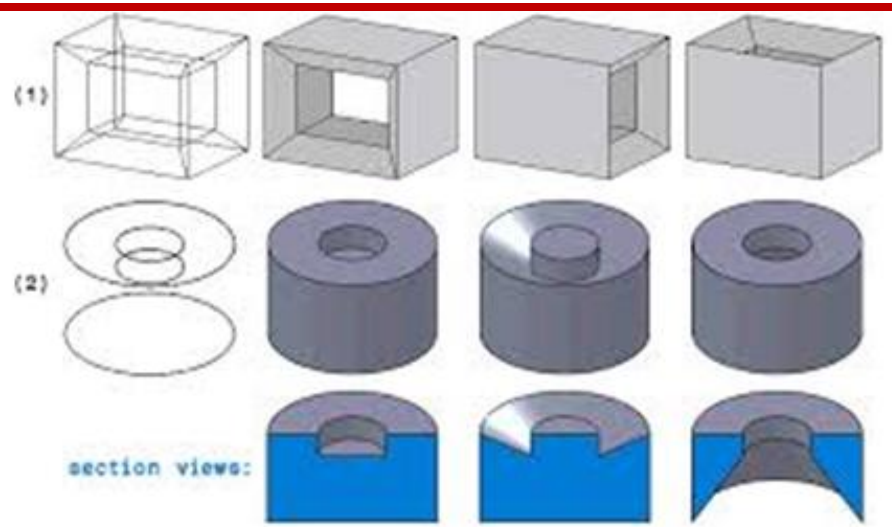
- **Topology** is a branch of mathematics concerned with spatial properties preserved under continuous deformation (stretching without tearing or gluing); these properties are the topological invariants.
- On its own, topology defines a "rubber" model.



GEOMETRIC MODELS

	 Wireframe model	 Surface model	 Solid model
1960	Development of wire and surface models		
1970	First use of wire and surface models		Development of solid models modelling
1980	Specific use of wire and surface models		First use of solid models
1990	General use of wire and surface models		Specific use of solid models
2000	General use of wire, surface and solid models		
2010	Introducing special techniques of wire, surface and solid models for product modelling		

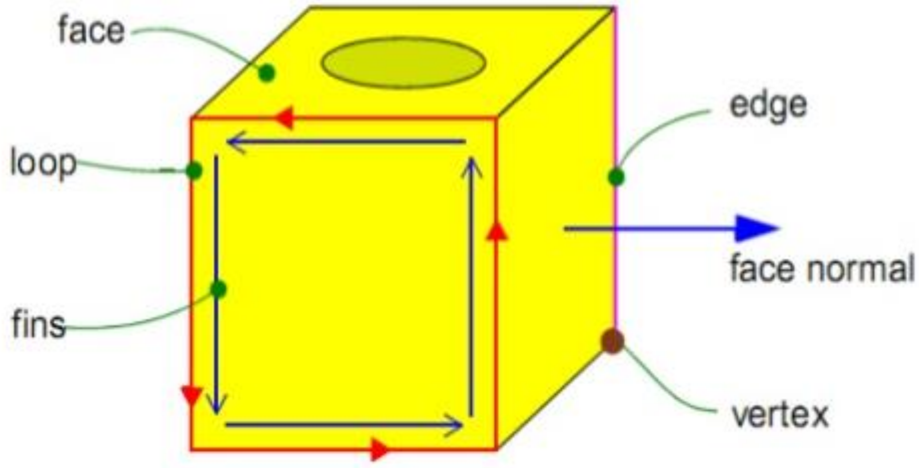
GEOMETRIC MODELS

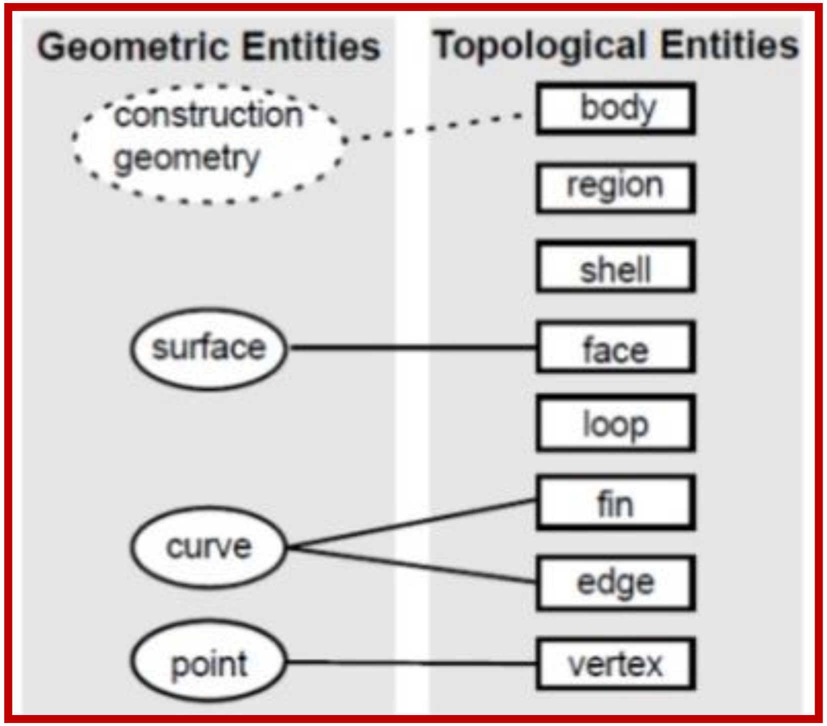


Automatic view generation (perspective and orthographic)	Impossible	Impossible	Possible
Cross-sectioning	Manually guided	Manually guided	Possible, even automated cross-hatching is possible
Elimination of hidden details	Manually guided	May be possible	Possible
Analysis functions (Geometric calculations)	Difficult or impossible	Difficult or impossible	Possible
Numerical control application	Difficult or impossible	Automatic possible	Automatic possible

Topological entities

- Topological entities comprise all the entities that are used to construct the structure or skeleton of a model.





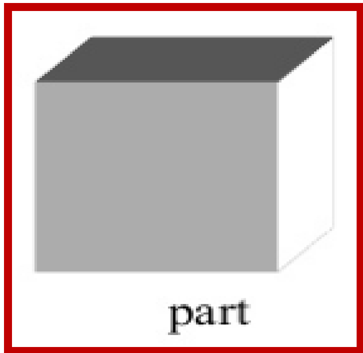
B-Rep is a method for representing shapes using the limits.

B-Rep models are composed of two parts:

- **Topology** describes how elements are bounded and connected.
- **Geometry** describes the shape of each individual element.c

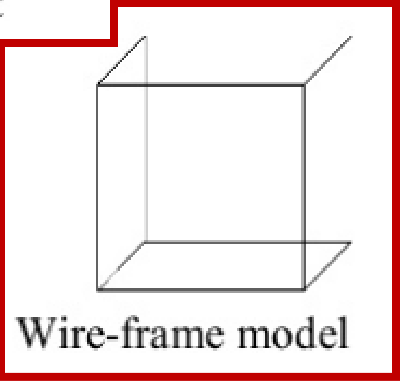
GEOMETRIC MODELS

WIREFRAME MODELS



A wireframe representation is a 3-D line drawing of an object showing only the edges without any side surface in between.

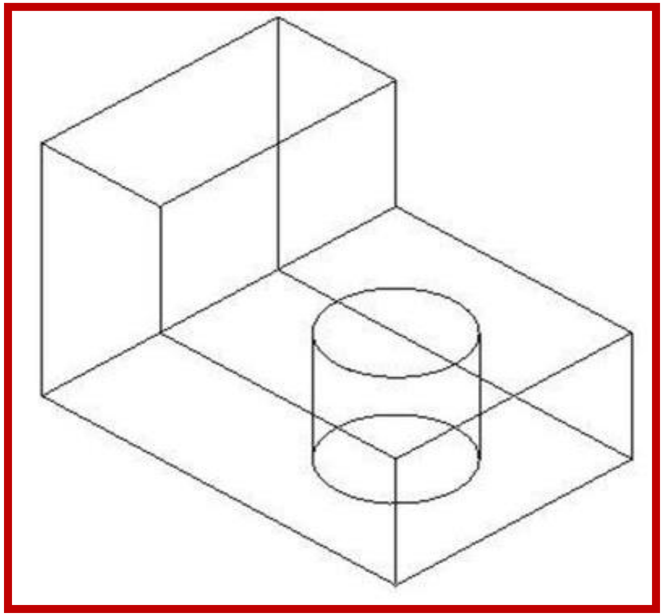
A frame constructed from thin wires representing the edges and projected lines and curves



A wireframe model of an object is the simplest and represents mathematically in the computers.

It is most commonly used technique and all commercial CAD/CAM systems are wire-frame based.

Basic wire-frame entities can be divided into analytic and synthetic entities.



Wire-frame modelling uses points and curves (i.e. lines, circles, arcs), and so forth to define objects.

The user uses edges and vertices of the part to form a 3-D object

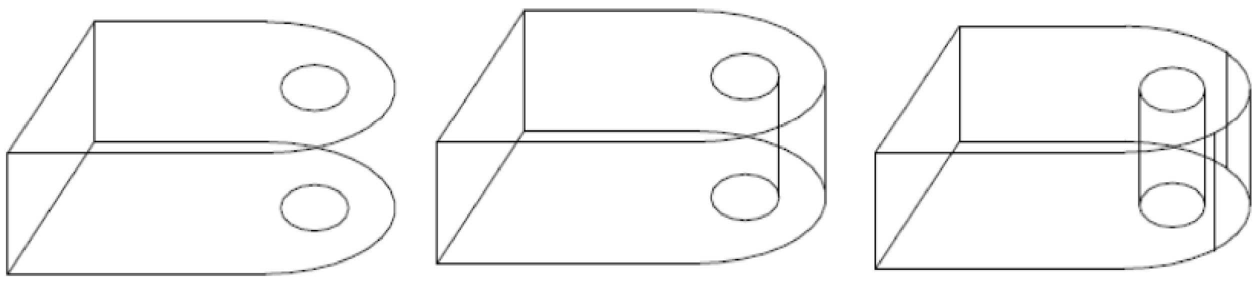
WIREFRAME MODELS

•Typically, a wireframe model consists of a finite set of points (vertices), connected in pairs by straight lines (edges), or arcs, circles, conics, and curves, so that the three dimensional form of a solid object can be visualized.

• The advantage of wireframe modeling is its simplicity to construct. It does not require as much computer time and memory as does surface or solid modeling. Wireframe modeling is considered a natural extension of traditional methods of drafting.

• The disadvantages of wireframe models are manifolds. Primarily, wireframe models are usually ambiguous representations of real objects and rely heavily on human interpretation.

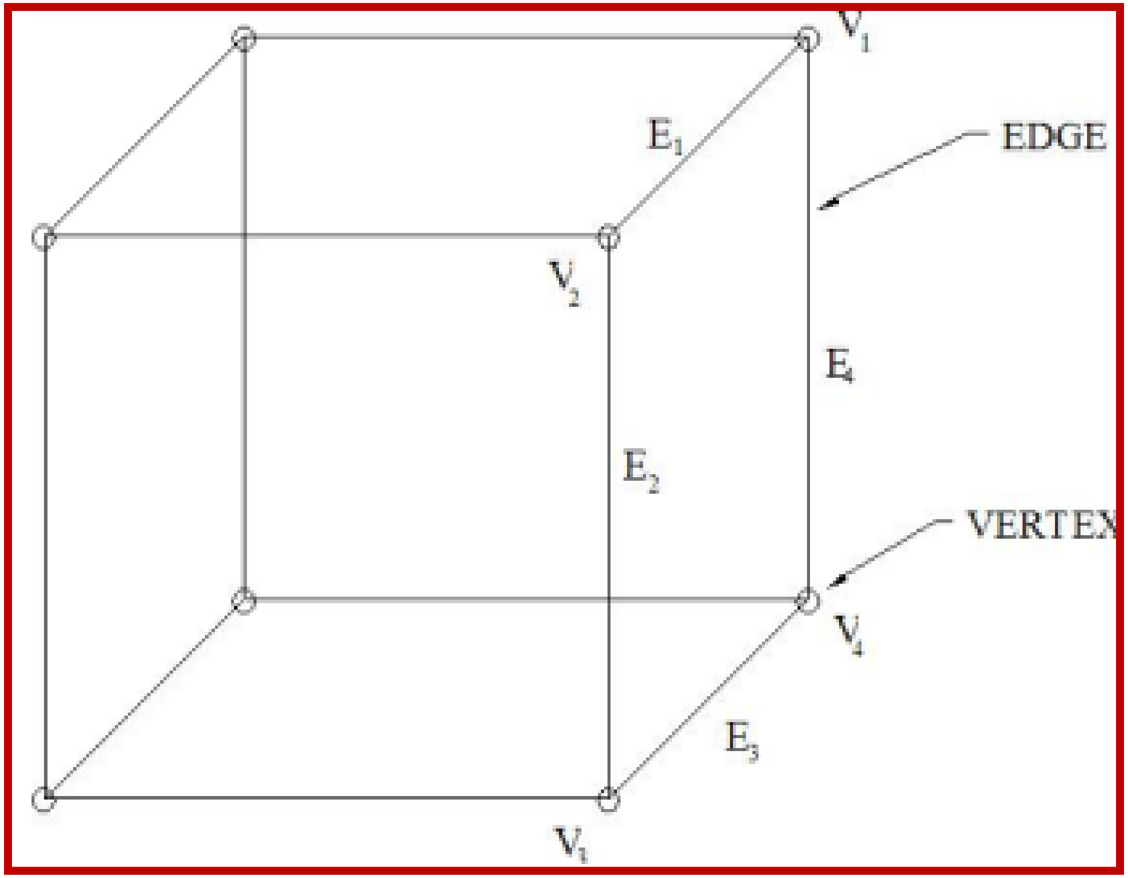
•Models of complex designs having many edges become very confusing and perhaps even impossible to interpret. Moreover, as shown in Figure , it is often difficult to display objects with curve surfaces using wireframe



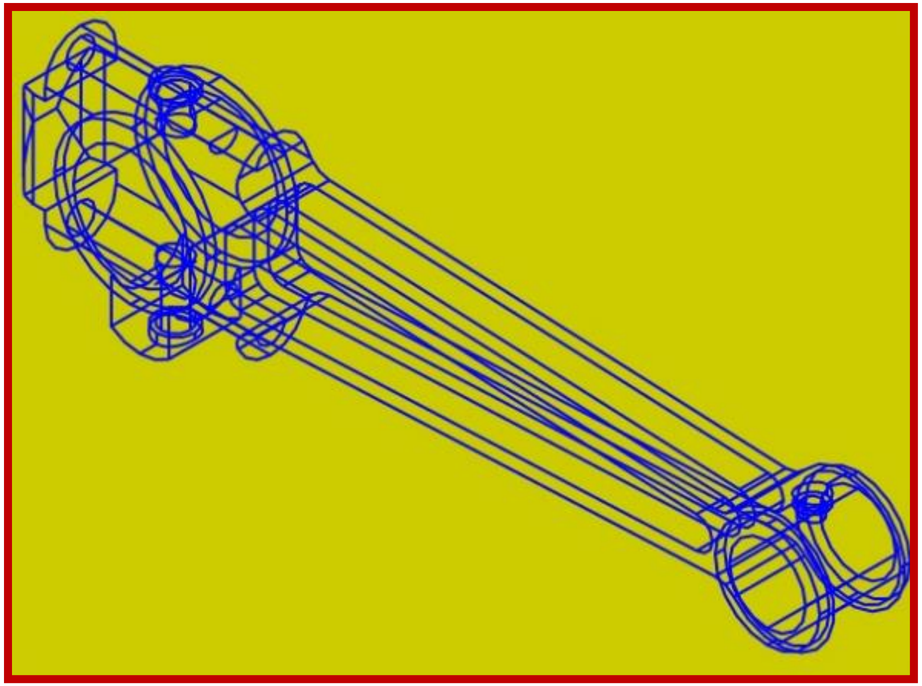
Displaying holes and curved ends in wireframe models

Wireframe Model

- Contains information about the locations of all the points (vertices) and edges in space coordinates.
- Each vertex is defined by x, y, z coordinate.
- Edges are defined by a pair of vertices.
- Faces are defined as three or more edges.
- Wireframe is a collection of edges, there is no skin defining the area between the edges.



Wireframe Model



Advantages

- Can quickly and efficiently convey information than multiview drawings.
- The only lines seen are the intersections of surfaces.
- Can be used for finite element analysis.
- Can be used as input for CNC machines to generate simple parts.
- Contain most of the information needed to create surface, solid and higher order models

Disadvantages

- Geometric entities are lines and curves in 3D
- Volume or surfaces of object not defined
- Easy to store and display
- Hard to interpret – ambiguous
- Hidden lines are not removed
- For complex items, the result can be a jumble of lines that is impossible to determine.
- No ability to determine computationally information such as the line of intersect between two faces of intersecting models.

GEOMETRIC MODELS

Surface Modeling

Surface modeling is more sophisticated than wireframe modeling in that it defines not only the edges of a 3D object, but also its surfaces.

In surface modeling, objects are defined by their bounding faces.

SURFACE ENTITIES

Similar to wireframe entities, existing CAD/CAM systems provide designers with both analytic and synthetic surface entities.

Analytic entities include :

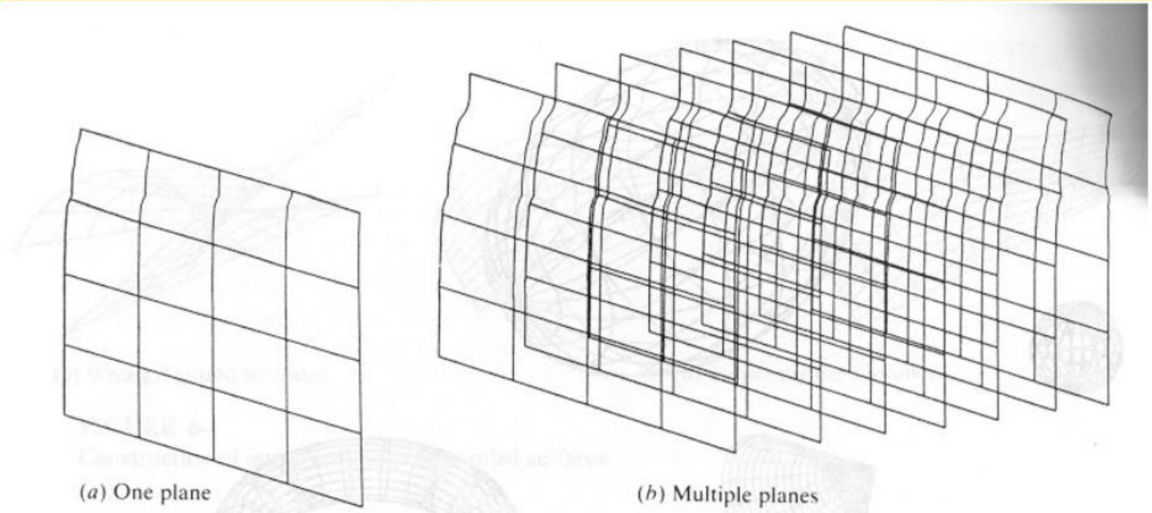
- Plane surface,
- Ruled surface,
- Surface of revolution, and
- Tabulated cylinder.

Synthetic entities include

- The bicubic Hermite spline surface,
- B-spline surface,
- Rectangular and triangular Bezier patches,
- Rectangular and triangular Coons patches, and
- Gordon surface.

GEOMETRIC MODELS

Plane surface. This is the simplest surface. It requires three noncoincident points to define an infinite plane.



(*a*) One plane (*b*) Multiple planes

Ruled (lofted) surface. This is a linear surface. It interpolates linearly between two boundary curves that define the surface (rails). Rails can be any wireframe entity. This **entity is ideal to represent surfaces that do not have any twists or kinks.**

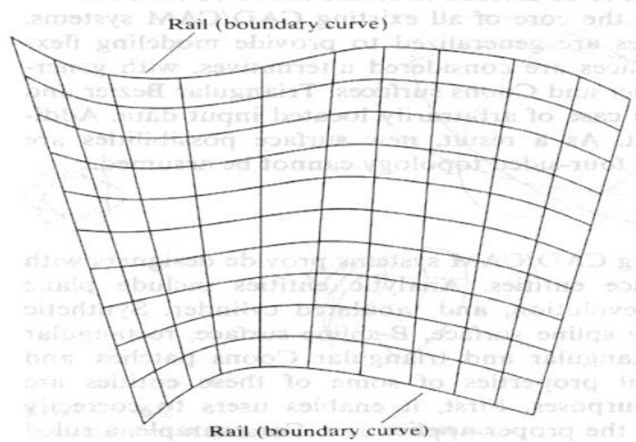


FIGURE 6-5
Ruled surface.

GEOMETRIC MODELS

Surface of revolution. This is an axisymmetric surface that can model axisymmetric objects. It is generated by rotating a planar wireframe entity in space about the axis of symmetry a certain angle.

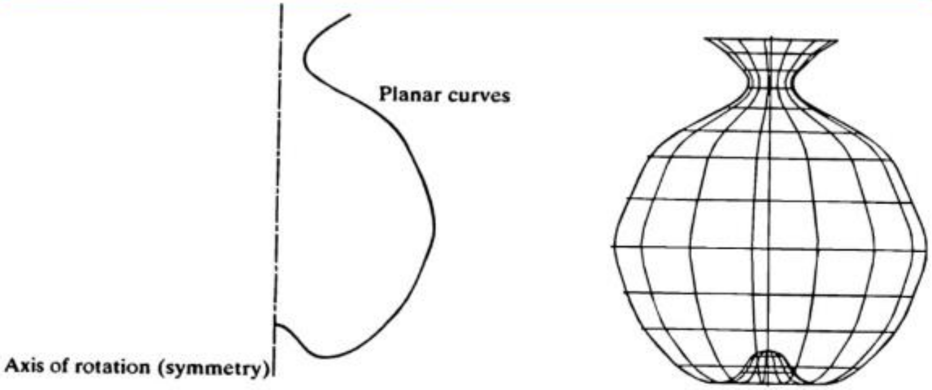


FIGURE 6-6
Surface of revolution.

Tabulated cylinder. This is a surface generated by translating a planar curve a certain distance along a specified direction (axis of the cylinder).

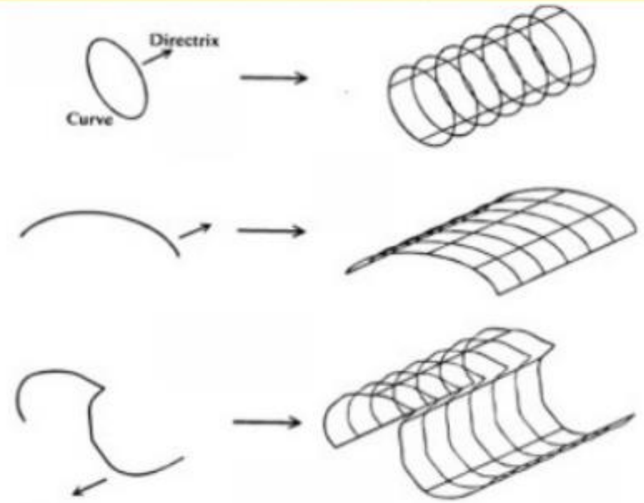
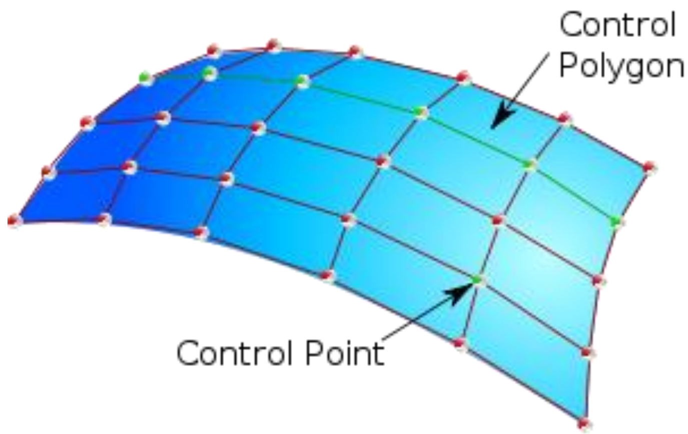


FIGURE 6-7
Tabulated cylinder.

GEOMETRIC MODELS



Bezier surface. This is a surface that approximates given input data. It is different from the previous surfaces in that it is a synthetic surface. Similarly to the Bezier curve, it does not pass through all given data points. It is a general surface that permits, twists, and kinks . The Bezier surface allows only global control of the surface.

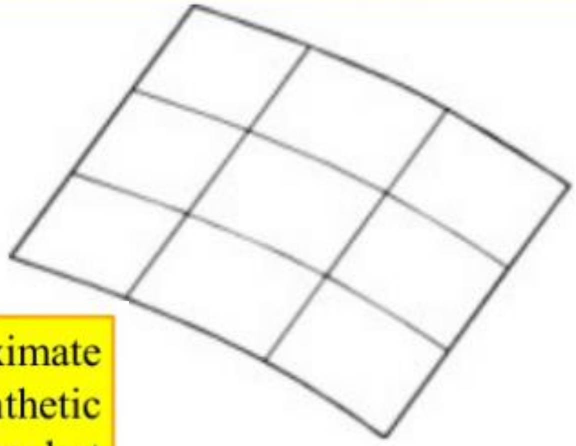
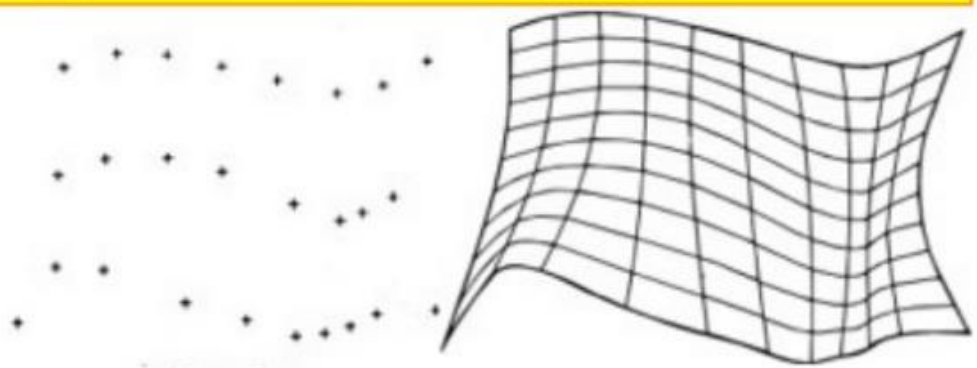


FIGURE 6-8
Bezier surface.

B-spline surface. This is a surface that can approximate or interpolate given input data (Fig. 6-9). It is a synthetic surface. It is a general surface like the Bezier surface but with the advantage of permitting local control of the surface.



(a) Data points

GEOMETRIC MODELS

Need for Solid Modeling

Recall weakness of wireframe and surface modeling

- Ambiguous geometric description
- incomplete geometric description
- lack topological information
- Tedious modeling process
- Awkward user interface

What is Solid Modeling

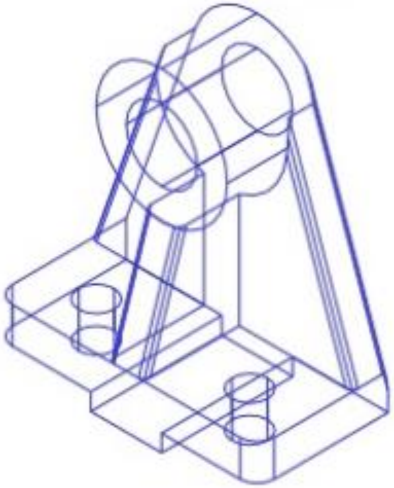
Solid modeling is based on *complete, valid and unambiguous* geometric representation of physical object.

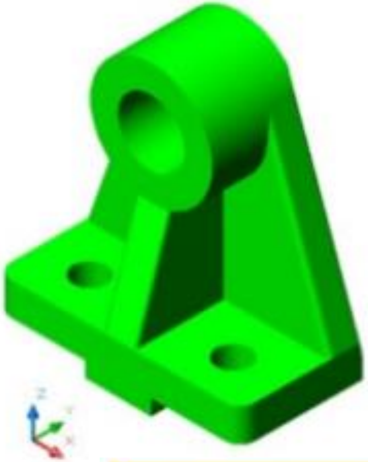
- Complete → points in space can be classified. (inside/ outside)
- Valid →vertices, edges, faces are connected properly.
- Unambiguous → there can only be one interpretation of object

GEOMETRIC MODELS

Solid Modeling

Solid models give designers a complete descriptions of constructs, shape, surface, volume, and density.



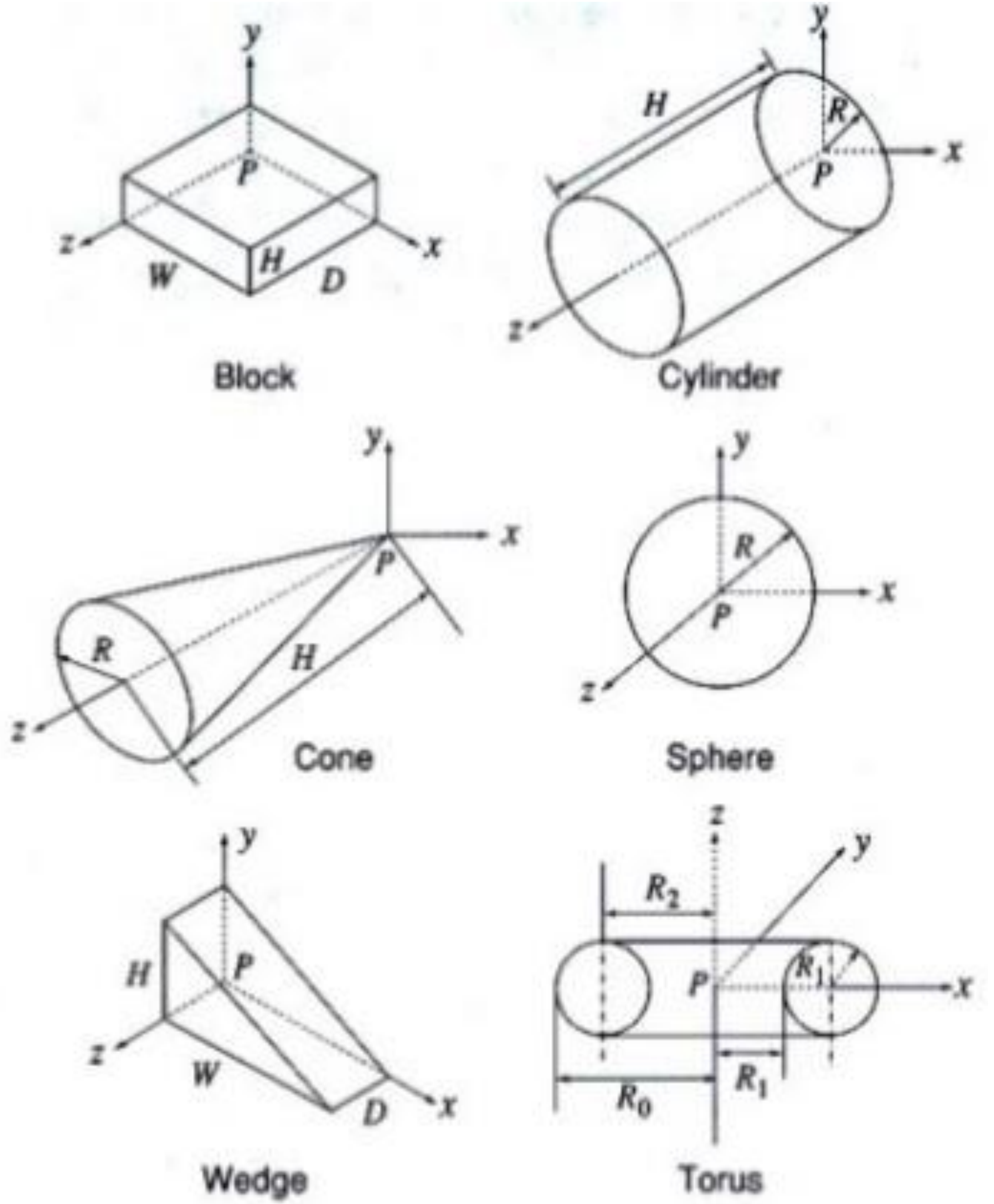


In CAD systems there are a number of representation schemes for solid modeling include:

- Primitive creation functions.
- Constructive Solid Geometry (CSG)
- Sweeping
- Boundary Representation (B-rep)

GEOMETRIC MODELS

Primitive creation functions:
These functions retrieve a solid of a simple shape from among the primitive solids stored in the program in advance and create a solid of the same shape but of the size specified by the user.

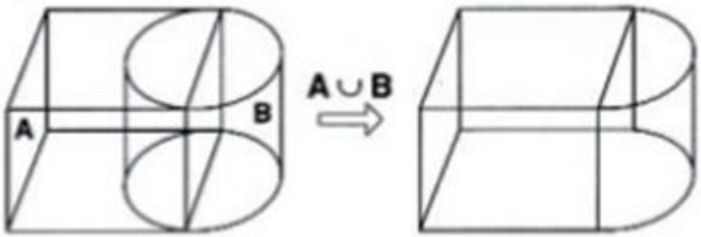


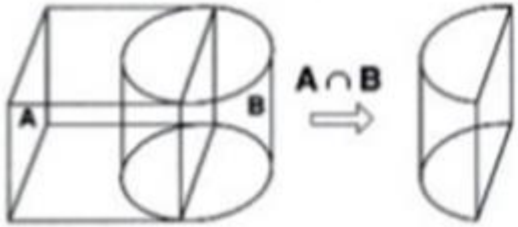
GEOMETRIC MODELS

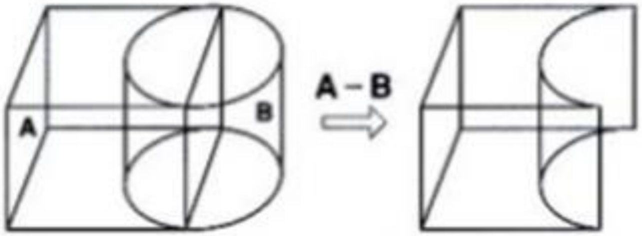
CSG - Solid Modeling

- Objects are represented as a combination of simpler solid objects (*primitives*).
- The primitives are such as cube, cylinder, cone, torus, sphere etc.
- Copies or “instances” of these primitive shapes are created and positioned.
- A complete solid model is constructed by combining these “instances” using set specific, logic operations (Boolean)
- Boolean operation
  - each primitive solid is assumed to be a set of points, a boolean operation is performed on point sets and the result is a solid model.
  - Boolean operation → union, intersection and difference
  - The relative location and orientation of the two primitives have to be defined before the boolean operation can be performed.
  - Boolean operation can be applied to two solids other than the primitives.

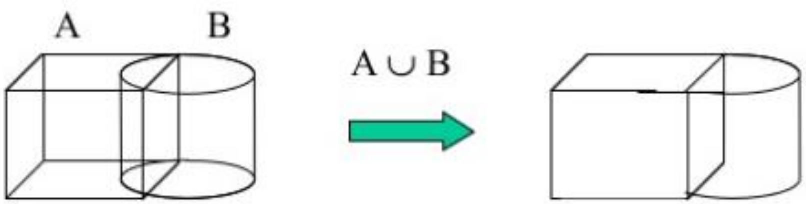
CSG uses primitive shapes as building blocks and Boolean set operators (U union, difference, and ∩ intersection) to construct an object.



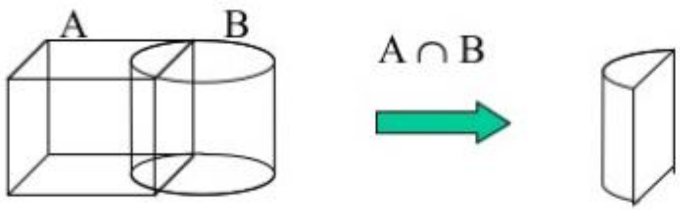




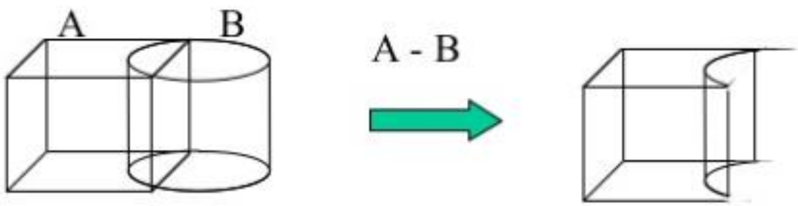
- Union
  - The sum of all points in each of two defined sets. (logical "OR")
  - Also referred to as Add, Combine, Join, Merge



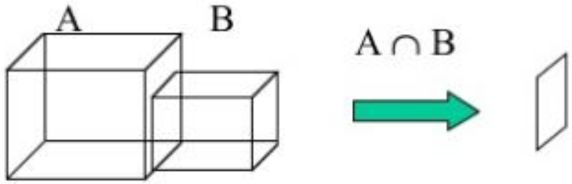
- intersection
  - Those points common to each of two defined sets (logical "AND")
  - Set must share common volume
  - Also referred to as common, conjoin



- Difference
  - The points in a source set minus the points common to a second set. (logical "NOT")
  - Set must share common volume
  - Also referred to as subtraction, remove, cut



- When using boolean operation, be careful to avoid situation that do not result in a valid solid



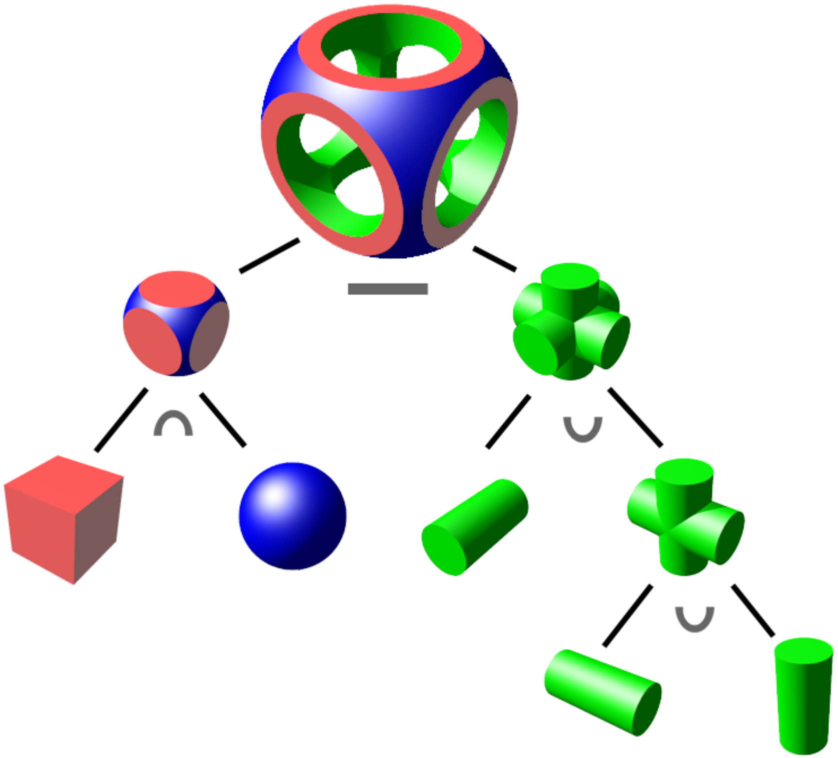
GEOMETRIC MODELS

- Boolean operation
  - Are intuitive to user
  - Are easy to use and understand
  - Provide for the rapid manipulation of large amounts of data.
- Because of this, many non-CSG systems also use Boolean operations

- CSG tree → stores the history of applying boolean operations on the primitives.
  - Stores in a binary tree format
  - The outer leaf nodes of tree represent the primitives
  - The interior nodes represent the boolean operations performed.

(CSG)- data structure

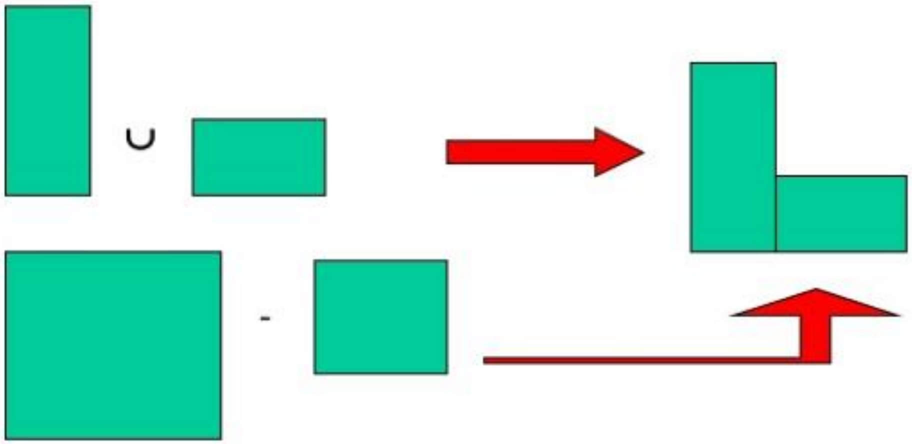
- Data structure does not define model shape explicitly but rather implies the geometric shape through a procedural description
  - E.g: object is not defined as a set of edges & faces but by the instruction : *union primitive1 with primitive 2*
- This procedural data is stored in a data structure referred to as a CSG tree
- The data structure is simple and stores compact data → easy to manage



GEOMETRIC MODELS

(CSG)- not unique

- More than one procedure (and hence database) can be used to arrive at the same geometry.



(CSG) - advantage

- CSG is powerful with high level command.
- Easy to construct a solid model – minimum step.
- CSG modeling techniques lead to a concise database→ less storage.
  - Complete history of model is retained and can be altered at any point.
- Can be converted to the corresponding boundary representation.

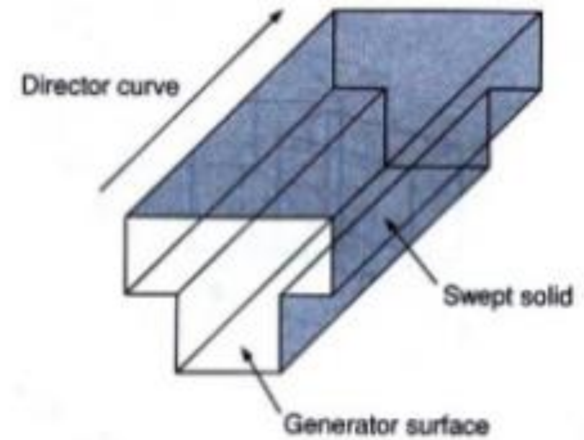
- CSG representation is unevaluated
  - Faces, edges, vertices not defined in explicit
- CSG model are always valid
  - Since built from solid elements.
- CSG models are complete and unambiguous

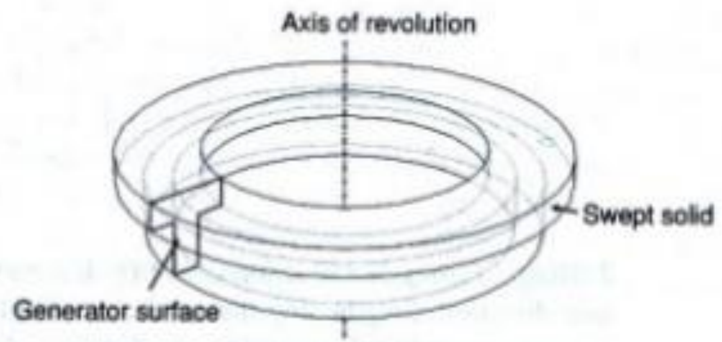
(CSG) - disadvantage

- Only boolean operations are allowed in the modeling process → with boolean operation alone, the range of shapes to be modeled is severely restricted → not possible to construct unusual shape.
- Requires a great deal of computation to derive the information on the boundary, faces and edges which is important for the interactive display/ manipulation of solid.

Sweeping

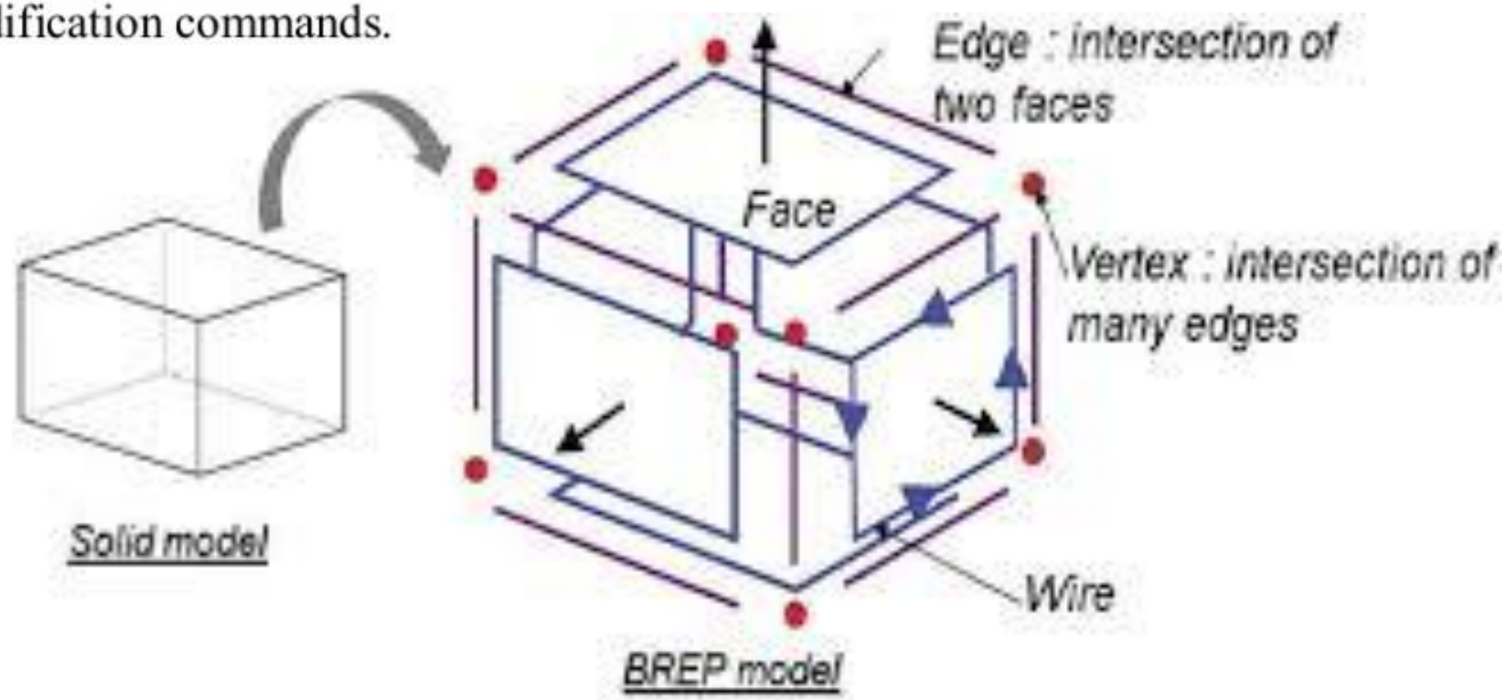
Sweeping *Sweeping* is a modeling function in which a planar closed domain is translated or revolved to form a solid. When the planar domain is translated, the modeling activity is called *translational sweeping;* when the planar region is revolved, it is called *swinging, or rotational sweeping*.





B-Rep vs surface modeling

- Surface model
  - A collection of surface entities which simply enclose a volume lacks the connective data to define a solid (i.e topology).
- B- Rep model
  - Technique guarantees that surfaces definitively divide model space into solid and void, even after model modification commands.

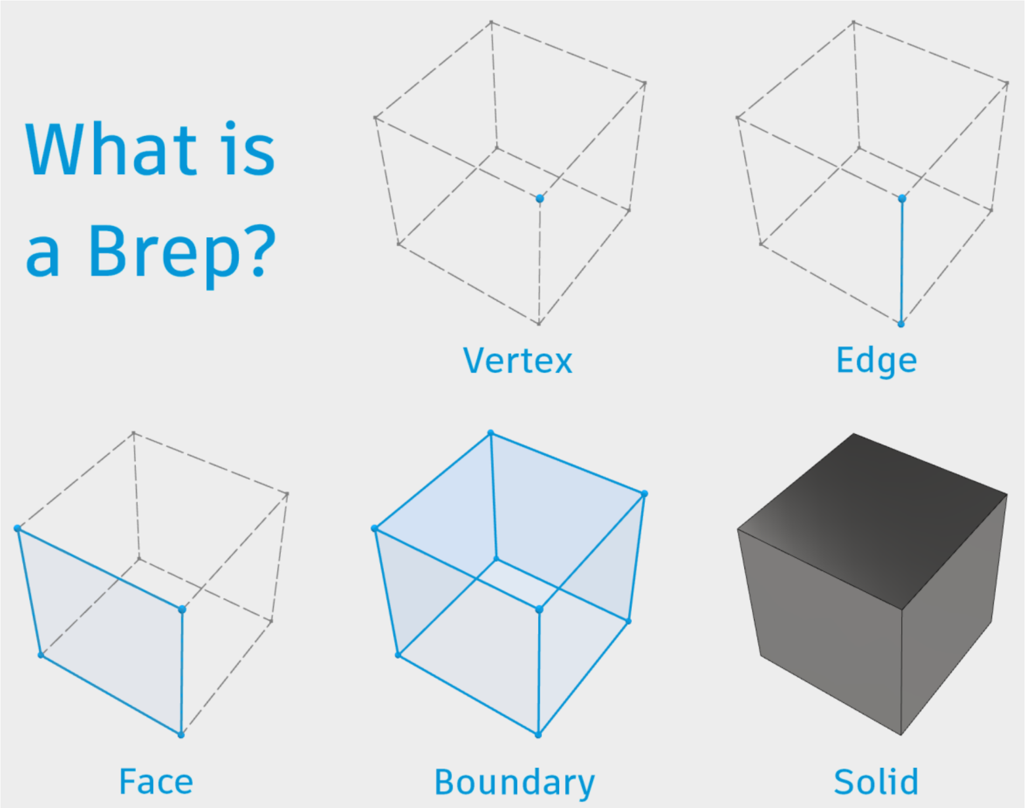


Boundary Representation

Objects are represented by their bounded faces.

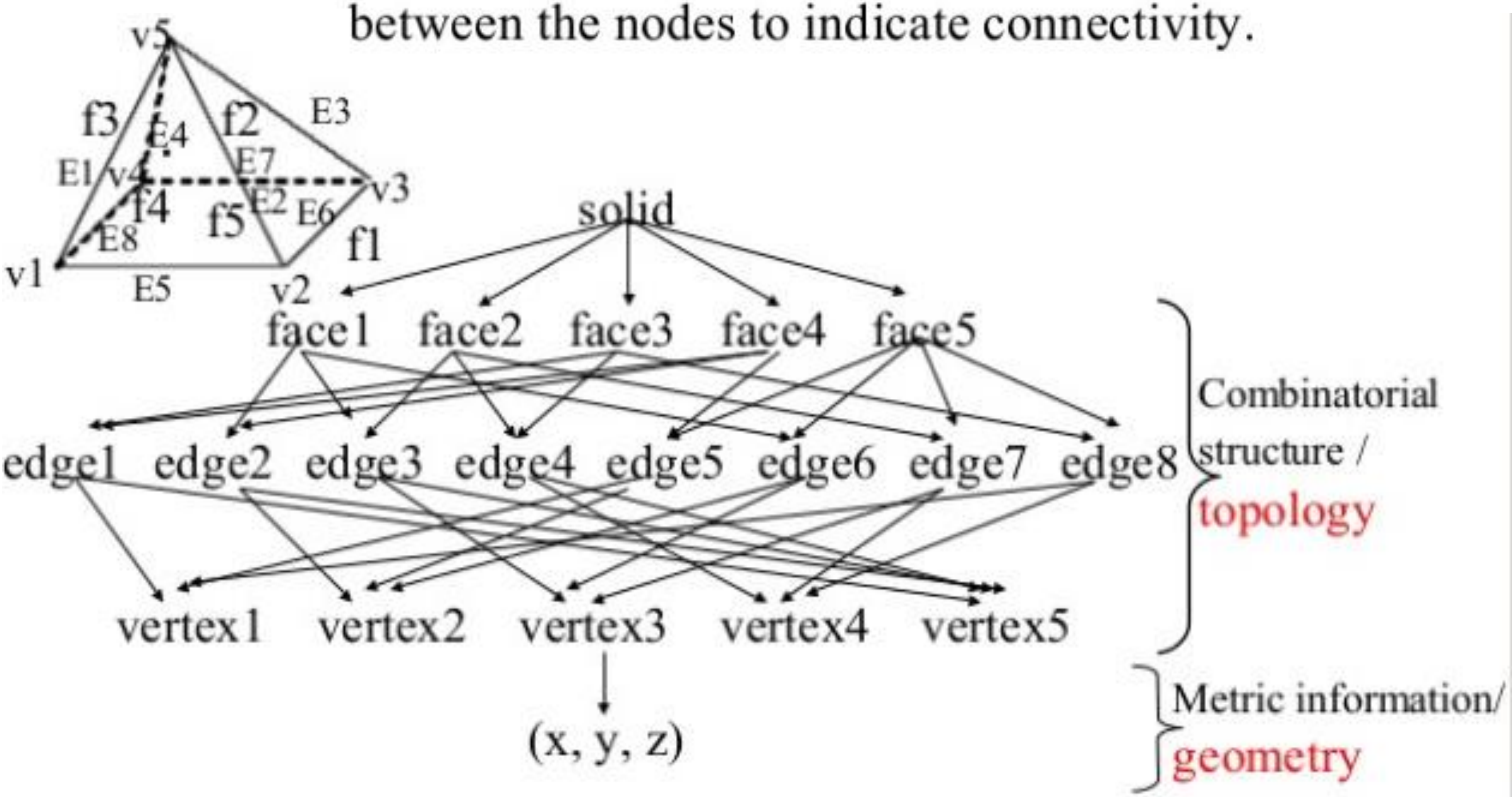
Solid model is defined by their enclosing surfaces or boundaries. This technique consists of the geometric information about the faces, edges and vertices of an object with the topological data on how these are connected.

- Why B-Rep includes such topological information?
  - A solid is represented as a closed space in 3D space (surface connect without gaps)
  - The boundary of a solid separates points inside from points outside solid.



B-Rep data structure

- B-Rep graph store face, edge and vertices as nodes, with pointers, or branches between the nodes to indicate connectivity.



B-Rep Data Structure

Three tables for storing B-Rep

Face Table

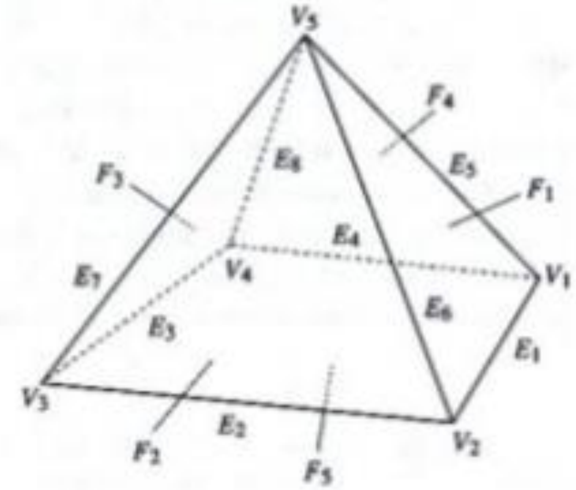
Face	*Edges*
F_1	E_1, E_5, E_6
F_2	E_2, E_6, E_7
F_3	E_3, E_7, E_8
F_4	E_4, E_8, E_5
F_5	E_1, E_2, E_3, E_4

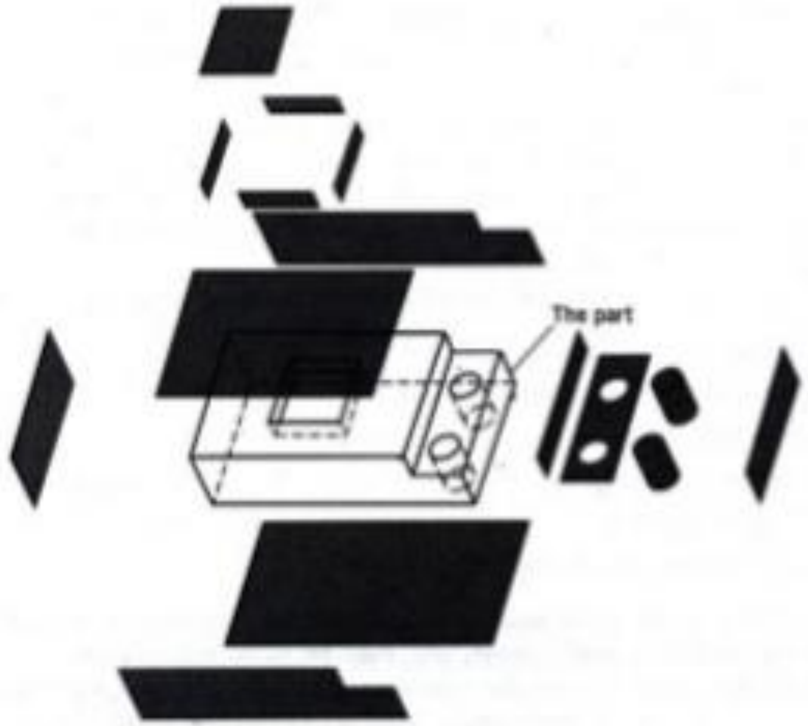
Edge Table

Edge	*Vertices*
E_1	V_1, V_2
E_2	V_2, V_3
E_3	V_3, V_4
E_4	V_4, V_1
E_5	V_1, V_5
E_6	V_2, V_5
E_7	V_3, V_5
E_8	V_4, V_5

Vertex Table

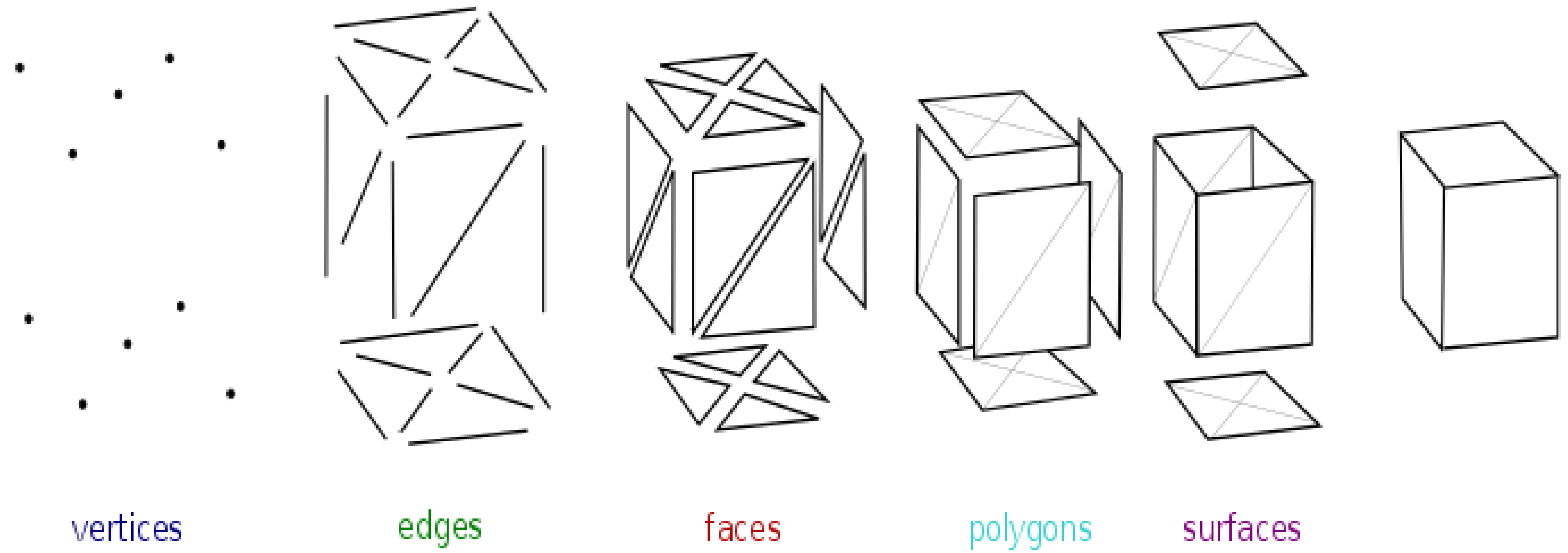
Vertex	*Coordinates*
V_1	x_1, y_1, z_1
V_2	x_2, y_2, z_2
V_3	x_3, y_3, z_3
V_4	x_4, y_4, z_4
V_5	x_5, y_5, z_5
V_6	x_6, y_6, z_6





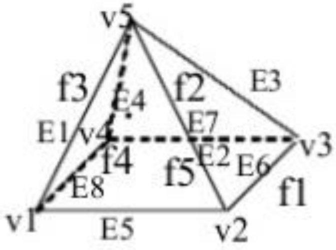
Boundary representation- validity

- System must validate topology of created solid.
- B-Rep has to fulfill certain conditions to disallow self-intersecting and open objects
- This condition include
  - Each edge should adjoin exactly two faces an have a vertex at each end.
  - Vertices are geometrically described by point coordinates
- This condition include (cont)
  - At least three edges must meet at each vertex.
  - Faces are described by surface equations
  - The set of faces forms a complete skin of the solid with no missing parts.
  - Each face is bordered by an ordered set of edges forming a closed loop.
  - Faces must only intersect at common edges or vertices.
  - The boundaries of faces do not intersect themselves



Boundary representation- validity

- Validity also checked through mathematical evaluation
  - Evaluation is based upon Euler's Law (valid for simple polyhedra – no hole)
  - V – E + F = 2   V-vertices E- edges   F- face loops

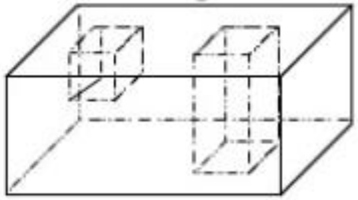


V = 5, E = 8, F = 5

5 – 8 + 5 = 2

Boundary representation- validity

- Expanded Euler's law for complex polyhedrons (with holes)
- Euler-Poincare Law:
  - V-E+F-H=2(B-P)
  - H – number of holes in face, P- number of passages or through holes, B- number of separate bodies.



V = 24, E=36, F=15, H=3, P=1,B=1

Boundary representation- ambiguity and uniqueness

- Valid B-Reps are unambiguos
- Not fully unique, but much more so than CSG
- Potential difference exists in division of
  - Surfaces into faces.
  - Curves into edges

Boundary representation- advantages

- Capability to construct unusual shapes that would not be possible with the available CSG→ aircraft fuselages, swing shapes
- Less computational time to reconstruct the image

disadvantages

- Requires more storage
- More prone to validity failure than CSG
- Model display limited to planar faces and linear edges

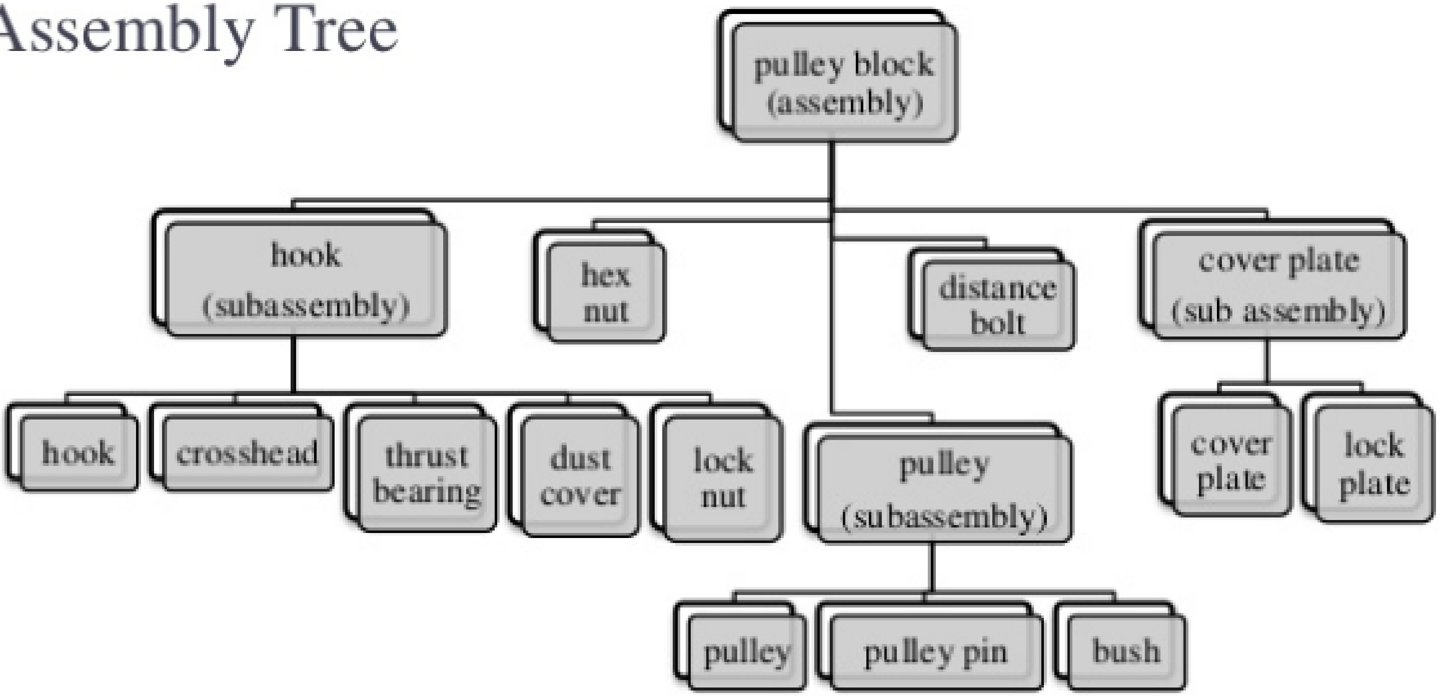
  - complex curve and surfaces only approximated

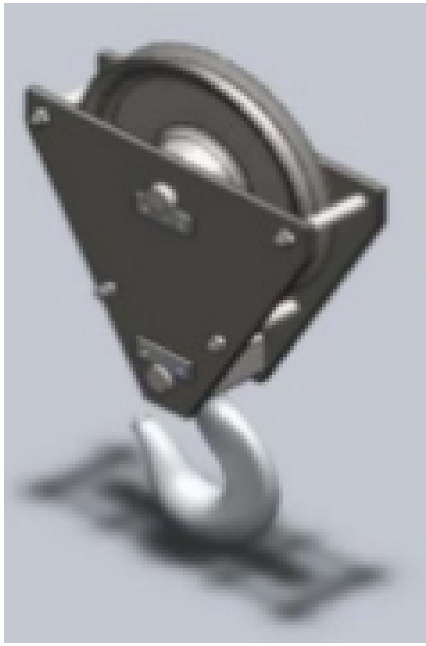
ASSEMBLY MODELS

- Assembly modeling is a combination of two or more components using parametric relationships.
- Typically a designer would start with a base part
- Add other components to the **base part** using merge commands.

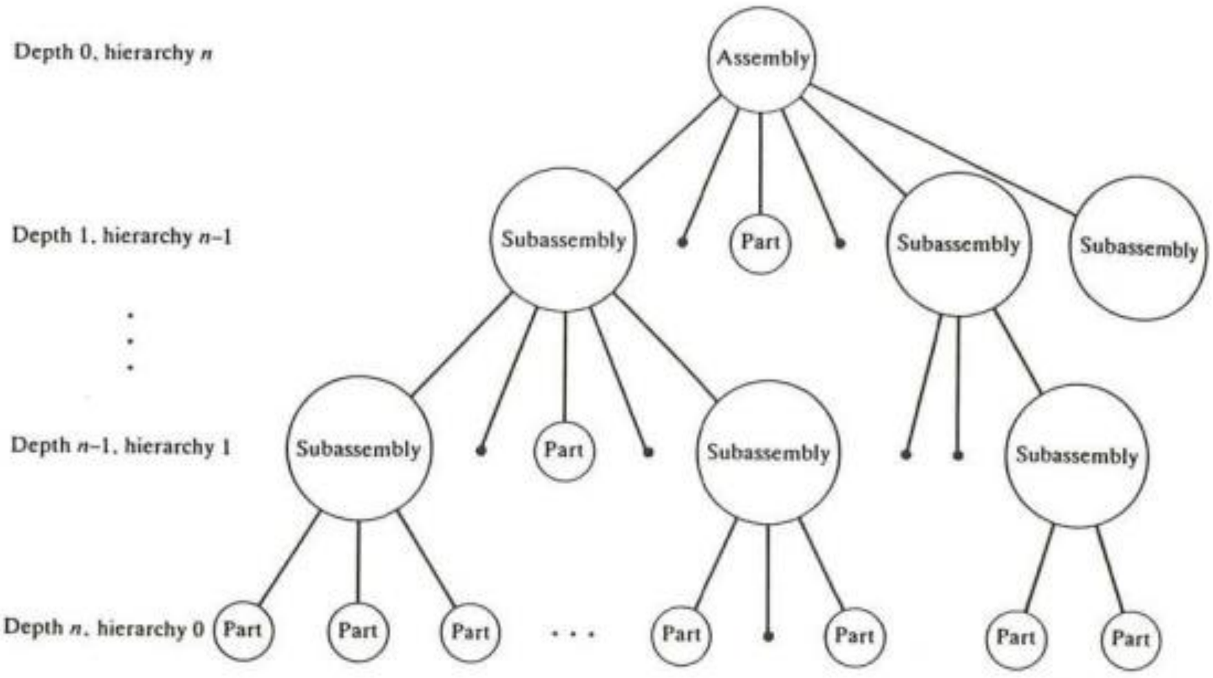
An exploded view consists of series of steps. One can create steps by selecting and dragging parts in graphical area.

Assembly Tree

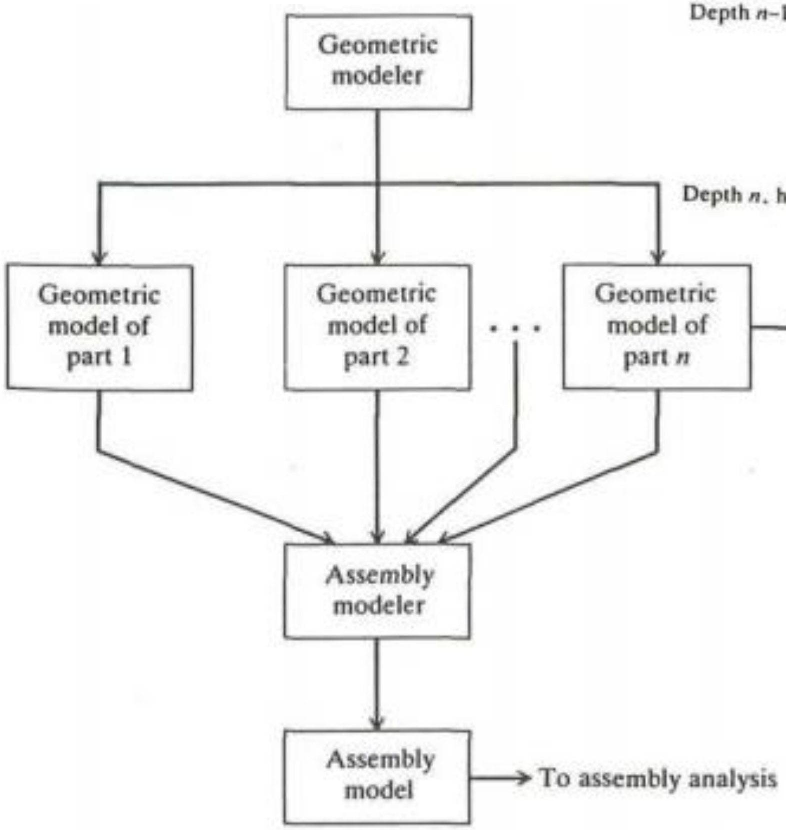




ASSEMBLY MODELS



Assembly Tree

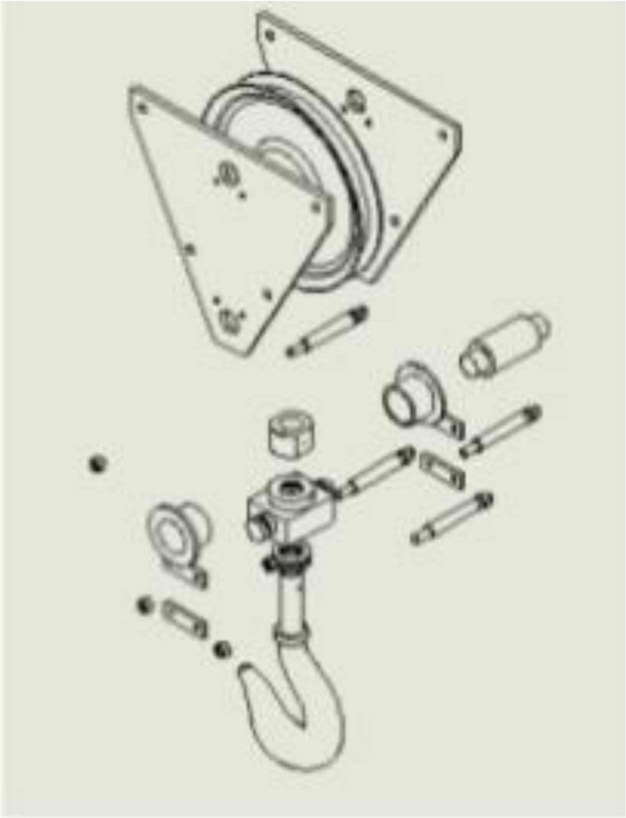


Geometric and Assembly Modelers

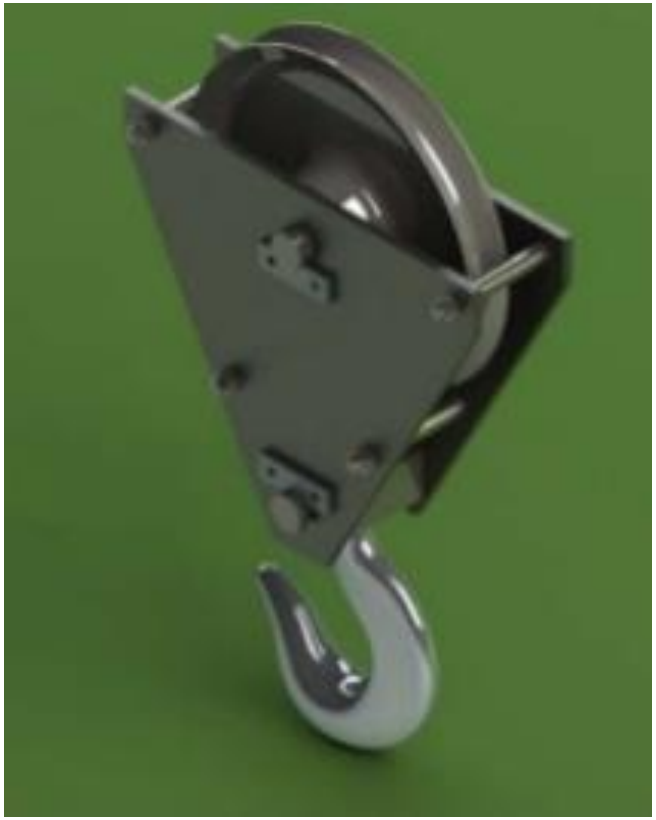
ASSEMBLY MODELS

Assembly of Pulley block

Exploded view



Assembly view



Assembly Approaches

- Bottom-Up Assembly Approach
- Top-Down Assembly Approach

Bottom-Up Assembly Approach

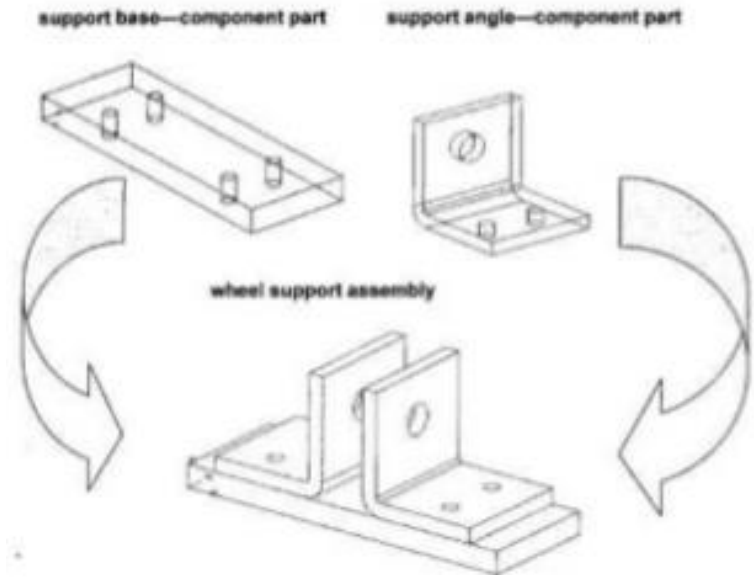
- The individual parts a created independently, inserted into the assembly, and located and oriented (using the mating conditions) as required by the design.
- The bottom-up-approach is the preferred technique if the parts have already been createc (off the shelf).
- It allows the designer to focus on the individual parts. It also makes it easier to maintain the relationships and regeneration behaviour of parts than in the top-down approach.

Top-Down Assembly Approach

- In this approach, the assembly file is created first with an assembly layout sketch.
- The parts are made in the assembly file or the concept drawing of the parts are inserted and finalized in the assembly file.
- In other words, the final geometry of the parts have not been defined before bringing them into the assembly file. The approach is ideal for large assemblies.

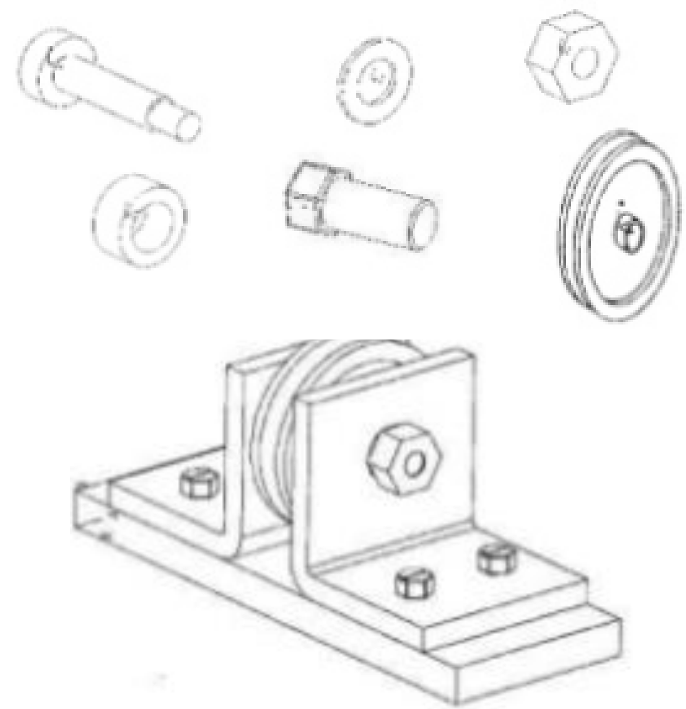
ASSEMBLY MODELS

Bottom-up assembly approach -:



- Allows the designer to use part drawings that already exist (off the shelf).
- Provides the designer with more control over individual parts.
- Multiple copies (instances) of parts can be inserted into the assembly.

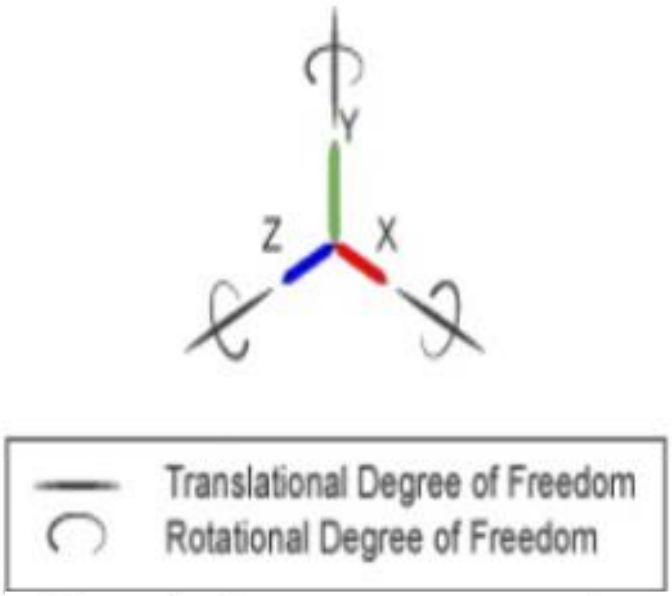
Top-down assembly approach -:



- The approach is ideal for large assemblies consisting of thousands of parts.
- The approach is used to deal with large designs including multiple design teams.
- It lends itself well to the conceptual design phase
- E.g. :
  - Piping and fittings
  - Welds
  - Lock pins

ASSEMBLY MODELS

Degrees of freedom



- **Translation** – movement along X, Y, and Z axis.
- **Rotation** – rotate about X, Y, and Z axis.

Mating conditions

Basic mates

- Coincidence
- Parallel
- Perpendicular
- Tangent
- Concentric
- Lock
- Angle
- Distance

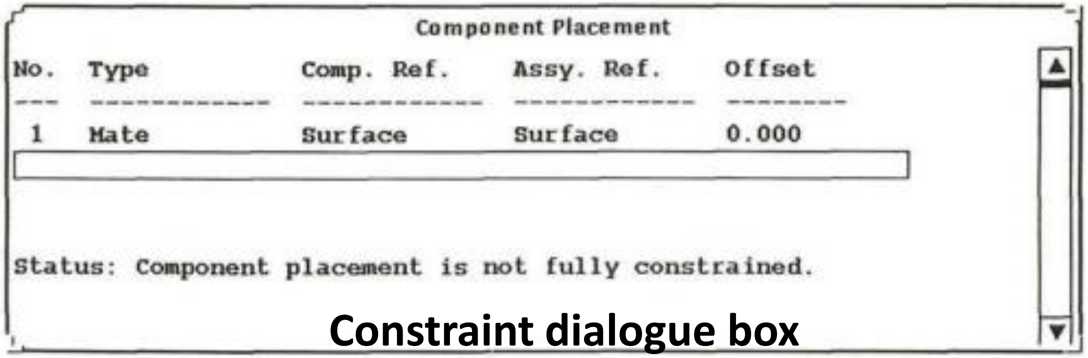
Advanced Mates

- Distance
- Linear/linear coplanar
- Path
- Width
- Symmetry
- Angle

Mechanical mates:

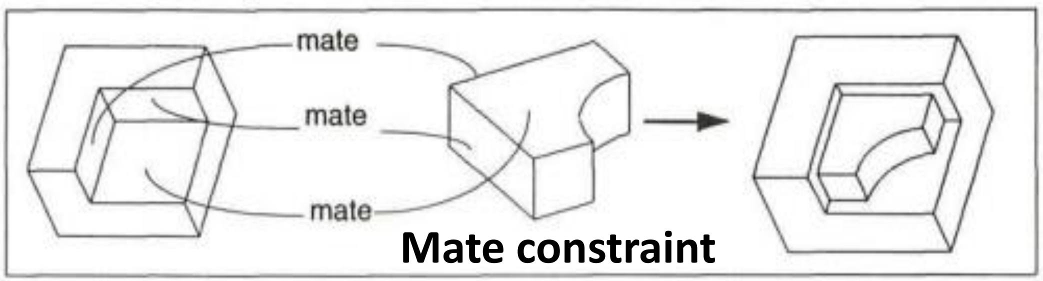
- Cam
- Hinge
- Gear
- Rack Pinion
- Screw
- Universal Joint

ASSEMBLY MODELS



Constraint dialogue box

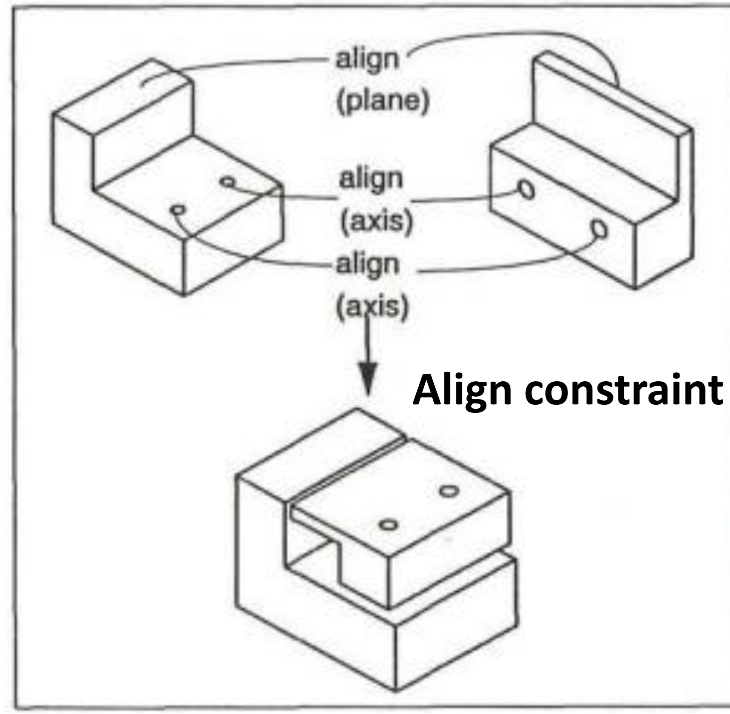
Constraint dialogue box opens up and apprises the user as to whether the part is fully constrained. Component parts have to be fully constrained before the assembly modeler can generate an unambiguous assembly model



Mate constraint

Mate and Mate Offset: The mate option permits two surfaces to touch one another, i.e. the two surfaces would become coincident and facing each other

In the case of the mate offset option, the two mating surfaces are separated by a distance equal to the user-specified offset value.



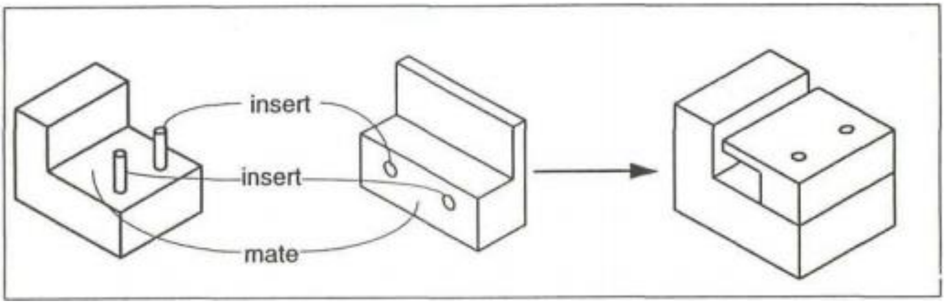
Align constraint

Align and Align Offset: The align option causes two planar surfaces to become coplanar, coincident and facing in the same direction as shown below. Using this option, revolved surfaces or axes can also be made coaxial.

The offset option aligns two surfaces and permits the two to be offset by a user-specified distance.

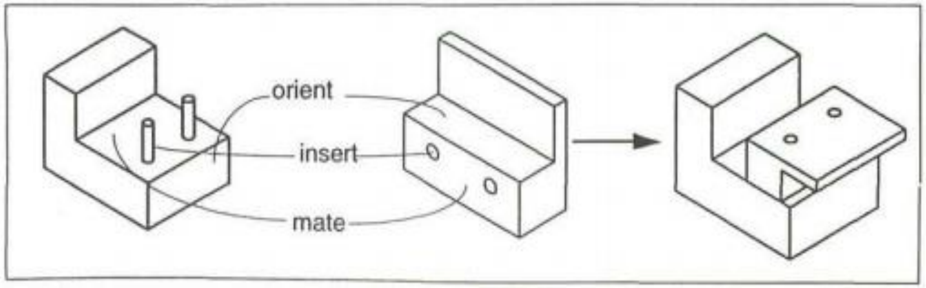
ASSEMBLY MODELS

Insert constraint



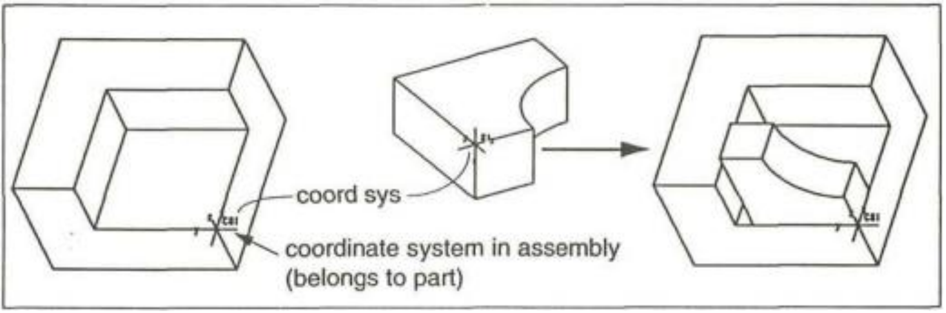
This option is used to insert a "male" revolved surface into a "female" revolved surface and aligns their respective axes

Orient constraint



Orient: The orient option causes two planar surfaces to become parallel and face each other

Coord sys constraint



Coord Sys: This option assembles a part onto the assembly by aligning their local coordinate system origins

GRAPHICS STANDARDS

Need for CAD data standardization

- Incompatibility among representations
- Complex CAD/CAM systems
- Shape, non-shape, design and manufacturing data
- Need to integrate and automate design and manufacturing processes to obtain maximum benefits from CAD/CAM systems
- Direct translators and neutral formats

- **GKS** (Graphical Kernel Systems)
- **PHIGS** (Programmer's Hierarchical Interface for Graphics)
- **CORE** (ACM-SIGGRAPH)
- **GKS-3D**
- **IGES** (Initial Graphics Exchange Specification)
- **DXF** (Drawing Exchange Format)
- **STEP** (Standard for the Exchange of Product Model Data)
- **DMIS** (Dimensional Measurement Interface Specification)
- **VDI** (Virtual Device Interface)
- **VDM** (Virtual Device Metafile)
- **GKSM** (GKS Metafile)
- **NAPLPS** North American Presentation Level Protocol Syntax)

GRAPHICS STANDARDS

As a result of these international organization efforts, various standard functions at various levels of the graphics system developed. These are:

1. IGES (Initial Graphics Exchange Specification) enables an exchange of model data basis among. CAD system

2. DXF (Drawing / Data Exchange Format) file format was meant to provide an exact representation of the data in the standard CAD file format.

3. STEP (Standard for the Exchange of Product model data) can be used to exchange data between CAD, Computer Aided Manufacturing (CAM) , Computer Aided Engineering (CAE) , product data management/enterprise data modeling (PDES) and other CAD systems.

4. CALS (Computer Aided Acquisition and Logistic Support) is an US Department of Defense initiative with the aim of applying computer technology in Logistic support.

5. GKS (Graphics Kernel System) provides a set of drawing features for two-dimensional vector graphics suitable for charting and similar duties.

6. PHIGS (Programmer's Hierarchical Interactive Graphic System) The PHIGS standard defines a set of functions and data structures to be used by a programmer to manipulate and display 3-D graphical objects.

7. VDI (Virtual Device Interface) lies between GKS or PHIGS and the device driver code. VDI is now called CGI (Computer Graphics Interface).

8. VDM (Virtual Device Metafile) can be stored or transmitted from graphics device to another. VDM is now called CGM (Computer Graphics Metafile).

9. NAPLPS (North American Presentation- Level Protocol Syntax) describes text and graphics in the form of sequences of bytes in ASCII code.

GRAPHICS STANDARDS

The heart of any CAD model is the component database. This includes the graphics entities like points, lines, arcs, circles etc. and the co-ordinate points, which define the location of these entities. This geometric data is used in all downstream applications of CAD, which include finite element modeling and analysis, process planning, estimation, CNC programming, robot programming, programming of co-ordinate measuring machines, ERP system programming and simulation.

In order to achieve at least a reasonably high level of integration between CAD, analysis and manufacturing operations, the component database must contain:

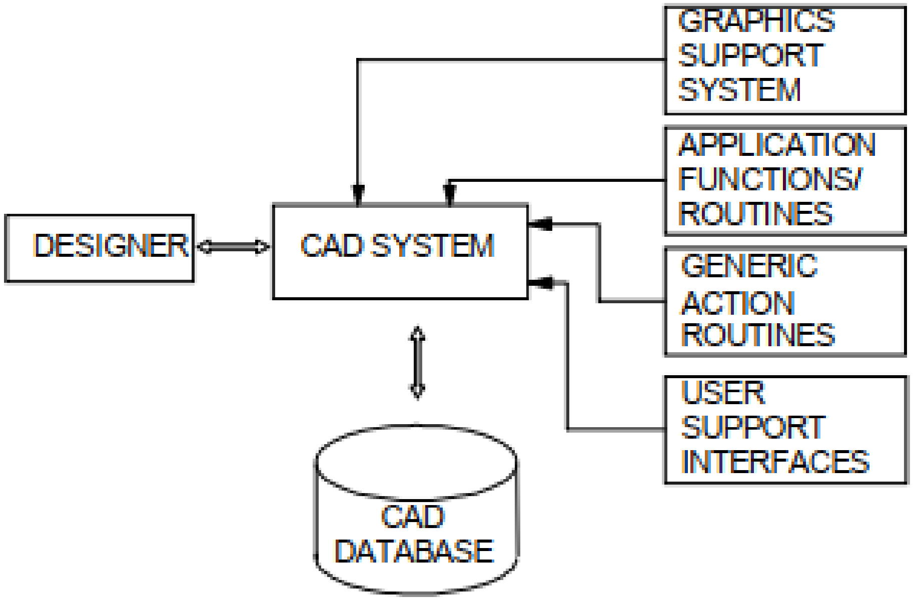
i. Shapes of the components (based on solid models)
ii. Bill of materials (BOM), of the assembly in which the components are used.
iii. Material of the components
iv. Manufacturing, test and assembly procedures to be carried out to produce a component so that it is capable of functioning as per the requirements of design.

GRAPHICS STANDARDS

In designing a data structure for CAD database the following factors are to be considered:

i. The data must be neutral
ii. The data structure must be user-friendly
iii. The data must be portable.

In order to achieve the above requirements, some type of standardization has to be followed by the CAD software designers. The basic elements associated with a CAD system are:



CAD System

- Operator (user)
- Graphics support system
- Other user interface support system
- Application functions
- Database

A diagrammatic presentation of these elements is given in Figure

GRAPHICS STANDARDS

The reasons for evolving a graphic standard thus include:

- Need for exchanging graphic data between different computer systems.
- Need for a clear distinction between modeling and reviewing aspects.

STANDARDS FOR GRAPHICS PROGRAMMING

Attempts to develop a graphics standard resulted in the following developments in 70's:

i. A Graphic Standards Planning Committee (GSPC) was formed in 1974 by ACM-SIGGRAPH (Association of Computing Machinery's Special Interest Group on Graphics and Interactive Techniques).

ii. A committee for the development of computer graphics standard was formed by DIN in 1975.

iii. IFIP organized a workshop on Methodology in Computer Graphics in 1976.

iv. A significant development in CAD standards is the publication of Graphical Kernel System (GKS) in 1982.

GRAPHICS STANDARDS

GKS (Graphical Kernel System) is an ANSI and ISO standard. **GKS** standardizes two-dimensional graphics functionality at a relatively low level. The primary purposes of the standard are:

- To provide for portability of graphics application programs.
- To aid in the understanding of graphics method by application programmers.
- To provide guidelines for manufacturers in describing useful graphics capabilities.

The **GKS (**ANSI X3.124-1985*)* consists of three basic parts:

i. An informal exposition of contents of the standard, which includes such things as positioning of text, filling of polygons etc.

ii. A formalization of the expository material outlined in (i) by way of abstracting the ideas into functional descriptions (input/output parameters, effect of each function etc.).

iii. Language bindings, which are the implementations of the abstract functions, described in (ii) in a specific computer language like FORTRAN, Ada or C.

FEATURES OF GKS

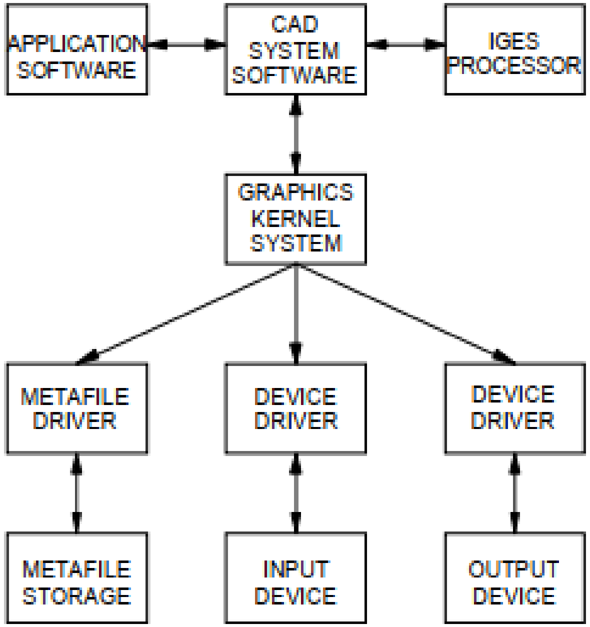
i. Device independence: The standard does not assume that the input or output devices have any particular features or restrictions.

ii. Text/Annotations: All text or annotations are in a natural language like English.

iii. Display management: A complete suite of display management functions, cursor control and other features are provided.

iv. Graphics Functions: Graphics functions are defined in 2D or 3D.

The drivers in GKS also include metafile drivers. Metafiles are devices with no graphic capability like a disc unit. The GKS always works in a rectangular window or world co-ordinate system. The window also defines a scaling factor used to map the created picture into the internal co-ordinate system of GKS called normalized device co-ordinates. Windows and view ports can then work in this co-ordinate system.



GKS Implementation in a CAD Workstation

GRAPHICS STANDARDS

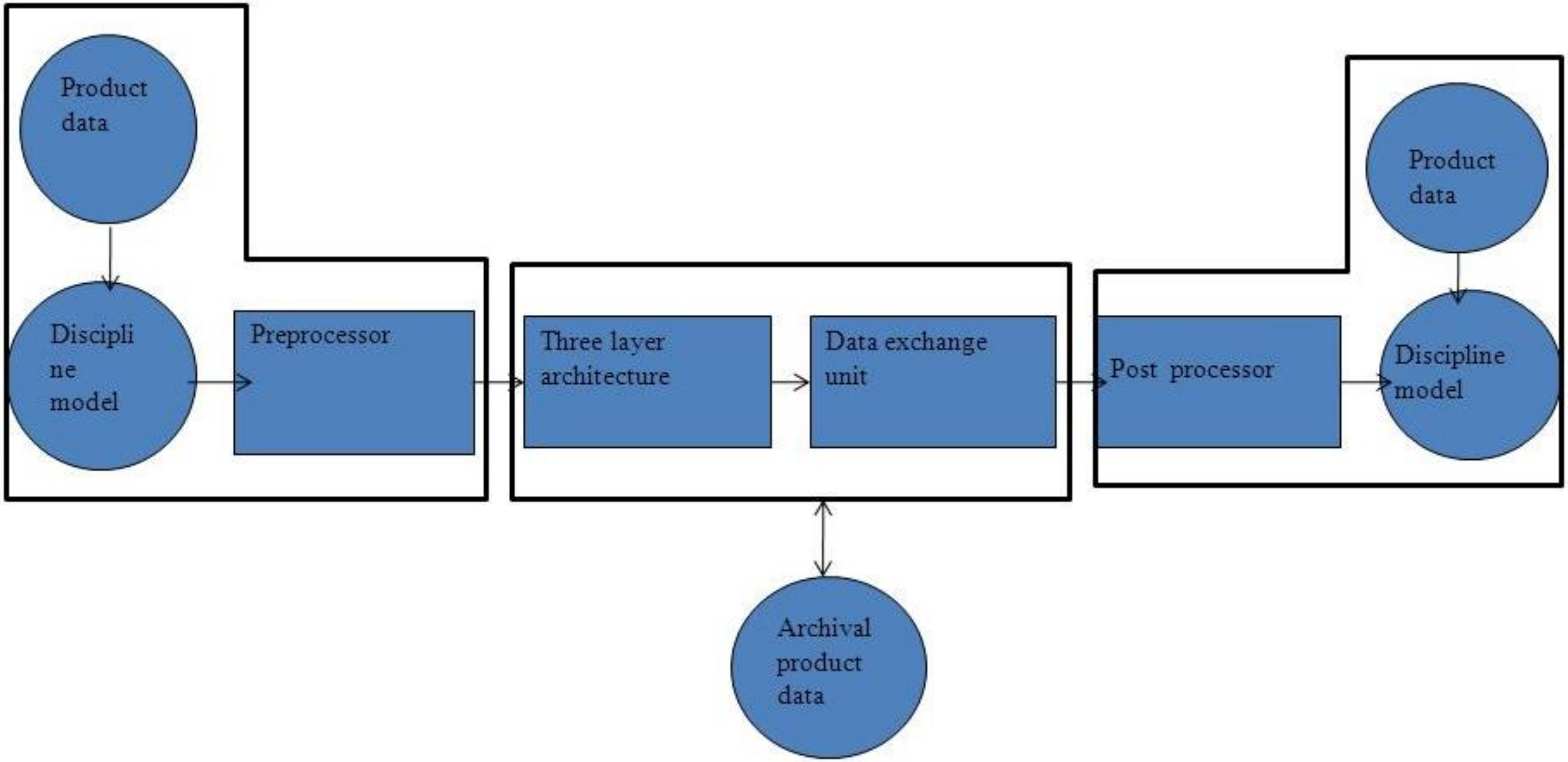
GKS offers two routines to define the user created pictures. They are primitive functions and attribute functions. Examples of primitive functions are:

- POLYLINE to draw a set of connected straight-line vectors
- POLYMARKER to draw a set of markers or shapes
- FILL AREA to draw a closed polygon with interior fill
- TEXT to create characters
- GDP (Generalized Drawing Primitive) to specify the standard drawing entities like circle, ellipse etc.

The attribute functions define the appearance of the image e.g. color, line-type etc. Current level of GKS is GKS-3D, which provides several other functions. GKS-3D is an extension to GKS, which allows the production of 3-D objects.

PRODUCT DATA EXCHANGE SPECIFICATION (PDES)

A likely alternative to IGES is the product data exchange specification (PDES) developed by IGES organisation. PDES is aimed at defining a more conceptual model. Parts will be based on solids and defined in terms of features such as holes, flanges, or ribs. Instead of dimensions PDES will define a tolerance envelope for the parts to be manufactured. PDES will also contain non-geometric information such as materials used, manufacturing process and suppliers. PDES will be a complete computer model of the part.



OTHER DATA EXCHANGE FORMATS

There are several existing alternative data exchange formats. These include the Standard Product Data Exchange Format (SDF) of Vought Corporation (available for CADAM, CADDS-5, PATRAN, and PRIME etc.) Standard Interchange Format (SIF) of Intergraph Corporation (available for Applicon, Autotrol, and Calma etc.), ICAM Product Data Definition Interface (PDDI), and VDA sculptured surface Interface (VDAFS), Electronic Design Interchange Format (EDIF), Transfer and Archiving of Product Definition Data (TAP) etc. Another alternative to IGES is the neutral format outlined in ANSI Y14.26M standard. It must be noted here that some of the features of many of these alternatives are superior to that of IGES.

GRAPHICS STANDARDS

EXCHANGE OF CAD DATA BETWEEN SOFTWARE PACKAGES

Necessity to translate drawings created in one drafting package to another often arises. For example you may have a CAD model created in PRO/E package and you may wish that this might be transferred to I-DEAS or Unigraphics. It may also be necessary to transfer geometric data from one software to another. This situation arises when you would want to carry out modeling in one software, say PRO/E and analysis in another software, say ANSYS. One method to meet this need is to write direct translators from one software to another. This means that each system developer will have to produce its own translators. This will necessitate a large number of translators. If we have three software packages we may require six translators among them. This is shown in Fig. 17.3.

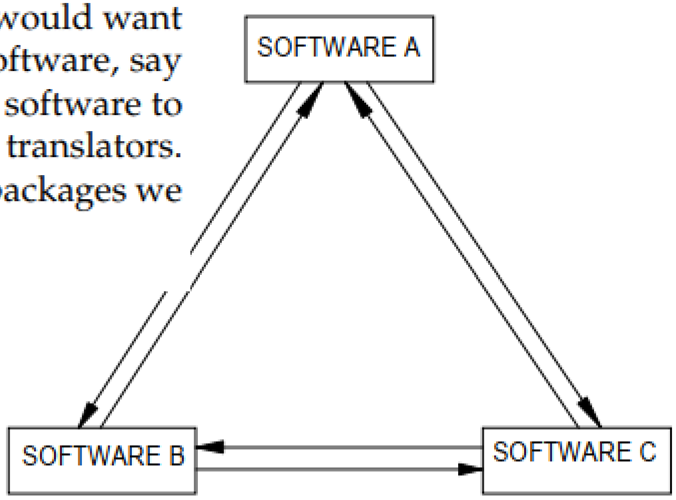


Fig. 17.3 Direct Data Translation

A solution to this problem of direct translators is to use neutral files. These neutral files will have standard formats and software packages can have pre-processors to convert drawing data to neutral file and postprocessors to convert neutral file data to drawing file. Figure 17.4 illustrates how the CAD data transfer is a accomplished using neutral file. Three types of neutral files are discussed in this chapter. They are:

i. Drawing exchange files (DXF)
ii. IGES files
iii. STEP files

GRAPHICS STANDARDS

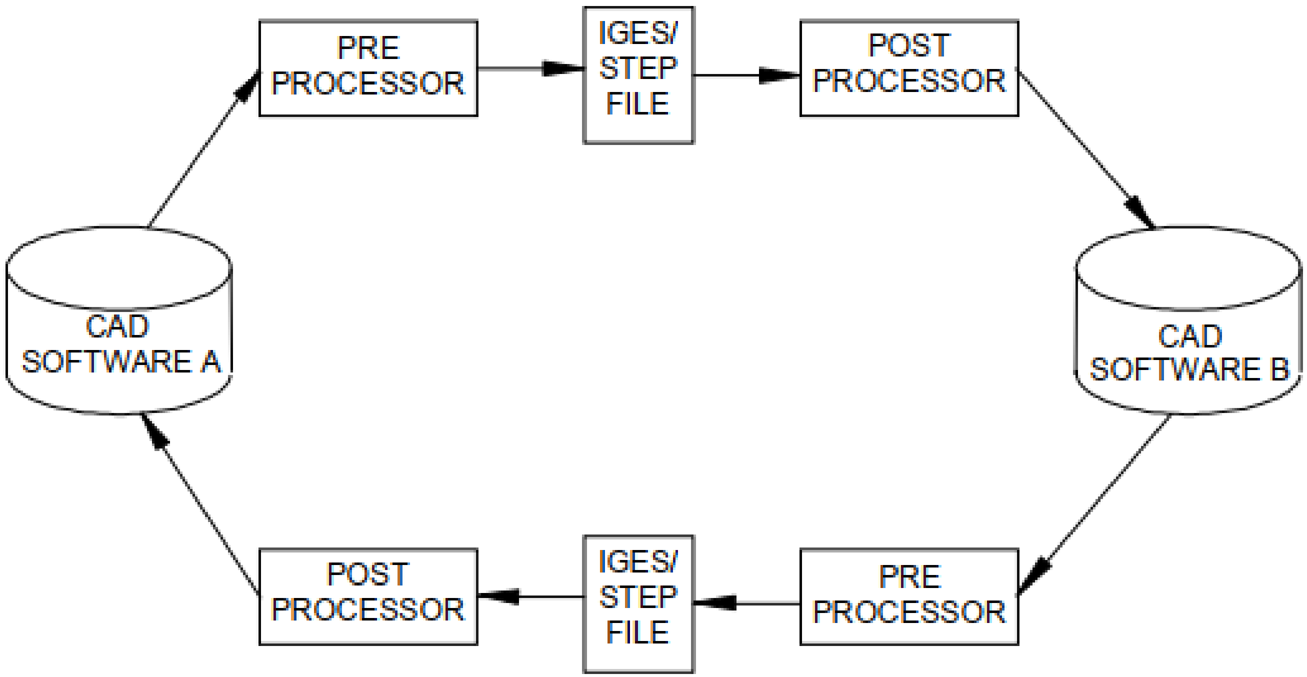


Fig. 17.4 CAD Data Exchange Using Neutral Files

DXF FILES

DXF file (Drawing Exchange File) is a popular data exchange format adopted by many CAD system vendors. DXF format is easy to interpret though it is a lengthy file. The data pertaining to the drawing entities are included in the entities section. Fig. 17.5 shows a plate with a hole. The contents of the entity section of the DXF file of this component are given in Table 17.1.

Table 17.1 A Portion of DXF File

	20	137.6432581938739
	127.6432581938739	30
	30	0.0
	0.0	11
0	11	137.1906423418079
SECTION	152.1906423418079	21
2	21	127.6432581938739
ENTITIES	137.6432581938739	31
0	31	0.0
LINE	0.0	0
5	0	CIRCLE
2B	LINE	5
330	5	31
1F	2D	330
100	330	1F
AcDbEntity	1F	100

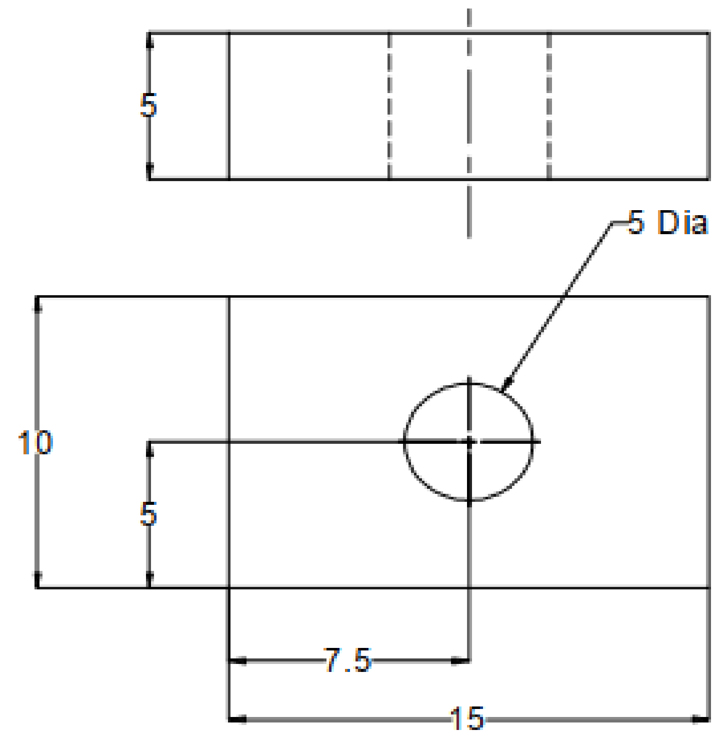


Fig. 17.5 A Plate with a Hole

GRAPHICS STANDARDS

INITIAL GRAPHICS EXCHANGE SPECIFICATION (IGES) GRAPHICS STANDARD

The IGES committee was established in the year 1979. The CAD/CAM Integrated Information Network (CIIN) of Boeing served as the preliminary basis of IGES. IGES version 1.0 was released in 1980. IGES continues to undergo revisions. IGES is a popular data exchange standard today. Figure 17.6 shows a CAD model of a plate with a centre hole. The wire frame model of the component is shown in Fig. 17.7. There are eight vertices (marked as PNT 0 - PNT 8), 12 edges and two circles that form the entities of the model. Table 17.2 shows the IGES output of the wire frame model.

IGES files can also be generated for:

i. Surfaces
ii. Datum curves and points

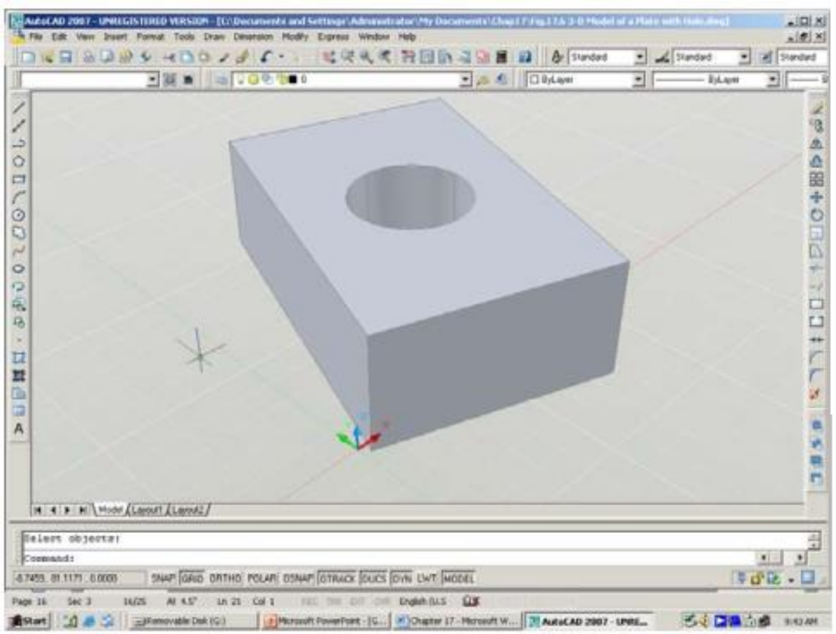


Fig. 17.6 3-D Model of a Plate

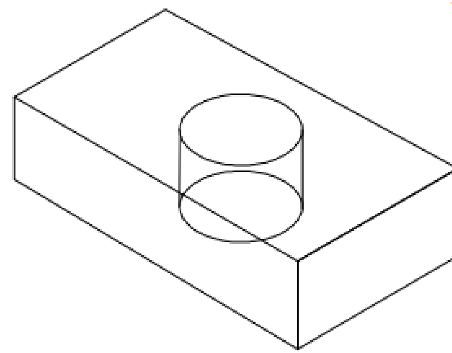


Fig. 17.7 Wire-frame Model of the Component

Table 17.2 IGES-Wire frame edges

PTC IGES file: Wireframe_Edges.igs	S	1
1H,,1H;,4HSTEP,6Hi1.igs,	G	1
49HPro/ENGINEER by Parametric Technology Corporation,7H1999390,32,38,7,	G	2
38,15,4HSTEP,1.,2,2HMM,32768,0.5,13H000104.164438,0.00187075,18.708,	G	3
5Hstaff,7HUnknown,10,0,13H000104.164438;	G	4

110	1	1	1	0	0	0	000000000D	1
110	0	0	1	0	LINE	1D		2
110	2	1	1	0	0	0	000000000D	3
110	0	0	1	0	LINE	2D		4
110	3	1	1	0	0	0	000000000D	5
110	0	0	1	0	LINE	3D		6
110	4	1	1	0	0	0	000000000D	7
110	0	0	1	0	LINE	4D		8
124	5	1	1	0	0	0	001000000D	9
124	0	0	1	0	XFORM	1D		10
100	6	1	1	0	0	9	000000000D	11

GRAPHICS STANDARDS

PRODUCT DATA TECHNOLOGY SUPPORT FOR COMPUTER AIDED CONCURRENT ENGINEERING

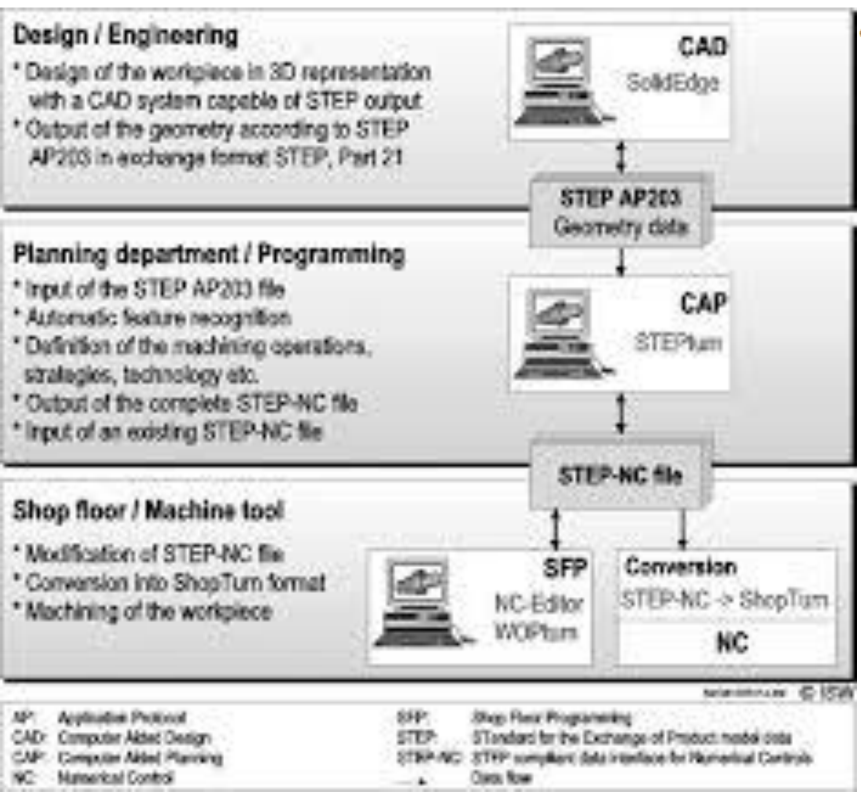
Seamless exchange of product data is critical to CAD/CAM/CAE systems. The Standard for the Exchange of Product Data (STEP) is the enabler for such seamless data exchange. It provides a worldwide standard for storing, sharing and exchanging product information among different CAD systems. Although STEP itself is the basis for Product Data Management System (PDM). It covers border functionalities. It includes methods of representing all critical product specifications such as shape information, materials, tolerances, finishes and product structure.

Whereas the Initial Graphics Exchange Specification (IGES) standard has widespread use, it has its shortcomings. It does not convey the extensive product information needed in the design and manufacturing cycle. Often IGES translators are required to move design data from one CAD system to another. STEP is often viewed as a replacement for IGES, though IGES is still expected to be in active use for some more time in the future. Although the current focus of STEP is on mechanical parts, STEP is a data exchange standard that would apply to a wide range of product areas, including electronics, architectural, engineering and construction, apparel and shipbuilding.

STEP ARCHITECTURE

STEP architecture has four main components:

- EXPRESS modeling language
- Data schemes including attributes such as geometry, topology, features and tolerance.
- Aapplication interface called Standard Data Access Interface (SDAI), which is a standard interface to enable applications to access and manipulate STEP data
- STEP database, which has the following forms:
  - ASCII format file for data exchange
  - Working from file, usually in binary format, that can be shared by multiple systems
  - Shared database, involving object oriented database management system or relational database system
- Knowledge base, with a database management system as a base coupled to an expert shell



17.14.2 STEP ENABLER FOR CONCURRENT ENGINEERING

STEP was released in early 1993 as a Draft International Standard (DIS). The initial release of STEP has four basic parts. These include:

- EXPRESS modeling language
- Two application protocols
- Drafting and Configuration Control Design for three-dimensional product data.
- Six application resources.

Subsequent releases of STEP provided added functionality in terms of the kinds of product supported and the extent of the product life cycle. While STEP is advancing towards maturity, it had been investigated for the feasibility of incorporation into framework system. Both STEP and Concurrent Engineering share the common goal of influencing the product cycle from design, assembly, etc. to the disposal stages which have been realized in the CONSENS system under ESPRIT EP6896. The object-oriented database for CONSENS has a schema with STEP definitions alongside company specific definitions. A module called Product Information Archive (PIA) provides functionality for STEP data access via SDAI. It is generic to be adopted for different domains.

For example it is used for product information by the Aircraft Company, Deutshces Aerospace and electronics manufacturing company, AEG.

STEP data export in a CAD modeling package has the following options:

(i) wire frame edges
(ii) surfaces
(iii) solids
(iv) shells
(v) Datum curves and points

A typical STEP output for the wire frame model shown in Fig. 17.7 is given in Table 17.3.

Table 17.3 STEP Output

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION((“),’1’);
FILE_NAME(‘STEP’,’2000-01-04T’,(‘staff’),(“),
‘PRO/ENGINEER BY PARAMETRIC TECHNOLOGY CORPORATION, 1999390’,
‘PRO/ENGINEER BY PARAMETRIC TECHNOLOGY CORPORATION, 1999390’,”);
FILE_SCHEMA((‘CONFIG_CONTROL_DESIGN’));
ENDSEC;
DATA;
#1=DIRECTION(“,(0.E0,-1.E0,0.E0));
#2=VECTOR(“,#1,1.E1);
#3=CARTESIAN_POINT(“,(0.E0,0.E0,0.E0));
#4=LINE(“,#3,#2);
#6=GEOMETRIC_CURVE_SET(“,(#5,#11,#16,#21,#27,#32,#37,#42,#47,#52,#57,
```

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 4 – COMPUTER AIDED MANUFACTURING – I - SMEA1501

4.1. PROCESS DATA

The data collected by the computer in computer process monitoring can generally be classified into three categories:

- *Process data.* These are measured values of input parameters and output variable, that indicate process performance, When the values are found to indicate a problem, the human operator takes corrective action.

- *Equipment data Process date.* These are measured values of input parameters and output variable, that indicate process performance, When the values are found to indicate a problem, the human operator takes corrective action.

- *Equipment data.* These data indicate the status of the equipment in the work cell. Functions served by the data include monitoring machine utilization, scheduling tool changes, avoiding machine breakdowns. diagnosing equipment malfunctions, and planning preventive maintenance

- *Product data.* Government regulations require certain manufacturing industries to collect and preserve production oeta on their products, The pharmaceutical and medical supply industries are prime examples. Computer monitoring is the most convert, means of satisfying these regulations. A firm may also want 10 collect product data for its own use.

4.2. MANUFACTURING PLANNING & CONTROL

Production planning and control (PPC) is concerned with the logistics problems that are encountered in manufacturing, that is, managing the details of what and how many products to produce and when, and obtaining the raw materials, parts, and resources to product those products. PPC: solves these logistics problems by managing information. The computer is essential for processing the tremendous amounts of data involved to define the products and the manufacturing resources to produce them and to reconcile these technical details with the desired production schedule. Let us nevertheless try to explain what is involved in each of the two function" production planning and production control.

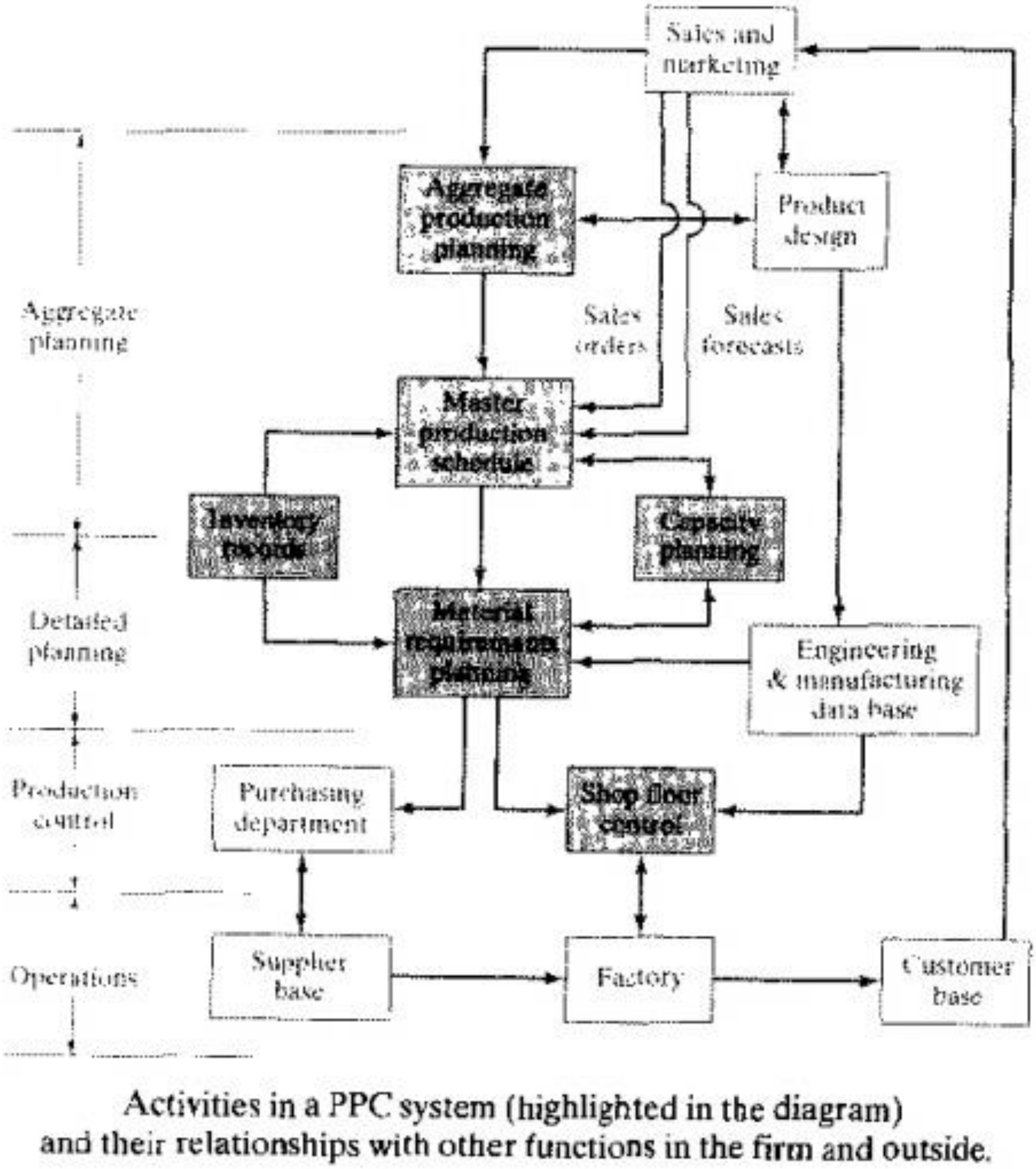


Fig. 4.1. PPC System

4.2. PRODUCTION PLANNING

It is concerned with: (1) deciding which products to make, how many of each, and when they should he completed: (2) scheduling the delivery *and/or* production of the pans and products: and (3) planning the manpower and equipment resources needed to accomplish the production plan. Activities within the scope of production planning include:

- *Aggregate production planning.* This involves planning the production output elects for major product lines produced by the firm. These plans must be coordinated among various functions in the firm, including product design, production, marketing and sales
- *Master production planning.* The aggregate production plan must be converted into a master production schedule (\1PS) which is a specific plan of the quantities to be produced of individual models within each product line.

- *Material requirements planning* (MRP) is a planning technique, usually implemented by computer that translates the MPS of end products into a detailed schedule for the raw materials and parts used in those end products
- *Capacity planning* is concerned with determining the labor and equipment resources needed to achieve the master schedule.

4.3. PRODUCTION CONTROL

It is concerned with determining whether the necessary resources 10 implement the production plan haven provided, and if not. it attempts to take corrective action to address the deficiencies. A, its name suggests, production control includes various systems and techniques for controlling production and inventory in the factory. The major topic, covered in this chapter are:

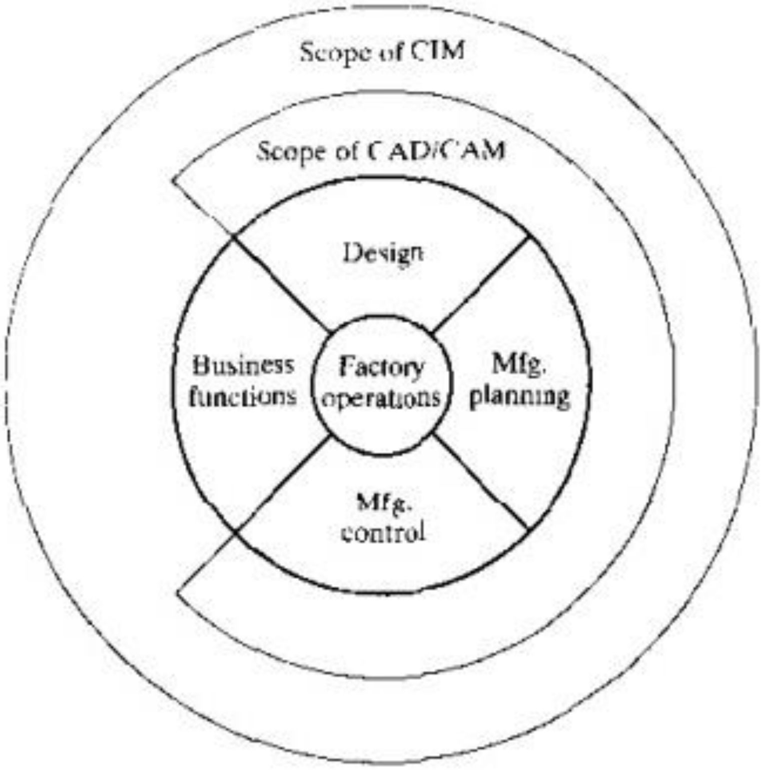
- *Shop floor control.* Shop floor control systems compare the progress and status of production orders in the factory to the production plans (MPS and parts explosion accomplished by MRP)
- *Inventory control.* Inventory control includes it variety of techniques for managing the inventory of a firm. One of the important tools in inventory control is the economic order quantity formula
- *Manufacturing resource planning.* Also known as MRP II. manufacturing resource planning combines MRP and capacity planning as well as shop floor control and other functions related to PPC
- *Just In time production systems.* The term "just in time" refers 10 a scheduling discipline in which materials and parts are delivered to the next work cell or production line station just prior to their heing used. This type of discipline tends to reduce inventory and other kinds of waste in manufacturing.

4.4. CAD/CAM INTEGRATION

CAD/CAM denotes an integration of design and manufacturing activities by means of computer systems. The method of manufacturing a product is a direct function of its design. With conventional procedures practiced for so many years in industry, engineering drawings were prepared by design draftsmen and later used by manufacturing engineers to develop the process plan. The activities involved in designing the product were separated from the activities associated with process planning. Essentially a two-step procedure was employed. This was time-consuming and involved duplication of effort by design and manufacturing personnel. Using CAD/CAM technology, it is possible to establish a direct link between product design and manufacturing engineering. It is the goal of CAD/CAM not only to automate certain phases of design. and certain phases of manufacturing, but also to automate the transition from design to manufacturing. In the ideal CAD/CAM system, it is possible to take the design specification of the product as it resides in the CAD data base and convert it into a process plan for making the product, this conversion. being done automatically by the CAD/CAM system. A large portion of the processing might be accomplished on a numerically controlled machine tool As part of the process plan, the NC part program is generated automatically by CAD/CAM, The CAD/CAM system downloads the NC program directly to the machine tool by means of a telecommunications network. Hence, under this arrangement, product design, NC programming, and physical production are all implemented by computer.

4.5. PRINCIPLES OF COMPUTER INTEGRATED MANUFACTURING

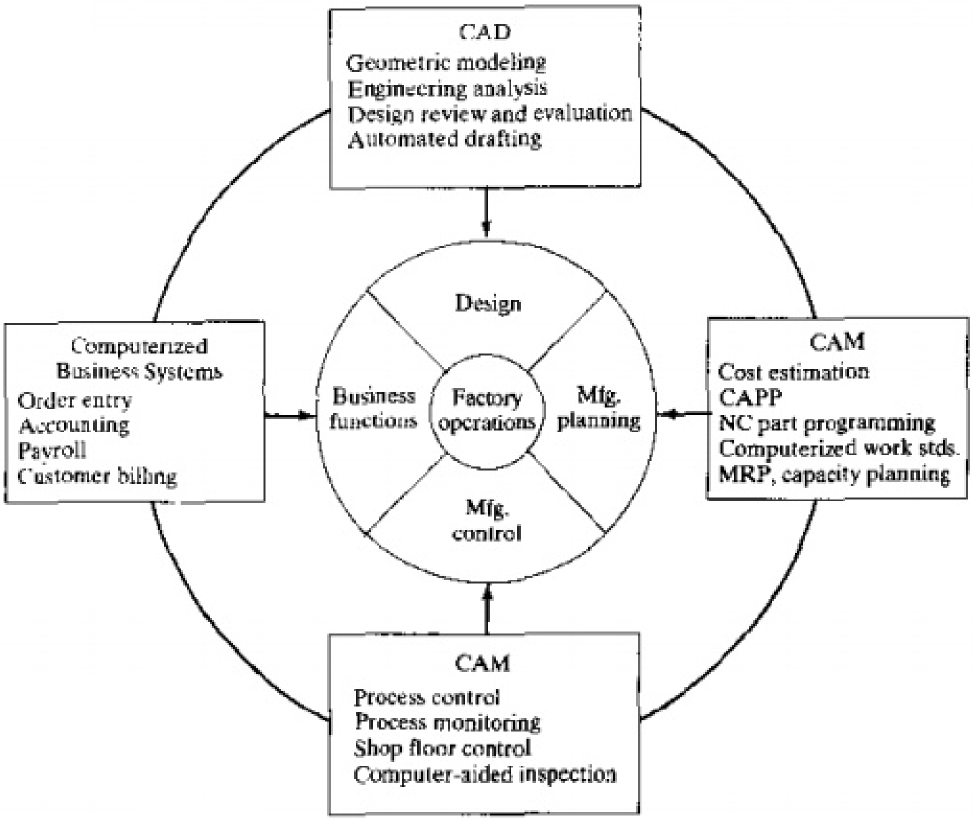
Computer integrated manufacturing includes all of the engineering functions of CAD/CAM, but it also includes the firm's business functions that are related to manufacturing. The ideal CIM system applies computer and communications technology to all of the operational functions and information processing functions in manufacturing from order receipt, through design and production, to product shipment.



The scope of CAD/CAM and CIM.

Fig. 4.2. CIM Wheel

The CIM concept is that all of the firm's operations related to production are incorporated in an integrated computer system to assist. augment. and automate the operations. The computer system b pervasive throughout the firm, touching all activities that support manufacturing. In this integrated computer system, the output of one activity serves as the input to the next activity, through the chain of events that starts with the sales order and culminates with shipment of the product. The components of the integrated computer system are illustrated in Figure 24.8. Customer orders are initially entered by the company's sales force or directly by the customer into a computerized order entry system. The orders contain the specifications describing the product. The specifications serve as the input to the product design department. New products are designed on a CAD system. The components that comprise the product are designed, the bill of materials is compiled, and assembly drawings are prepared. The output of the design department serves as the input to manufacturing engineering, where process planning. tool design, and similar activities are accomplished to prepare for production. Many of these manufacturing engineering activities are supported by the (1M system. Process planning is performed using CAPP. Tool and fixture design is done on a CAD system, making use of the product model generated during product design. The output from manufacturing engineering provides the input to production planning and control. where material requirements planning and scheduling are performed using the computer system. And so it goes. through each step in the manufacturing cycle. Pull implementation of C1M results in the automation of the information flow through every aspect of the company's organization.



Computerized elements of a CIM system.

Fig. 4.3. Elements of CIM system

4.6. HIERARCHICAL COMPUTER STRUCTURES AND NETWORKING

A hierarchical network design involves dividing the network into discrete layers. Each layer, or tier, in the hierarchy provides specific functions that define its role within the overall network. This helps the network designer and architect to optimize and select the right network hardware, software, and features to perform specific roles for that network layer. Hierarchical models apply to both LAN and WAN design. The benefit of dividing a flat network into smaller, more manageable blocks is that local traffic remains local. Only traffic that is destined for other networks is moved to a higher layer. For example, the flat network has now been divided into three separate broadcast domains.

A typical enterprise hierarchical LAN campus network design includes the following three layers:

- Access layer: Provides workgroup/user access to the network
- Distribution layer: Provides policy-based connectivity and controls the boundary between the access and core layers
- Core layer: Provides fast transport between distribution switches within the enterprise campus.

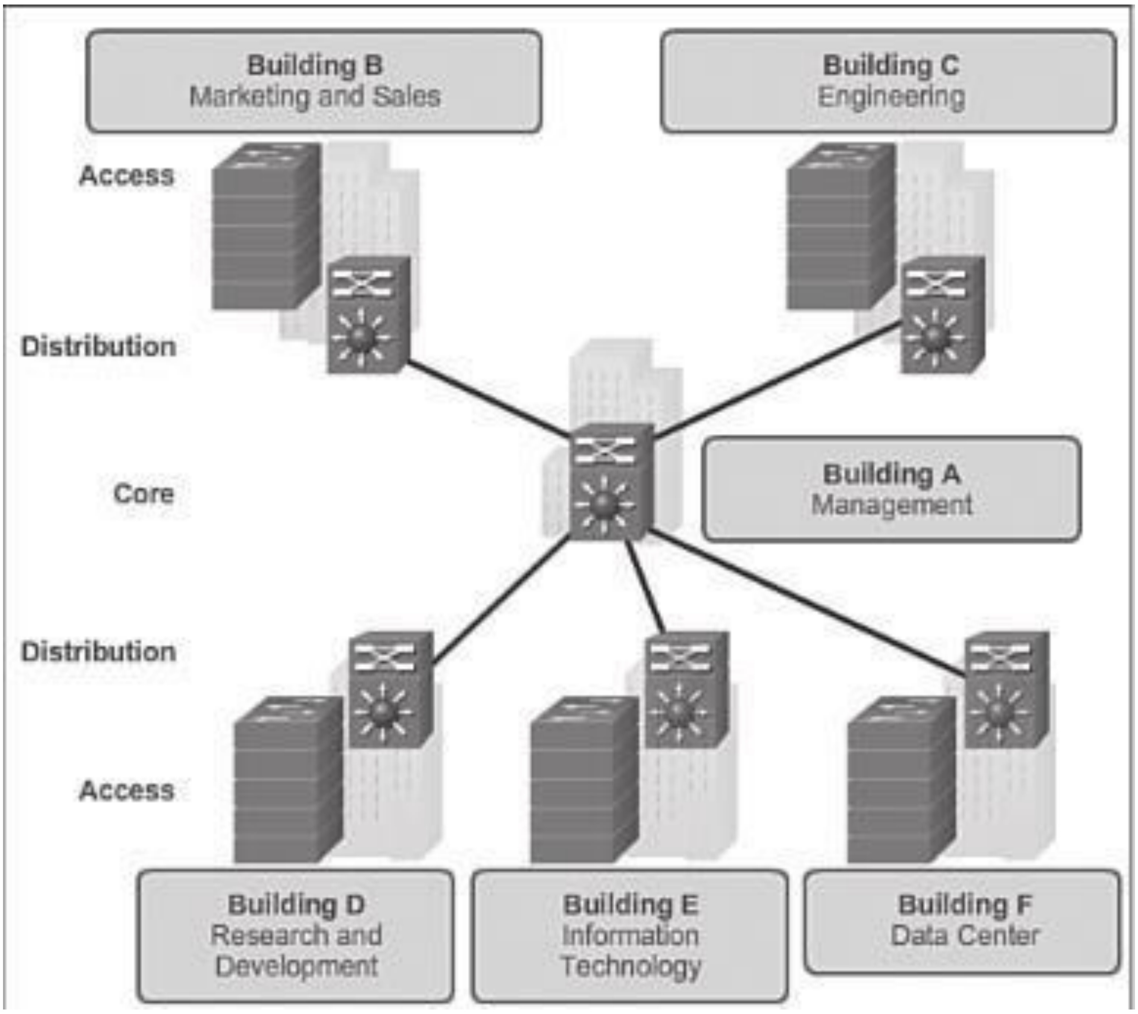


Fig. 4.4. LAN Environment

In a LAN environment, the access layer highlighted grants end devices access to the network. In the WAN environment, it may provide steelworkers or remote sites access to the corporate network across WAN connections. The access layer serves a number of functions, including:

- Layer 2 switching
- High availability
- Port security
- QoS classification and marking and trust boundaries
- Address Resolution Protocol (ARP) inspection
- Virtual access control lists (VACLs)
- Spanning tree
- Power over Ethernet (PoE) and auxiliary VLANs for VoIP

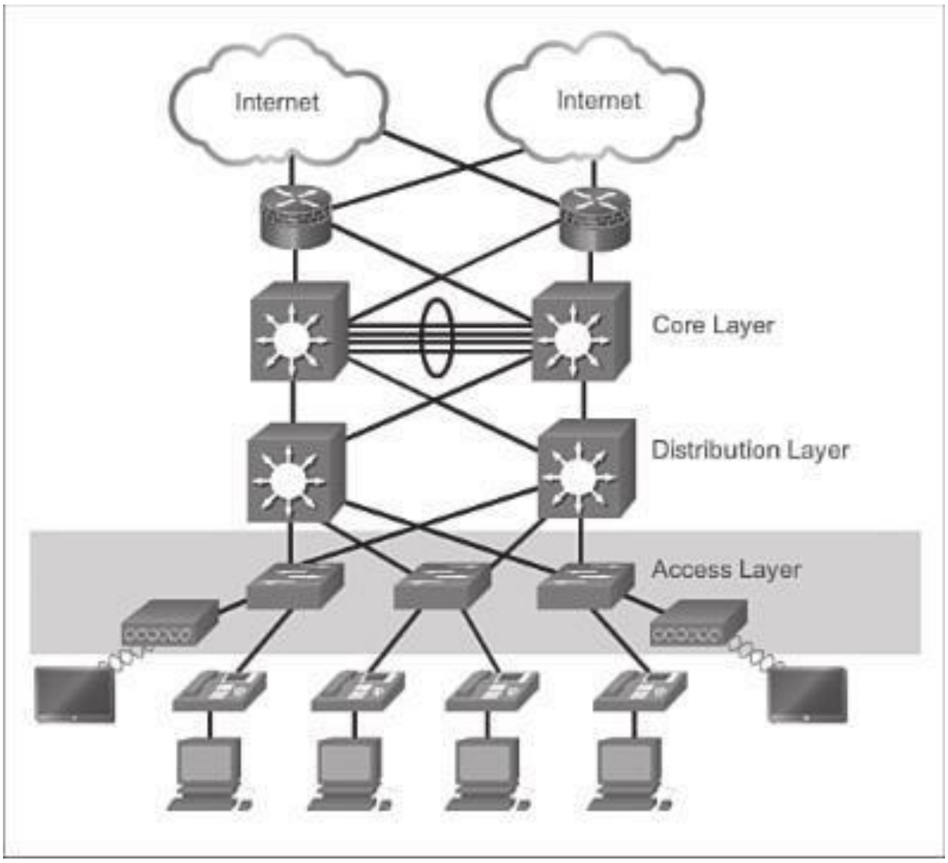


Fig. 4.5. Access System

The distribution layer aggregates the data received from the access layer switches before it is transmitted to the core layer for routing to its final destination.

The distribution layer device is the focal point in the wiring closets. Either a router or a multilayer switch is used to segment workgroups and isolate network problems in a campus environment.

A distribution layer switch may provide upstream services for many access layer switches. The distribution layer can provide:

- Aggregation of LAN or WAN links.
- Policy-based security in the form of access control lists (ACLs) and filtering.
- Routing services between LANs and VLANs and between routing domains (e.g., EIGRP to OSPF).
- Redundancy and load balancing.
- A boundary for route aggregation and summarization configured on interfaces toward the core layer.
- Broadcast domain control, because routers or multilayer switches do not forward broadcasts. The device acts as the demarcation point between broadcast domains.

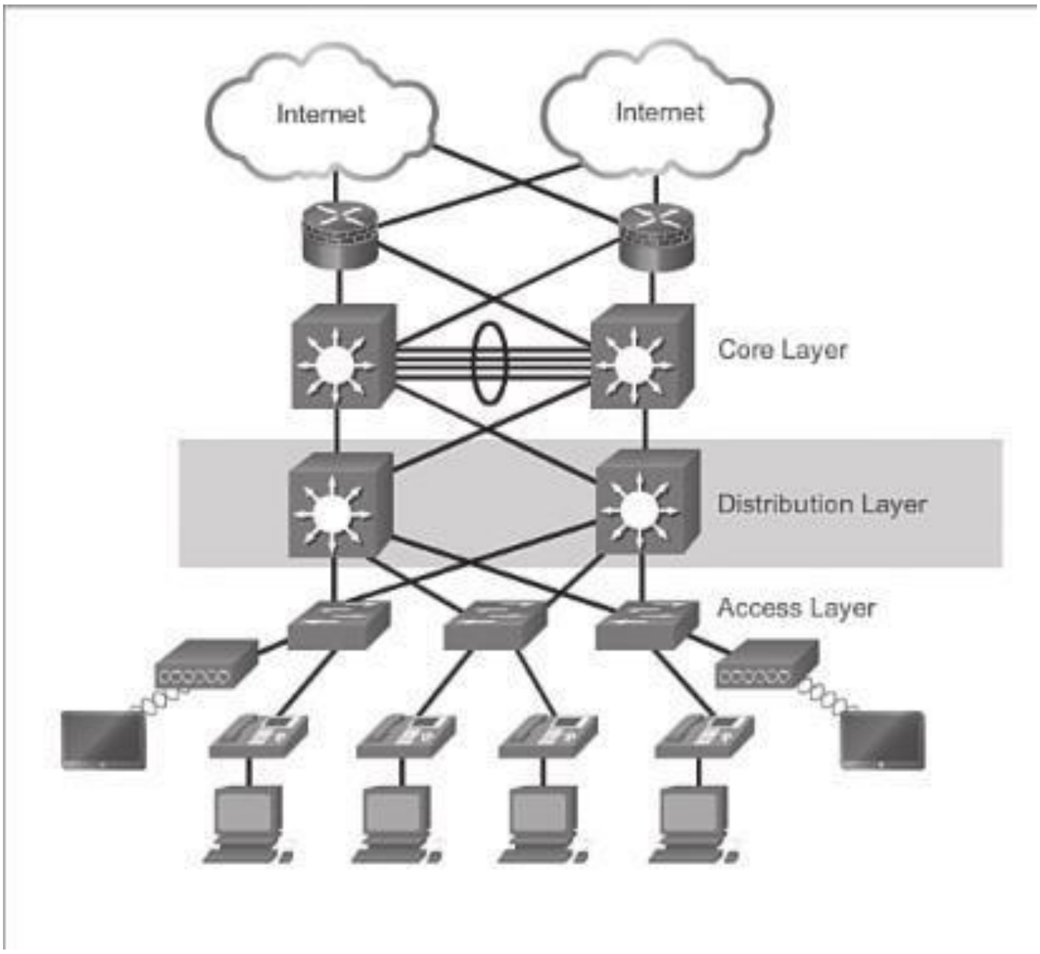


Fig. 4.6. Distribution System

The core layer is also referred to as the network backbone. The core layer consists of high-speed network devices such as the Cisco Catalyst 6500 or 6800. These are designed to switch packets as fast as possible and interconnect multiple campus components, such as distribution modules, service modules, the data center, and the WAN edge.

The core should be highly available and redundant. The core aggregates the traffic from all the distribution layer devices, so it must be capable of forwarding large amounts of data quickly. Considerations at the core layer include:

- Providing high-speed switching (i.e., fast transport)
- Providing reliability and fault tolerance
- Scaling by using faster, and not more, equipment
- Avoiding CPU-intensive packet manipulation caused by security, inspection, quality of service (QoS) classification, or other processes

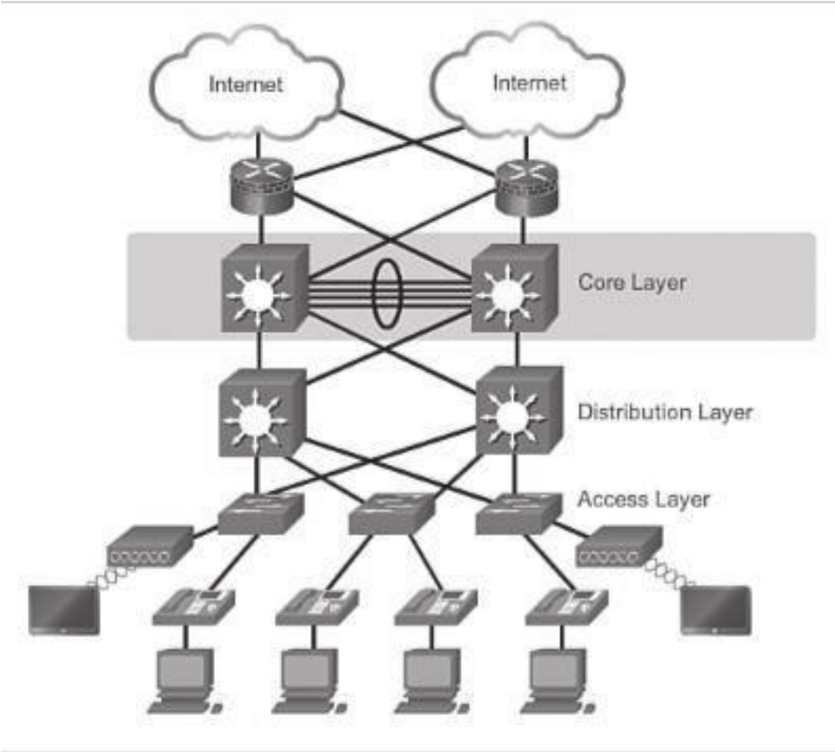


Fig. 4.7. Core System

4.7. LOCAL AREA NETWORK

A computer network spanned inside a building and operated under single administrative system is generally termed as Local Area Network (LAN). Usually, LAN covers an organization offices, schools, colleges or universities. Number of systems connected in LAN may vary from as least as two to as much as 16 million. LAN provides a useful way of sharing the resources between end users. The resources such as printers, file servers, scanners, and internet are easily sharable among computers.

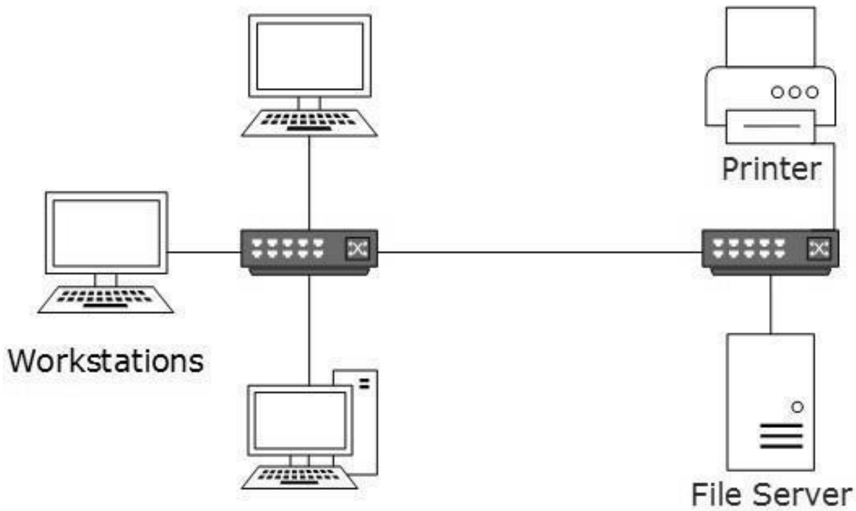


Fig. 4.8. Local area network environment

LANs are composed of inexpensive networking and routing equipment. It may contains local servers serving file storage and other locally shared applications. It mostly operates on private IP addresses and does not involve heavy routing. LAN works under its own local domain and controlled centrally.

4.7.1. Metropolitan Area Network

The Metropolitan Area Network (MAN) generally expands throughout a city such as cable TV network. It can be in the form of Ethernet, Token-ring, ATM, or Fiber Distributed Data Interface (FDDI). Metro Ethernet is a service which is provided by ISPs. This service enables its users to expand their Local Area Networks. For example, MAN can help an organization to connect all of its offices in a city.

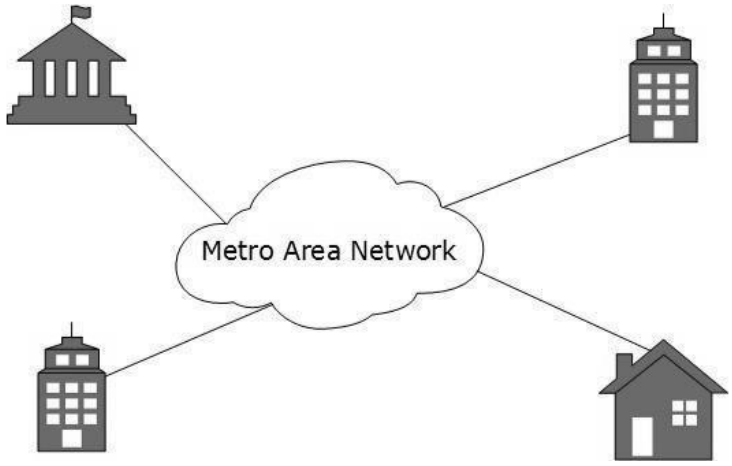


Fig. 4.9. MAN System

Backbone of MAN is high-capacity and high-speed fiber optics. MAN works in between Local Area Network and Wide Area Network. MAN provides uplink for LANs to WANs or internet.

4.7.2. Wide Area Network

As the name suggests, the Wide Area Network (WAN) covers a wide area which may span across provinces and even a whole country. Generally, telecommunication networks are Wide Area Network. These networks provide connectivity to MANs and LANs. Since they are equipped with very high speed backbone, WANs use very expensive network equipment.

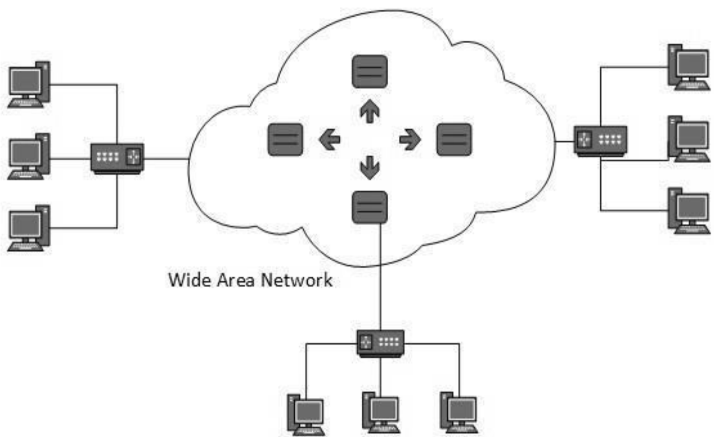


Fig. 4.10. WAN System

WAN may use advanced technologies such as Asynchronous Transfer Mode (ATM), Frame Relay, and Synchronous Optical Network (SONET). WAN may be managed by multiple administration.

4.7.3. Internet Work

A network of networks is called an internetwork, or simply the internet. It is the largest network in existence on this planet. The internet hugely connects all WANs and it can have connection to LANs and Home networks. Internet uses TCP/IP protocol suite and uses IP as its addressing protocol. Present day, Internet is widely implemented using IPv4. Because of shortage of address spaces, it is gradually migrating from IPv4 to IPv6.

Internet enables its users to share and access enormous amount of information worldwide. It uses WWW, FTP, email services, audio, and video streaming etc. At huge level, internet works on Client-Server model.

LAN uses Ethernet which in turn works on shared media. Shared media in Ethernet create one single Broadcast domain and one single Collision domain. Introduction of switches to Ethernet has removed single collision domain issue and each device connected to switch works in its separate collision domain. But even Switches cannot divide a network into separate Broadcast domains.

Virtual LAN is a solution to divide a single Broadcast domain into multiple Broadcast domains. Host in one VLAN cannot speak to a host in another. By default, all hosts are placed into the same VLAN.

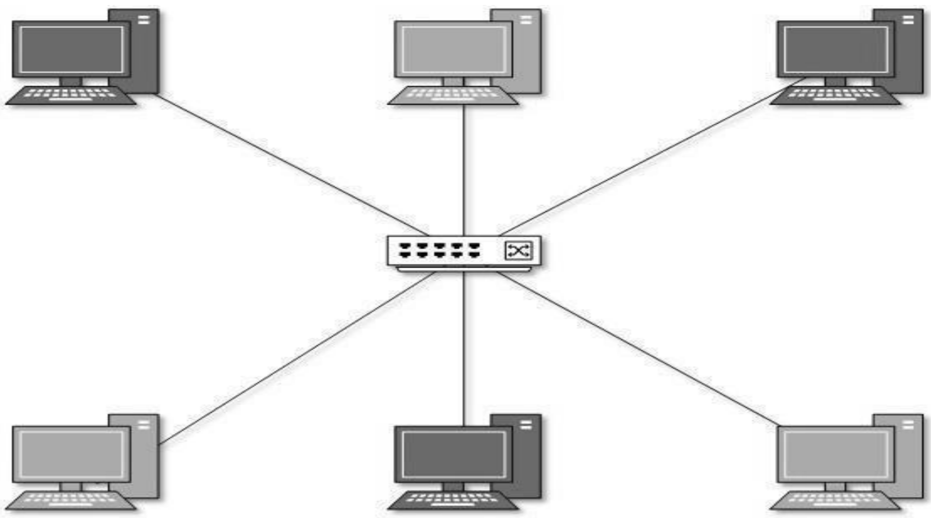


Fig. 4.11. Internet Work System

In this diagram, different VLANs are depicted in different color codes. Hosts in one VLAN, even if connected on the same Switch cannot see or speak to other hosts in different VLANs. VLAN is Layer-2 technology which works closely on Ethernet. To route packets between two different VLANs, a Layer-3 device such as Router is required.

4.8. NETWORK TOPOLOGY

A Network Topology is the arrangement with which computer systems or network devices are connected to each other. Topologies may define both physical and logical aspect of the network. Both logical and physical topologies could be same or different in a same network.

4.8.1. Point – to – Point

Point-to-point networks contains exactly two hosts such as computer, switches, routers, or servers connected back to back using a single piece of cable. Often, the receiving end of one host is connected to sending end of the other and vice versa.

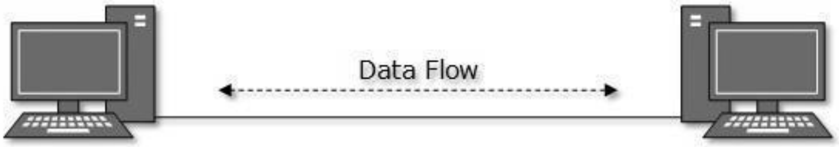


Fig. 4.12. Point-to-point System

If the hosts are connected point-to-point logically, then may have multiple intermediate devices. But the end hosts are unaware of underlying network and see each other as if they are connected directly.

4.8.2. Bus Topology

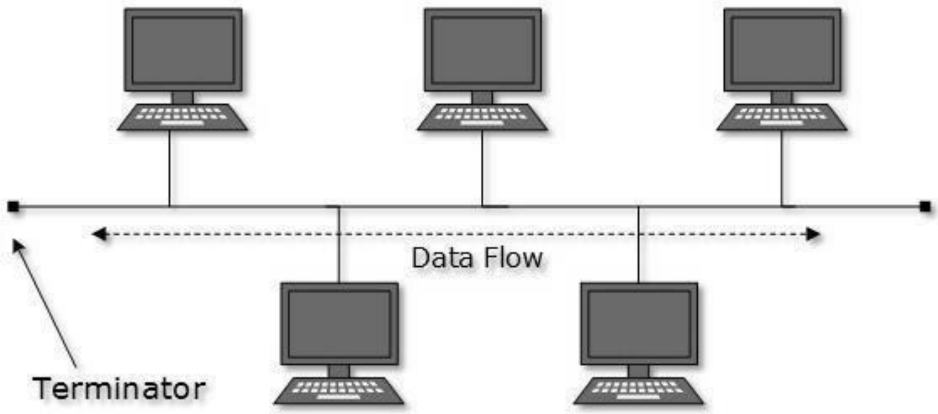


Fig. 4.13. Bus System

In case of Bus topology, all devices share single communication line or cable. Bus topology may have problem while multiple hosts sending data at the same time. Therefore, Bus topology either uses CSMA/CD technology or recognizes one host as Bus Master to solve the issue. It is one of the simple forms of networking where a failure of a device does not affect the other devices. But failure of the shared communication line can make all other devices stop functioning. Both ends of the shared channel have line terminator. The data is sent in only one direction and as soon as it reaches the extreme end, the terminator removes the data from the line.

4.8.3 Star Topology

All hosts in Star topology are connected to a central device, known as hub device, using a point-to-point connection. That is, there exists a point to point connection between hosts and hub. The hub device can be any of the following: Layer-1 device such as hub or repeater, Layer-2 device such as switch or bridge, and Layer-3 device such as router or gateway

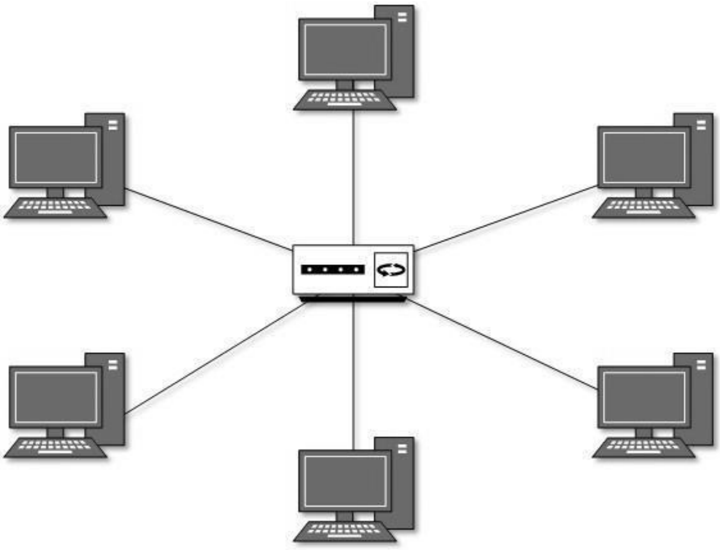


Fig. 4.14. Star System

As in Bus topology, hub acts as single point of failure. If hub fails, connectivity of all hosts to all other hosts fails. Every communication between hosts takes place through only the hub. Star topology is not expensive as to connect one more host, only one cable is required and configuration is simple.

4.8.4. Ring Topology

In ring topology, each host machine connects to exactly two other machines, creating a circular network structure. When one host tries to communicate or send message to a host which is not adjacent to it, the data travels through all intermediate hosts. To connect one more host in the existing structure, the administrator may need only one more extra cable.

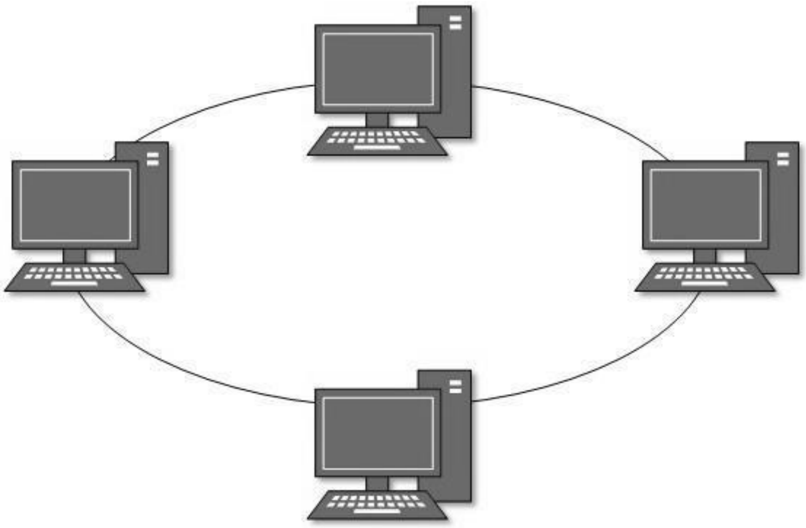


Fig. 4.15. Ring System

Failure of any host results in failure of the whole ring. Thus, every connection in the ring is a point of failure. There are methods which employ one more backup ring.

4.8.5. Mesh Topology

In this type of topology, a host is connected to one or multiple hosts. This topology has hosts in point-to-point connection with every other host or may also have hosts which are in point-to-point connection with few hosts only.

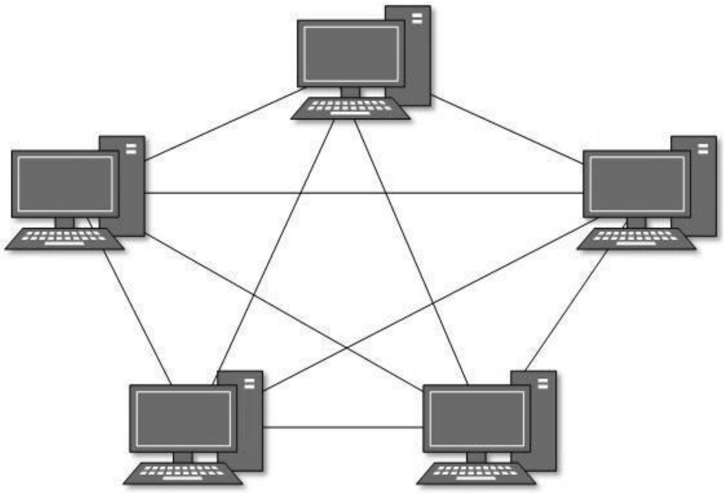


Fig. 4.16. Star System

Hosts in Mesh topology also work as relay for other hosts which do not have direct point-to-point links. Mesh technology comes into two types:

Full Mesh: All hosts have a point-to-point connection to every other host in the network. Thus for every new host n(n-1)/2 connections are required. It provides the most reliable network structure among all network topologies.

Partially Mesh: Not all hosts have point-to-point connection to every other host. Hosts connect to each other in some arbitrarily fashion. This topology exists where we need to provide reliability to some hosts out of all.

4.8.5. Tree Topology

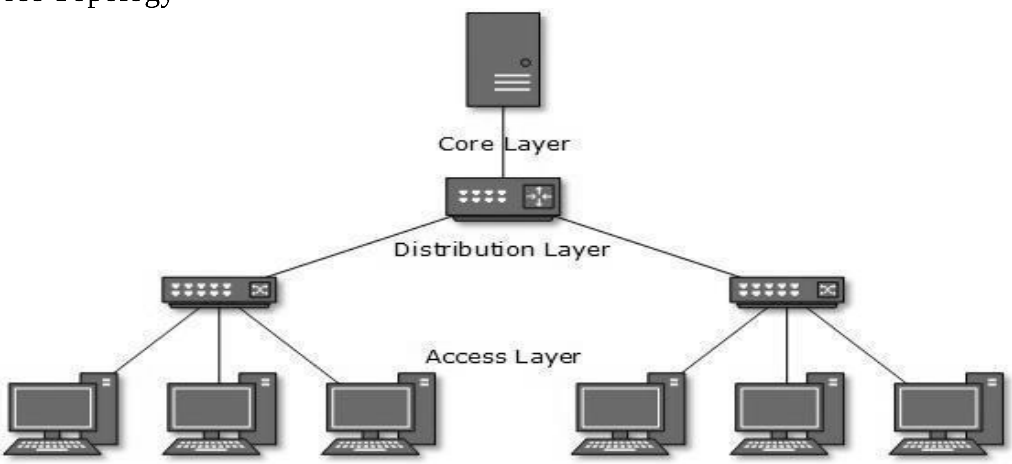


Fig. 4.17. Tree System

Also known as Hierarchical Topology, this is the most common form of network topology in use presently. This topology imitates as extended Star topology and inherits properties of Bus topology. This topology divides the network into multiple levels/layers of network. Mainly in LANs, a network is bifurcated into three types of network devices. The lowermost is access-layer where computers are attached. The middle layer is known as distribution layer, which works as mediator between upper layer and lower layer. The highest layer is known as core layer. All neighboring hosts have point-to-point connection between them. Similar to the Bus topology, if the root goes down, then the entire network suffers even though it is not the single point of failure. Every connection serves as point of failure, failing of which divides the network into unreachable segment.

4.8.6. Daisy Topology

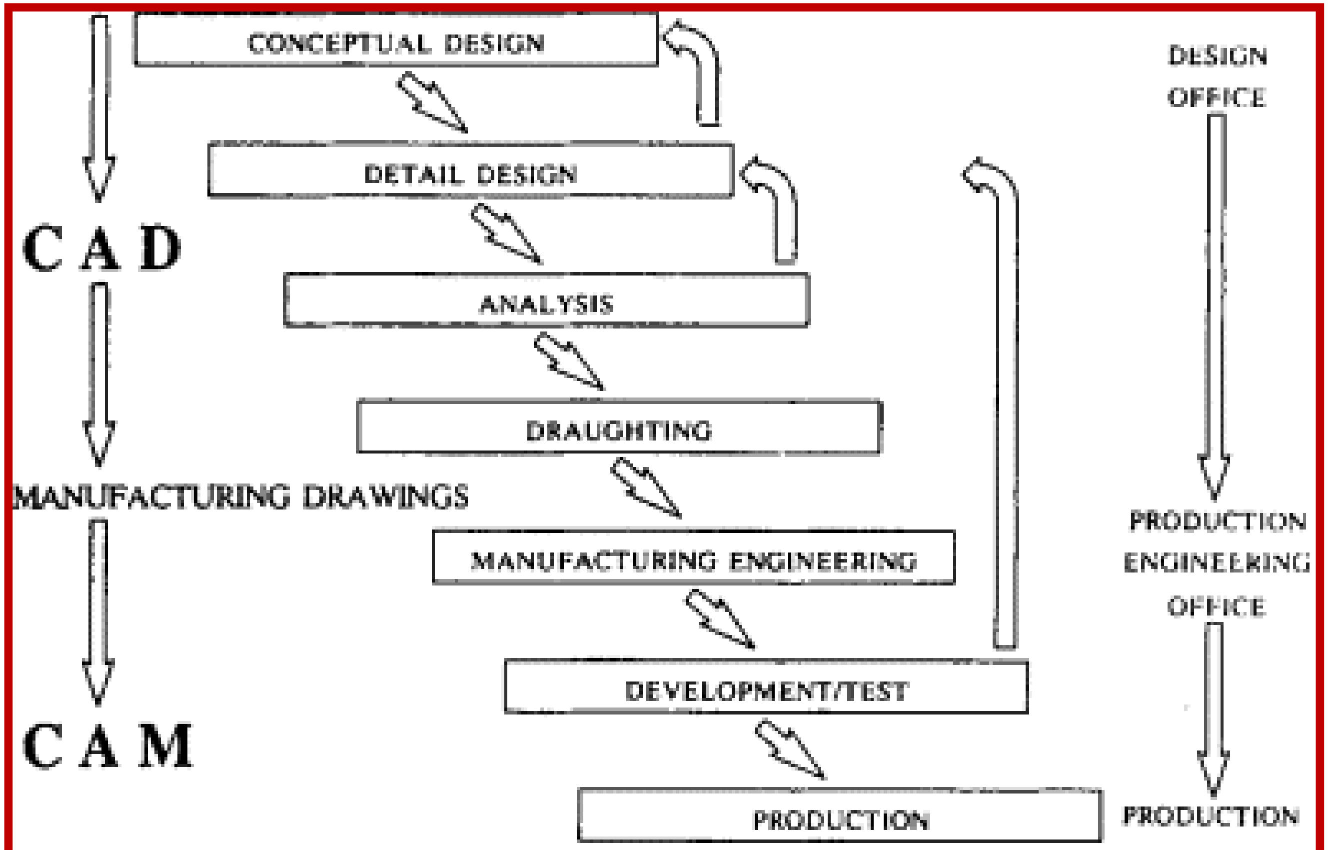
This topology connects all the hosts in a linear fashion. Similar to Ring topology, all hosts are connected to two hosts only, except the end hosts. Means, if the end hosts in daisy chain are connected then it represents Ring topology.

Fig. 4.18. Daisy System

Each link in daisy chain topology represents single point of failure. Every link failure splits the network into two segments. Every intermediate host works as relay for its immediate hosts.

COMPUTER AIDED MANUFACTURING -I

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



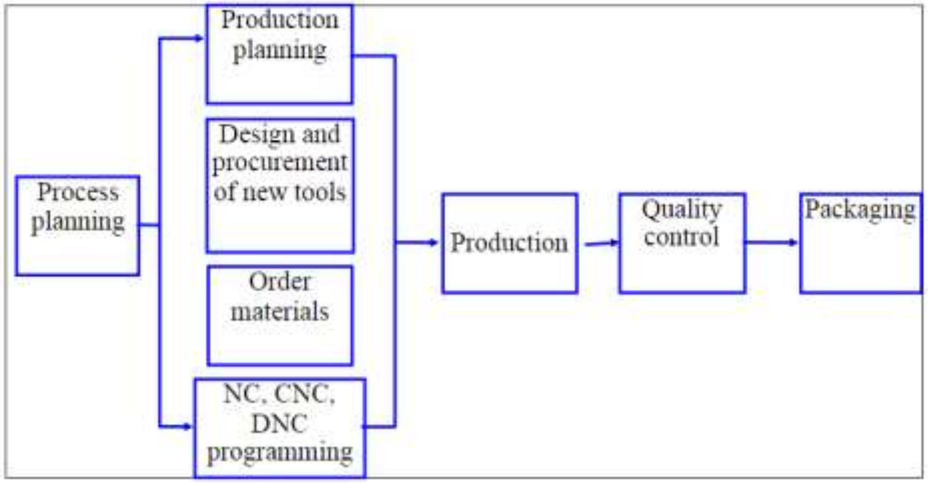
❖ Computer – Aided Manufacturing (CAM)

- **CAM** is the use of computer system to **plan, manage, and control** the operations of manufacturing plants through either **direct or indirect** computer interface with plant's production process.
- **CAM** is the use of computer based software tools that assist engineers and machinists in manufacturing or prototyping product components.
- **CAM** – utilize part geometer defined by CAD drawing.
- **CAM** – use the materials tools, work serious that can be used in actual machining process.
- **CAM** – use computers in process planning , scheduling, shop floor control, work study, quality control .. etc.

What is CAM?

The effective utilization of computers in manufacturing.

CAM is 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.



Benefit of CAM

- The application of CAM in the production offers advantages to a company to **develop capabilities** by combining traditional economies of scale with economies of scope resulting in the **desired flexibility and efficiency**
- Greater **supervision** of the production
- **Fast response to changes** in market demand
- Greater **flexibility**
- **Product variety**
- **Small lot-sizes**
- **Distributed processing capability**
- **Reduced waste**

	CAD	CAM
Purpose	making 2D technical drawings and 3D models	using 3D models to design machining process
Procedure	sketching with 2D primitives and in case of 3D adding 3rd dimension to tchem (extruding, revolving)	automatic and manual path planning for machining tools
Software examples	Autodesk AutoCAD and Inventor, SolidWorks, Solid Edge, CATIA, Creo	EdgeCAM, NX CAM, MasterCAM
Advantages	much easierm more accurate and faster drafting, making 3D models impossible without computers	automatization of machining process
Disadvantages	requires expensive software and knowledge how to use it, sometimes you can loose your data easily if you don't save it	expensive software, requires knowledge how to use it, it depends on CAD model accuracy, glitches can occur

Evolution Of CAM

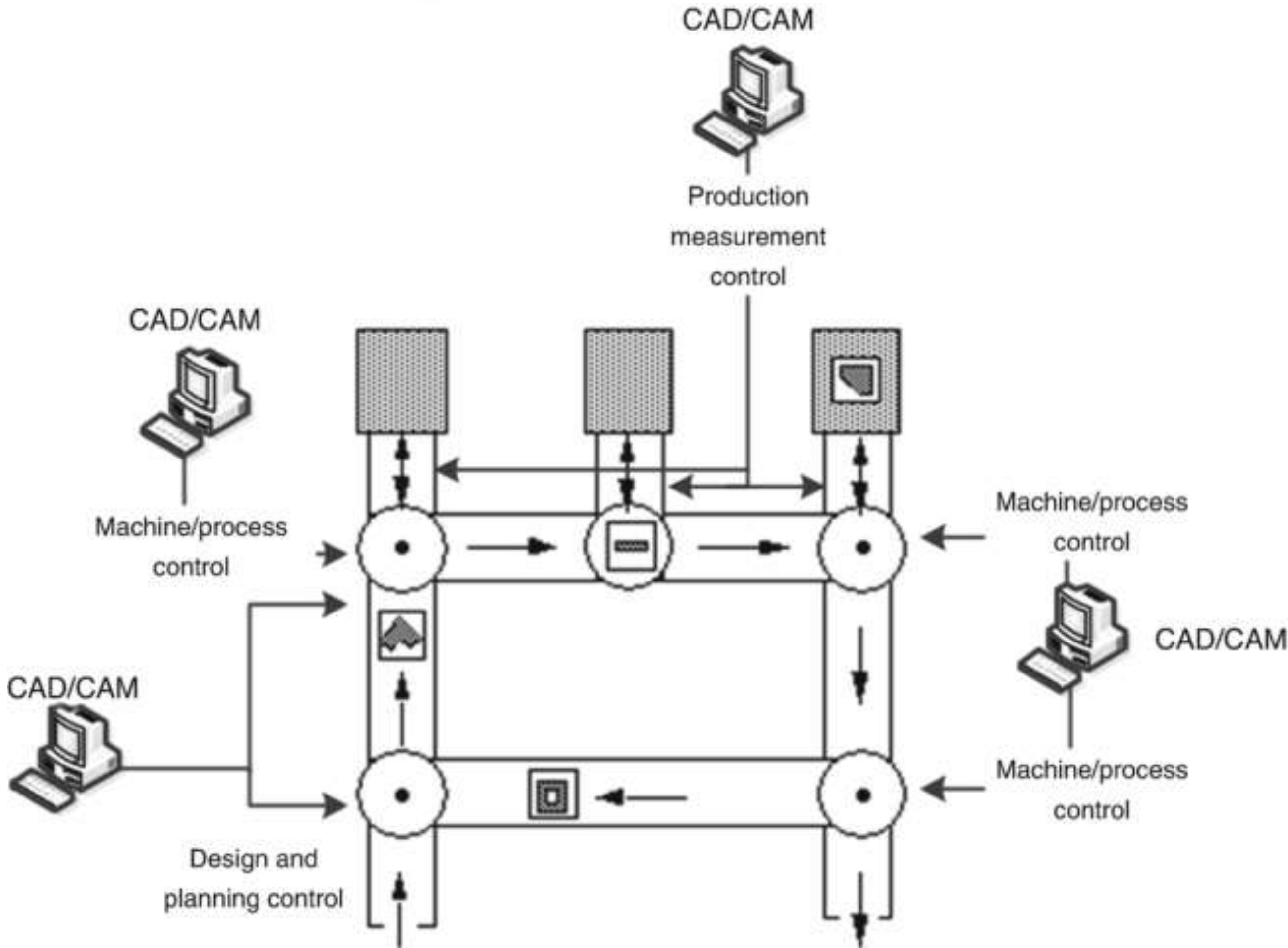
- The roots of **CAD/CAM** trail back to the beginning of civilization, when the engineers of the ancient civilizations such as Egyptians, Greeks and Romans acknowledged the importance of the graphical communication.
- Later on, Leonardo Da Vinci developed technics, such as cross-hatching and isometric views
- The invention of computers and xerography made possible the creation of graphics and visualization (1991)
- In the early 1950s, shortly after the World War II, the need for complex parts led to the invention of the **Numerical Control** (**NC**) that substituted the requirements for skilled human machine operators (Chang et al. 2006)
- At the same time another invention, namely the *digital computer*, assisted the development of **NC** and provided the means for the creation of **robots**, **computer aided design** (CAD), **computer-aided manufacturing** (**CAM**) and **flexible manufacturing systems** (**FMS**)

1950's	NC hardwired relay control
	APT language for NC
1960's	Industrial robot
	Interactive computer graphics
1970's	CNC computer
	DNC/FMS
	CAD/CAM
	PLC device & cell control
	Computer vision
	3-D CAD
1980's	Solid modeling
	Factory networking
	MAP/TOP
	CIM
	Concurrent engineering
1990's	Intelligent Mfg System

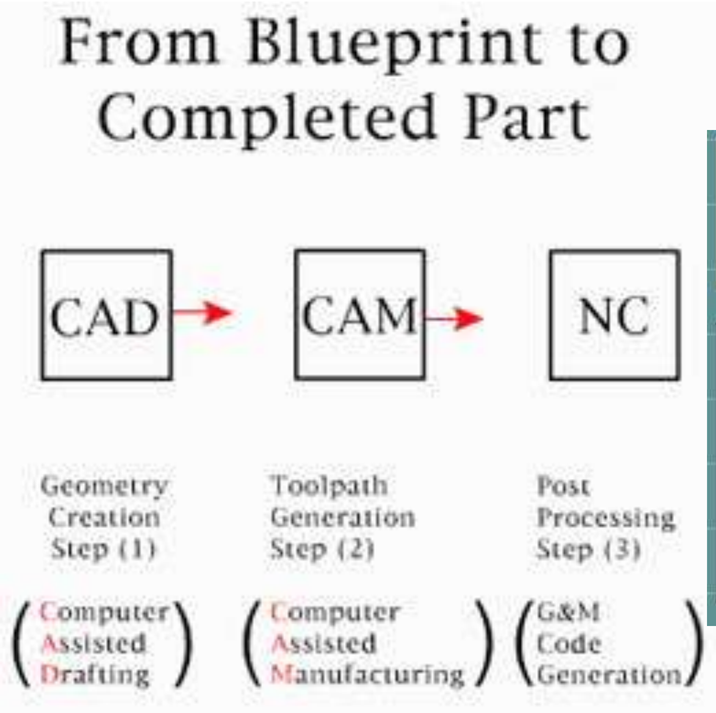
TECHNOLOGIES RELATED TO CAM

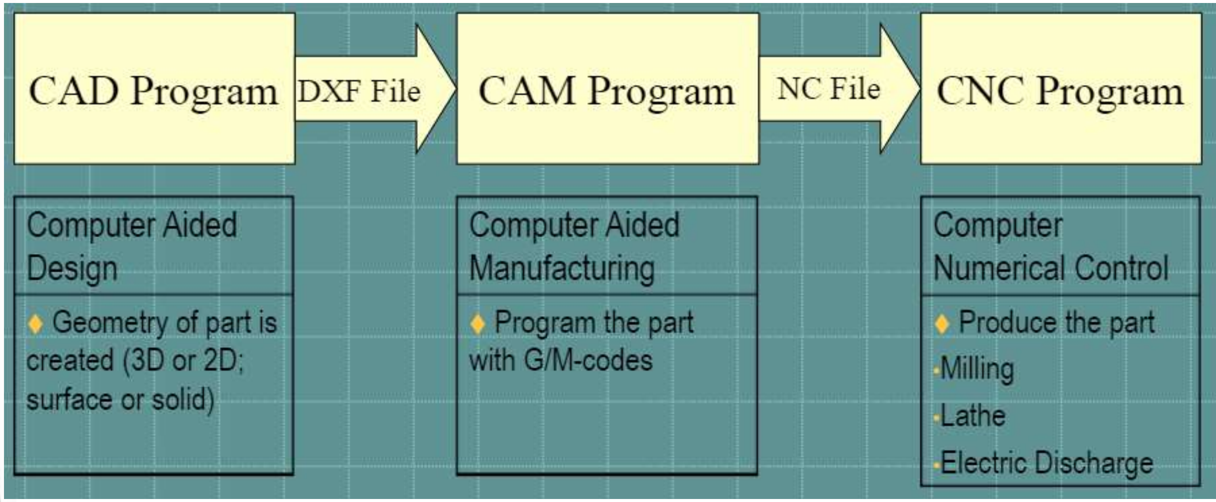
There are several constituent technologies in (CAM). Some of them are:

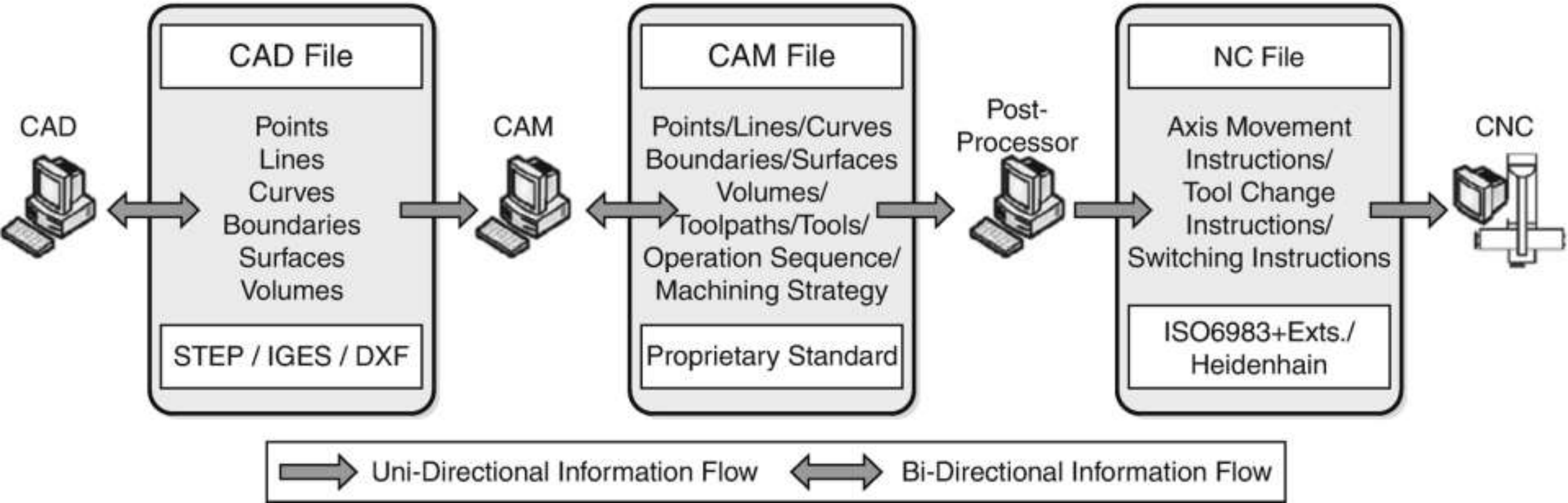
- (i) Computer Numerical Control
- (ii) CAM software
- (iii) Robotics
- (iv) Flexible manufacturing
- (v) Computer Aided Process Planning
- (vi) Enterprise resource planning
- (vii) Product life cycle management

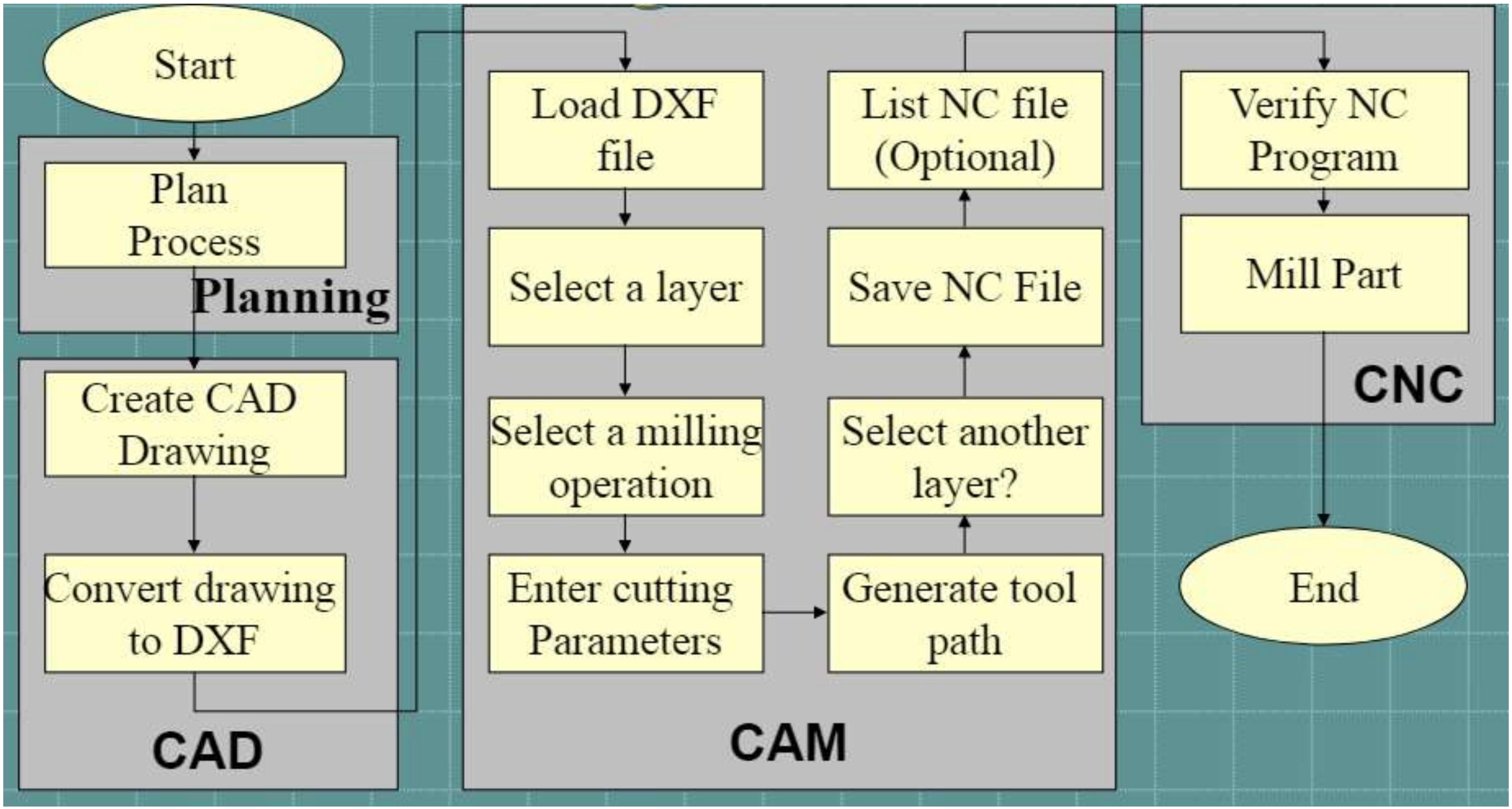


COMPUTER AIDED MANUFACTURING -I








Start
Plan Process
Planning
Create CAD Drawing
Convert drawing to DXF
CAD
Load DXF file
Select a layer
Select a milling operation
Enter cutting Parameters
Generate tool path
Select another layer?
Save NC File
List NC file (Optional)
CAM
Verify NC Program
Mill Part
CNC
End

COMPUTER AIDED MANUFACTURING -I

Why we need computer for design and manufacturing ?

For example: We are dealing with 20,000 parts in a car

Now…. with computer

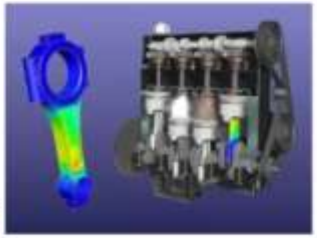
CAD (Solid Modeling) ⟷ **CAA** (Computer Aided Analysis)

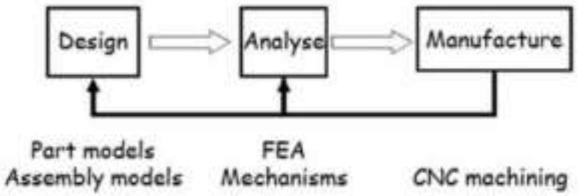
↓

CAM (Computer Aided Manufacturing) /Direct Manufacturing

↓

CNC Manufacturing



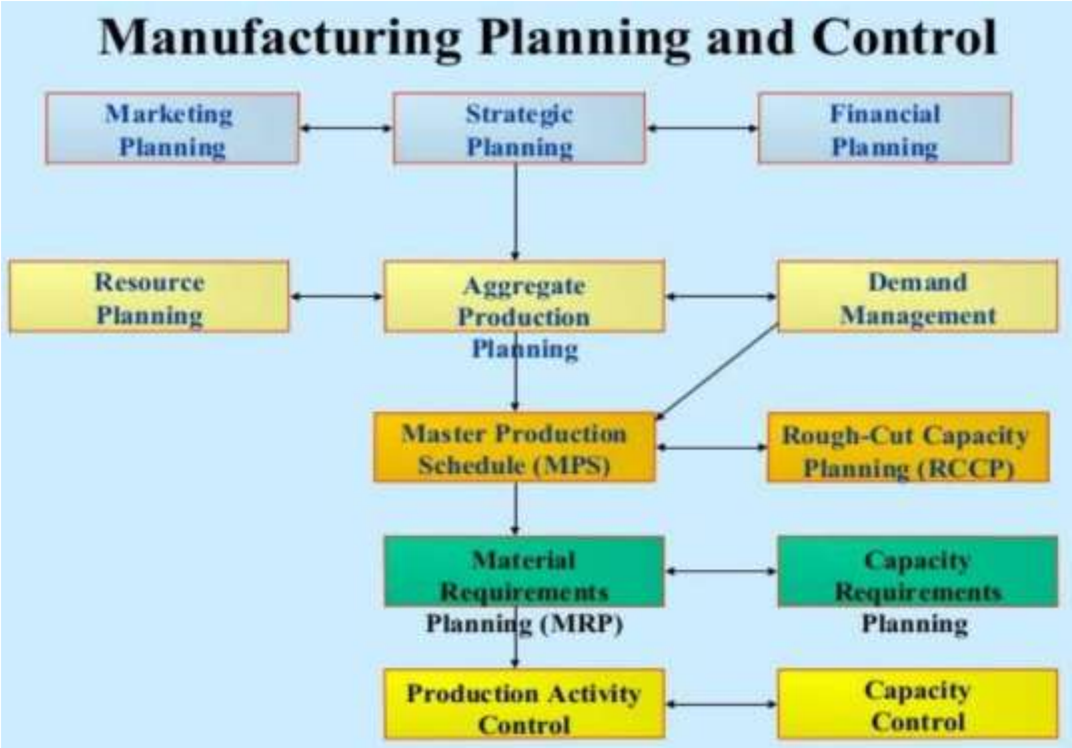


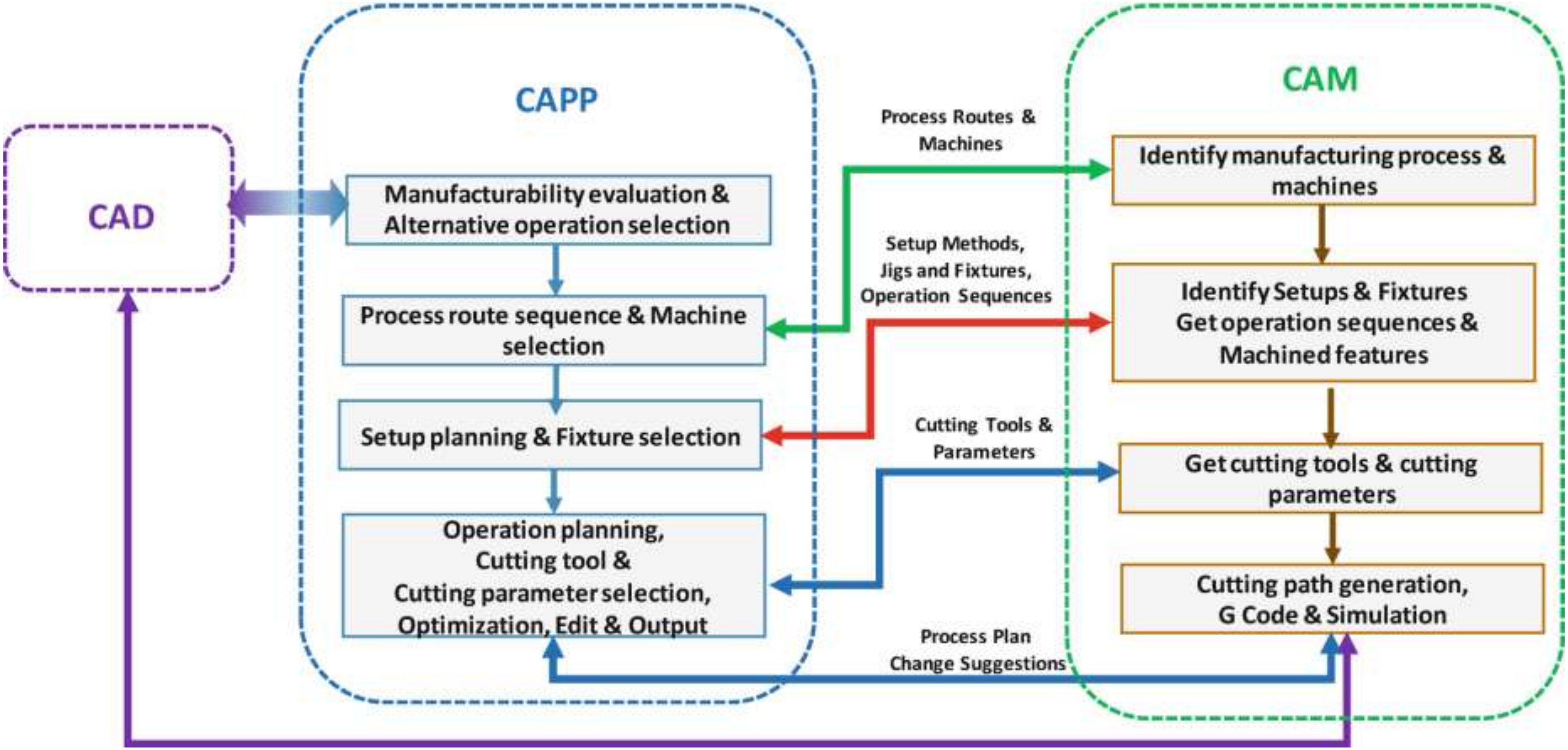
COMPUTER AIDED MANUFACTURING -I

❖ CAM application can be divided into two broad categories.

1. **CAM application in Manufacturing planning**
   - Computer aided process planning
   - Computer assisted NC part programming
   - CAD/CAM assisted NC part programming
   - Computerized machinability data system
   - Computerized work standards
   - Cost estimating
   - Production and inventory planning
   - Computer aided assembly line balancing

2. **CAM application in Manufacturing control**
   - Process monitoring
   - Quality control
   - Shop floor control
   - Inventory control
   - JIT – Just In Time production system
   - **CAQ** (computer-aided quality assurance)
   - **CAI** (computer aided Inspection)





CAPP
CAM
CAD
Manufacturability evaluation & Alternative operation selection
Process route sequence & Machine selection
Setup planning & Fixture selection
Operation planning, Cutting tool & Cutting parameter selection, Optimization, Edit & Output
Process Routes & Machines
Setup Methods, Jigs and Fixtures, Operation Sequences
Cutting Tools & Parameters
Process Plan Change Suggestions
Identify manufacturing process & machines
Identify Setups & Fixtures Get operation sequences & Machined features
Get cutting tools & cutting parameters
Cutting path generation, G Code & Simulation

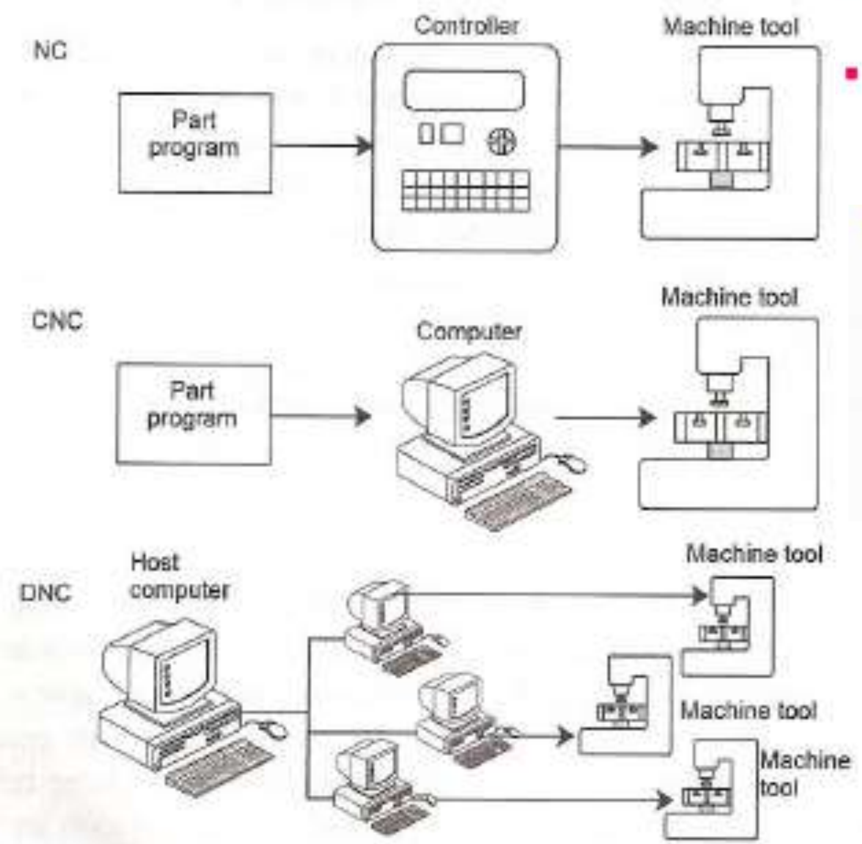


Figure 1.7: NC, CNC, and DNC Systems

Numerical Control (NC)

Form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data

- The alphanumeric data represent relative positions between a workhead (e.g., cutting tool) and a workpart
- When the current job is completed, a new program can be entered for the next job

CNC : Computer Numerical Control

- Conventionally, an operator decides and adjusts various machines parameters like feed , depth of cut etc depending on type of job , and controls the slide movements by hand. In a CNC Machine functions and slide movements are controlled by motors using computer programs.

Direct Numerical Control (DNC)

The purpose of a Direct Numerical Control (DNC) system is to provide a central digital repository for all manufacturing and NC data, and to make this data available to the shop floor. Features of a complete DNC solution include:

Central management and revision control of NC programs and related CAM data;

Direct connection from the data repository to CNC machines on the shop floor;

Configuration options to support specific requirements and preferences of each manufacturer.

S.NO	NC MACHINE	CNC MACHINE
1.	Here NC stands for Numerical Control	CNC stands for Computer Numerical Control.
2.	It is defined as the machine which is controlled by the set of instructions in the form of numbers, letters and symbols. The set of instructions is called as program.	It is defined as the machine which is used to control the motions of the work piece and tool with the help of prepared program in computer. The program is written in alphanumeric data.
3.	In NC machine the programs are fed into the punch cards.	In CNC machines the programs are fed directly into the computer by a small keyboard similar to our traditional keyboard.
4.	Modification in the program is difficult.	Modification in the program is very easy.
5.	A high skilled operator is required.	A less skilled operator is required.
6.	The cost of the machine is less.	The cost of the CNC machine is high.
7.	Maintenance cost is less	The maintenance cost is high.
8.	The programs in the NC machine cannot be stored.	In CNC machines, the programs can be stored in the computer and can be used again and again.
9.	It offers less flexibility and computational capability.	It offers additional flexibility and computational capability.
10.	The accuracy is less as compared with the CNC.	It has high accuracy.
11.	It requires more time for the execution of the job.	It takes very less time in the execution of the job.
12.	It is not possible to run it continuously.	It can be run continuously for 24 hours of a day.

Numerical Control (NC) Defined

- **NC (numerical control) machine tools** are the machine tool, of which the various functions are controlled by : letters , numbers and symbols.

- The NC machine tool runs on a program fed to it; without human operator. The NC program consist of a set of instruction or statement for controlling the motion of the drives of the machine tools as well as the motion of the cutting tool.

- NC machine tools , one or more of the following function may be automatic :

i. Starting and stopping of the machine tool spindle;
ii. Controlling the spindle speed;
iii. Positioning the tool at the desired location and guiding it along the desired path by automatic control of the motion of slides;
iv. Controlling the feed rate; and
v. Changing the tools.

Components of NC machine tool system

1. **Part program:-**

- Using the part drawing and the cutting parameters, the part program is written.
- The part program is a set of step by instruction to the machine tool for carrying out the operation.
- **Method use for part programming**

1. Manual part programming
2. Computer-aided part programming

2. **Program Tape:-**

- The part program is entered on the program tape.
- The program is entered on the tape in the form of punched holes. The holes are punched with the help of punching machine.

3. **Machine Control Unit(MCU):-**

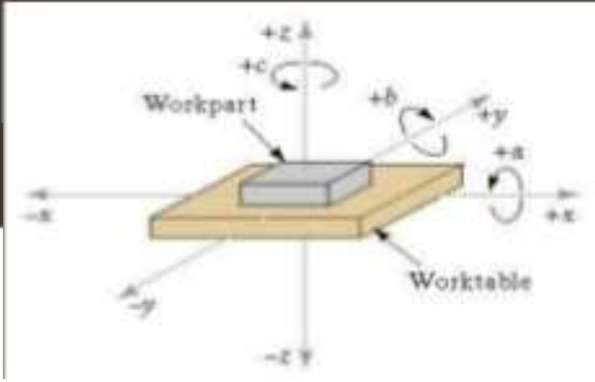
- The program tape is read by the tape reader.
- The controller takes input from the tape reader.

4. **Machine Tool:-**

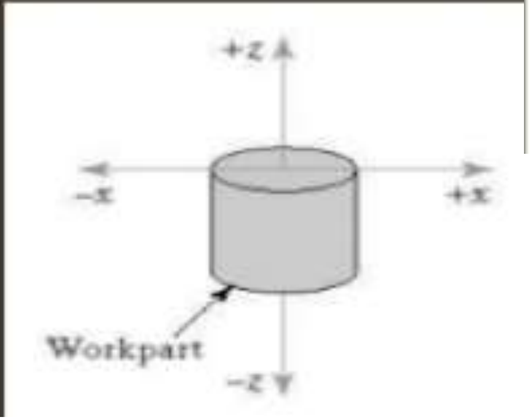
- The machine tool is operated by the controller of the machine control unit.

NC Coordinate Systems

- **For flat and prismatic (block-like) parts:**
  - Milling and drilling operations
  - Conventional Cartesian coordinate system
  - Rotational axes about each linear axis



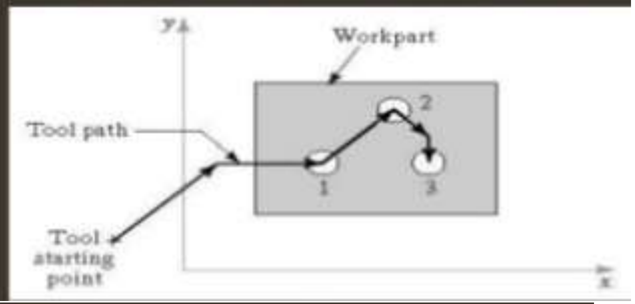
- **For rotational parts:**
  - Turning operations
  - Only *x*- and *z*-axes



Motion Control Systems

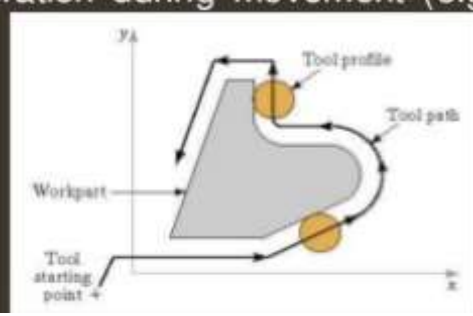
1. **Point-to-Point systems**

- Also called position systems
- System moves to a location and performs an operation at that location (e.g., drilling)
- Also applicable in robotics



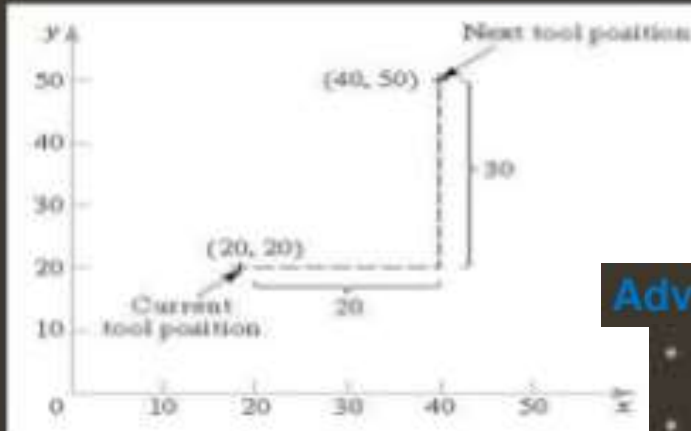
2. **Continuous path systems**

- Also called contouring systems in machining
- System performs an operation during movement (e.g., milling and turning)



Absolute vs. Incremental Positioning

- Absolute positioning
  - *Move is:* $x = 40$, $y = 50$
- Incremental positioning
  - *Move is:* $x = 20$, $y = 30$.



Advantages of NC machine tool

- Cycle time reduction
- Complex machining operation
- High degree of accuracy
- Less inspection required
- Reduction of scrap and wastage
- Increasing productivity
- Lower tooling cost
- Reduction of human error
- Greater operation safety
- Greater operation efficiency
- Reduction space required
- Operator skill-level reduced

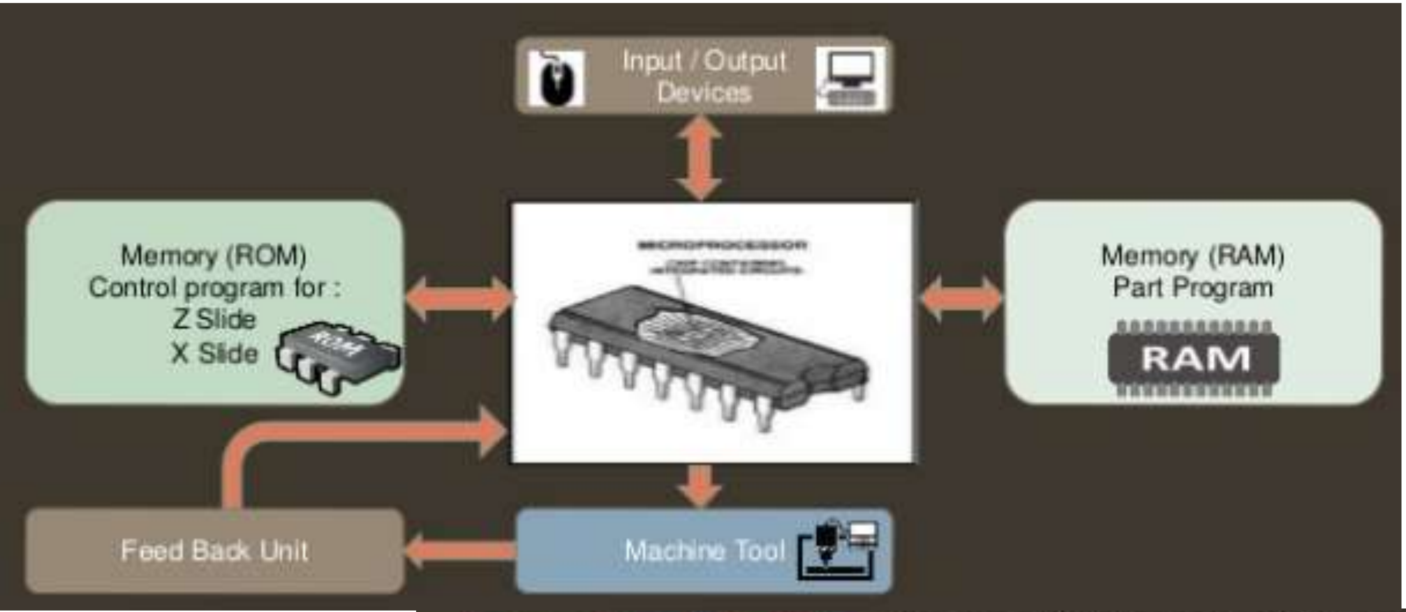
Limitation of NC machine tool

- High investment cost
- High maintenance effort
- Need for skilled programmers
- High utilization required

Introduction to CNC Machine Tools

- In **CNC (Computer Numerical Control) machines**, a dedicated computer is used to perform the most of basic NC machine functions.
- **CNC (Computer Numerical Control) machine** is a NC machine which uses a dedicated computer as the machine control unit.
- The entire program is entered and stored in computer memory. The machining cycle for each component is controlled by the program contained in the computer memory.
- The stored part program listing can be used for future production also.
- The main components of CNC machine tools are as follows :

1. Input / Output Console.
2. Microprocessor Based control unit.
3. Memory.
4. Feedback unit.
5. Machine Tool.
6. Interfaces.



- Input / Output Console : It is the unit through which part program is fed to the CNC machine tool system and required output is taken out. It basically consists of monitor and Keyboard.
- Microprocessor : This controller takes input from Input / Output device, Feedback from feedback unit and actuates the drives as well as the tool of the machine tool.
- Memory : It consists of RAM & ROM. The RAM stores part program, while ROM stores the programs for machine control.
- Feedback unit : The feedback unit takes input from machine tool and transfers it to control unit for necessary corrections.
- Machine tool : Machine tool is operated by the control unit.
- Interfaces : They are the connections between the different components of the CNC machine tool system.

Classification of CNC Machine tool systems

(a) According to type of Feedback systems

1. Open loop type CNC machine.
2. Closed loop type CNC machine.

(b) According to type of tool motion control

1. Finite positioning control CNC machines.
2. Continuous path control CNC machines.

(c) According to program methods

1. Absolute Programming CNC machine systems.
2. Incremental Programming CNC machine systems.

(d) According to type of controller

1. Hybrid controller CNC systems.
2. Straight controller CNC systems.

(e) According to axis & type of operations

1. CNC horizontal machining centre.
2. CNC vertical machining centre.
3. CNC turning centre.
4. CNC milling centre.

1. Open-Loop type CNC Machine

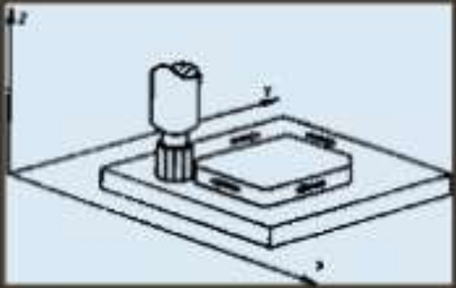
- It does not have any feedback mechanism.
- It only has motion control but do not have any provision for feedback, which is needed to be compared with input for better control & correction of drive system.

2. Closed-Loop type CNC Machine

- It has a feedback mechanism.
- It has the motion control with a provision of feedback of feedback.
- Which can be used for accurately controlling the drive system by comparing it with the input information until the required or desired position is achived.

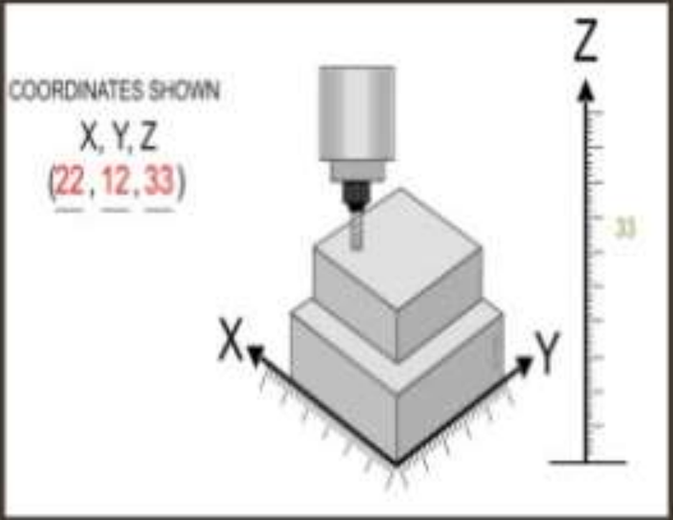
COMPUTER AIDED MANUFACTURING -I

1. Finite position control CNC machine



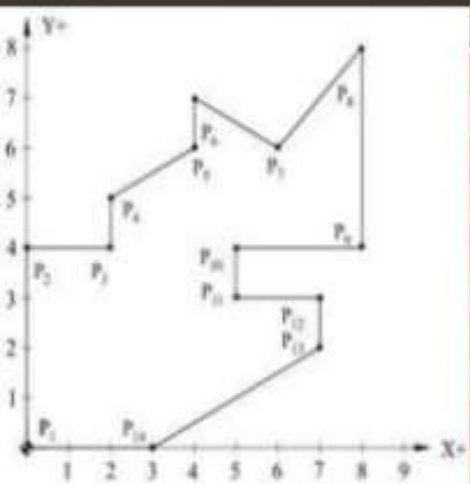
- In point to point CNC machines, the movement of cutting tool from one predefined position to another predefined position is important, while the path along which this tool moves is irrelevant. Commonly used in drilling & punching operations.
- Straight cut line control mode is the extension version of point to point method, straight cut is obtained controlling the movement of tool with controlled feed rate in one of the axis direction at a time. Commonly used in Face milling, pocket milling and step turning operations.

2. Continuous path control CNC machine



- The continuous path control system is used for continuous, simultaneous & coordinated motions of cutting tool & work piece along different axes.
- Such motion enables machining of different contoured profiles & curved surfaces.
- Types : 2 axis, 2 ½ axis, 3 axis, Multi axis countering.

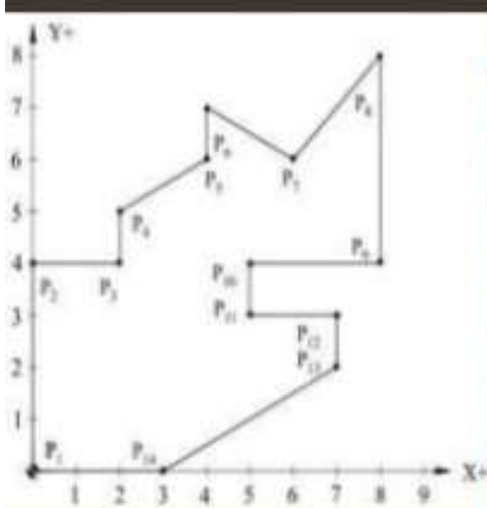
1. Absolute programming CNC machine systems



X	Y
0	0
0	4
2	4
2	5
4	6
4	7
6	6
8	8
8	4
5	4

- In Cartesian coordinate geometry system using absolute measurement, each point is always specified using same zero established for a given coordinate system.

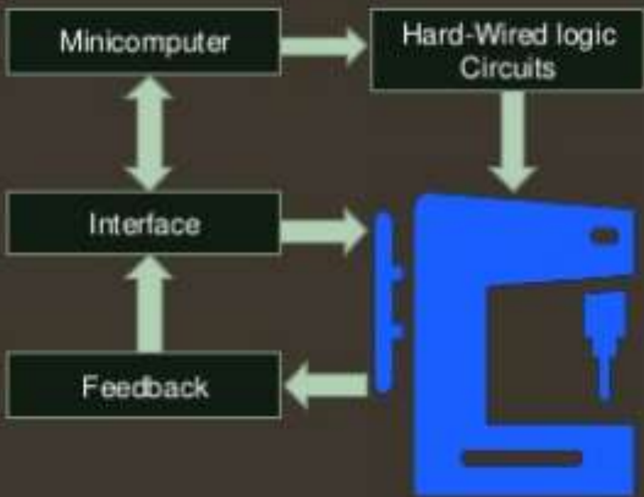
2. Incremental programming CNC machine systems



X	Y
0	0
0	4
2	0
0	1
2	1
0	1
2	-1
2	2
0	-4
-	-

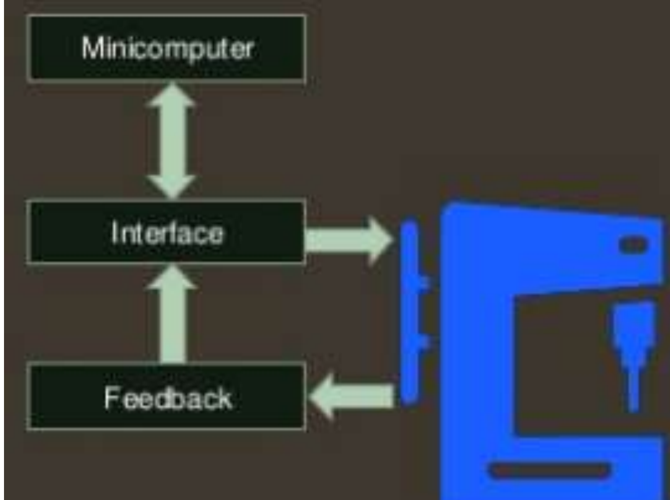
- In Cartesian coordinate geometry system using incremental measurement , each point is specified using the path differential from the preceding point position. So in such programming , controller must store and process additional path measurement.

1. Hybrid controller CNC systems



1. Hard wired logic circuits : It performs those functions for which they are best suited, such as feed rate generation and interpolation.
2. Soft wired computer : The computer performs the remaining control functions plus other duties not normally associated with a conventional hard-wired controller.

2. Stage controller CNC systems



- It uses a computer to perform all the functions.
- The interpolation, feed rate generation and all other functions are performed by the computer with the help of software.
- The only hard-wired elements are those required to interface the computer with machine tool and operator's console.

Advantages & Limitations of CNC machine tools

Advantages

- Ease of program input.
- Multiple program storage.
- Online part programming and editing.
- Use of advanced interpolation.
- Automatic tool compensation.
- Auto generation of part program for existing components.
- Change in system of units.

Limitations

- Higher investment cost.
- Higher maintenance cost.
- Requires specialised operators.

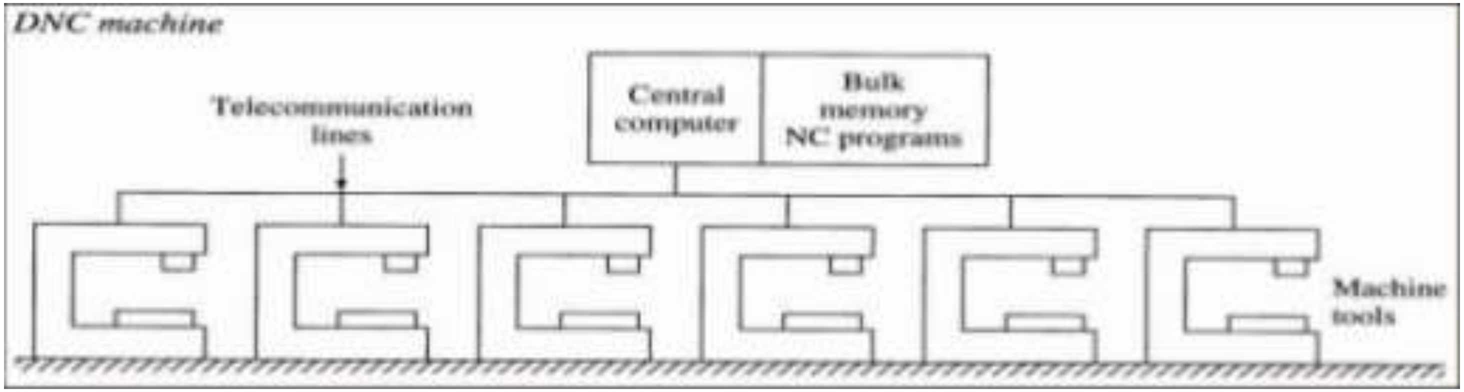
Introduction DNC

- DNC is a manufacturing system in which a number of machines are controlled by a computer through direct- connection and in real time.
- Also, defined by EIA as: DNC is a system connecting a set of NC machines to a common memory for part program or machine program storage with provision for on- demand distribution of data to machines.
- The tape reader is omitted.
- Involves data connection and processing from the machine tool back to the computer.

Components

1. Central computer
2. Bulk memory which stores the NC part programs.
3. Telecommunication lines
4. Machine Tools.

- A central computer connected to a number of machine tools and control them
- Part program of all machine tools are stored in the memory of the central computer and transmitted on direct transmission lines on demand
- Two way information flow take place in real time
- Various machine tools can communicate with the computer in real time
- Programs in full or segment can be transferred to NC machines
- Computer can be used for program editing
- No tape readers are used
- No limitation for the number or size of programs stored



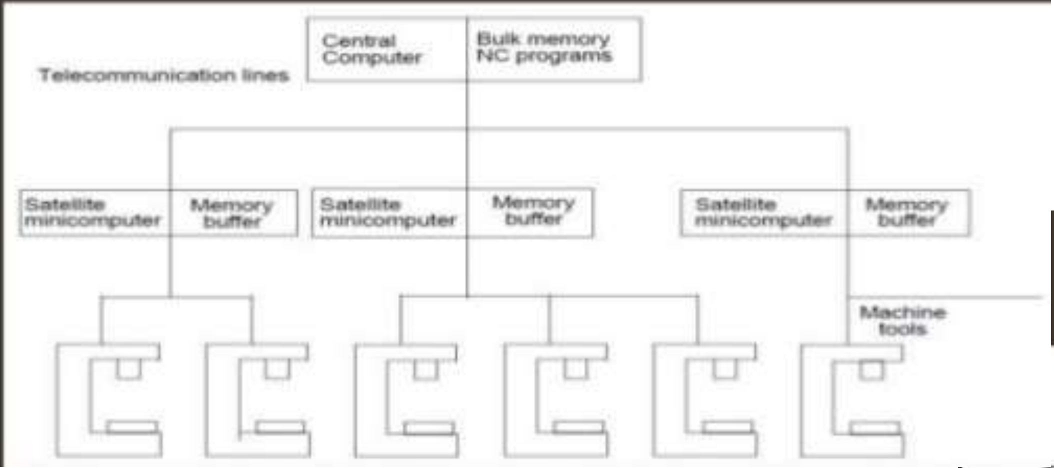
The configuration of the DNC system can be divided into:

1. DNC system without satellite computer.

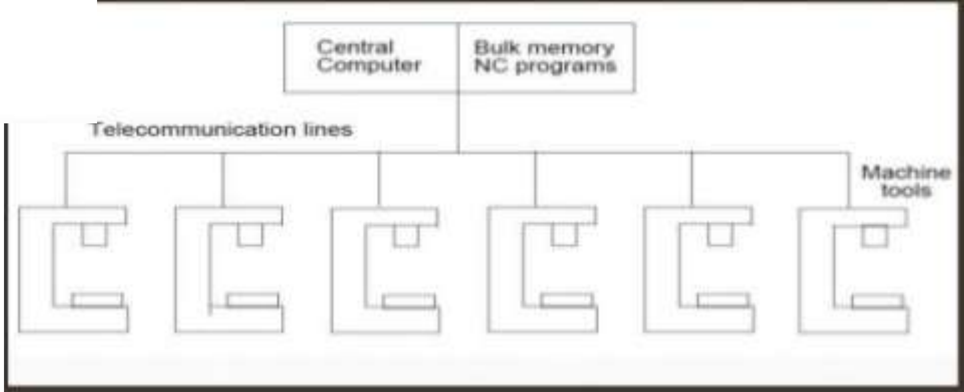
2. DNC system with satellite computer.

Satellite computers are minicomputers and they serve to take some of the burden off central computer. Each satellites controls several machine tools.

DNC system with satellite computer



DNC system without satellite computer



Functions of DNC

The functions which a DNC system is designed to perform:

1. NC without punched tape.
2. NC part program storage.
3. Data collection, processing, and reporting.
4. Communication

Advantages of DNC System

- Elimination of punched tapes and tape readers
- Convenient storage of NC part programs in computer files
- Greater computational capability and flexibility
- Reporting of shop performance.
- Convenient editing and diagnostic features.

Comparison between NC, CNC and DNC machine tools

NC Machine Tool System	CNC Machine Tool System	DNC Machine Tool System
1. The part program is fed to the machine through the tapes or other such media.	1. In CNC machine tool system, the program is fed to the machine through the computer.	1. The part program is fed to the machine through the Main computer
2. In order to modify the program, the tapes have to be changed.	2. The programs can be easily modified with the help of computer.	2. In order to modify the program, single computer is used
3. In NC machine tool system, tape reader is a part of machine control unit.	3. The microprocessor or minicomputer forms the machine control unit. The CNC machine does not need tape reader.	3. Large memory of DNC allows it to store a large amount of part program.
4. System has no memory storage and each time it is run using the tape.	4. It has memory storage ability, in which part program can be stored.	4. Same part program can be run on different machines at the same time.
5. It can not import CAD files.	5. System can import CAD files and convert it to part program.	5. The data can be processed using the MIS software so as to effectively carry out the Production planning and scheduling.
6. It can not use feedback system.	6. The system can use feedback system.	
7. They are not software driven.	7. The system is software driven.	

NC PART PROGRAMMING

WHAT IT IS COMPRISED OF ?

- COLLECTION OF DATA
- ARRANGEMENT OF INFORMATION IN A STANDARD FORMAT.
- CALCULATION OF TOOL PATH

CLASSIFICATION OF DATA REQUIRED TO PRODUCE A PART ?

INFORMATION FROM THE DRAWING

- DIMENSIONS OF FEATURES
- SEGMENT SHAPE

MISCELLANEOUS INFORMATION

- SURFACE QUALITY
- TOLERANCES
- TOOL & W/P MATL.
- MACHINING CONDITIONS
- AUXILIARY FUNCTION

DATA DETERMINED BY THE PART PROGRAMMER

- DIRECTION OF THE CUTTING
- TOOL CHANGE
- SEQUENCING (REQUIRES FAMILIARITIES WITH NC PROCESS)
- FAMILIARITY WITH NC M/C TOOL SYSTEMS

HOW THE TAPES CAN BE PRODUCED ?

- MANUAL
- COMPUTER ASSISTED PROGRAMMING

VARIOUS FUNCTIONS

- **SEQUENCE NUMBER N:**
  - DISPLAYED IN THE CONSOLE. EACH BLOCK.
- **PREPARATORY FUNCTION G:**
  - PREPARES **MCU** TO BE READY TO PERFORM SPECIFIC MODE OF OPERATION.
  - PRECEDS THE DIMENSION WORD / NUMBER.

    EX. G21 – METRIC DATA INPUT.
- **DIMENSION WORD:**
  - DISTANCE DIMENSION WORDS X, Y, Z.
  - CIRCULAR DIMENSION – IN CIRCULAR INTERPOLATION & THREAD CUTTING.
  - I, J, K – DISTANCE TO ARC CENTER (OR THREAD LEAD) PARALLEL TO X, Y, Z.

CIRCULAR INTERPOLATION:

- **PREPARATORY FUNCTIONS (G17,G18,G19) FOR PLANE OF ARC**
- **FOR DIRECTION OF TOOL ON THE ARC (G02,G03….)**

- 4 DIMENSION WORDS/BLOCK – 2 TO THE END OF THE ARC + 2 FOR THE DISTANCE OF THE ARC CENTER.
- AN ARC MUST END IN THE SAME QUADRANT.
- IF MORE THAN 1 QUANDRANT – 2 OR MORE BLOCKS OF NFORMATION.

THREAD CUTTING

- THREAD CUTTING MODE BY PREPARATORY FUNCTIONS G33-G35
- FOUR DIMENSION WORDS/BLOCK.
- LEADS PARALLELED TO X, Y, Z AXES – BY i, j, k
- NO ALGEBRAIC SIGN (+ OR -).

- **ANGULAR DIMENSION WORD : A, B, C AROUND X, Y, Z, RESPECTIVELY**
- **FOR ANGULAR DIMESNION AROUND SPECIAL AXIS D, E.**
- **DIMESNION WORDS – CO-ORDINATES (INCREMENTAL / ABSOLUTE)**
- **THE MISCELLANEOUS FUNCTION M:**

  - **2 DIGITS AUXILIARY INFORMATION NOT RELATED TO DIMENSIONS – SPINDLE COMMAND, COOLANT ON/OFF ETC.**

  - **'STOP' (M00,M01) AND 'END' ARE EXECUTED AFTER COMPLETION OF OTHER COMMANDS IN THE BLOCK.**

G-Code	Function	G-Code	Function	G-Code	Function
G00	Positioning (Rapid Traverse)	G42	Start Nose Radius Compensation Right	G91	Incramental Distance Mode
G01	Linear Interpolation (Feed)	G48	Max RPM In CSS	G92	Offset Coordinates And Set Parameters
G02	Clockwise Circular Interpolation	G50	Reset All Scale Factors To 1.0	G92.x	Cancel G92 etc.
G03	Counter Clockwise Circular Interpolation	G51	Set Axis Data Input Scale Factors	G94	Feed Per Minute Mode
G04	Dwell (Time Delay)	G52	Temporary Coordinate System Offsets	G95	Feed Per Revolution Mode
G10	Coordinate System Origin Setting	G53	Move In Absolute Machine Coordinates	G96	Spindle - Constant Surface Speed Mode
G15	Polar Coordinate Moves In G00	G54	Fixture Offset 1 (Front Tool Post)	G97	Spindle - Revolutions Per Minute Mode
G16	Polar Coordinate Moves In G01	G55	Fixture Offset 2 (Rear Tool Post)	G98	Initial Level Return After Canned Cycles
G17	X/Y Plane Select	G56-59	Fixture Offsets 3 - 6	G99	R-Point Level Return After Canned Cycles
G18	X/Z Plane Select	G61	Exact Stop		
G19	Y/Z Plane Select	G64	Constant Velocity		
G20	Imperial Units (Inch)	G76	Threading (Canned Cycle)		
G21	Metric Units (Millimeter)	G77			
G28	Return Home	G78			
G28.1	Reference Axes	G80	Cancel Motion Mode (Inc Canned Cycles)		
G30	Return Home	G81	Drilling (Canned Cycle)		
G32	Threading (Canned Cycle)	G82	Drilling With Dwell (Canned Cycle)		
G40	Cancel Nose Radius Compensation	G83	Peck Drilling (Canned Cycle)		
G41	Start Nose Radius Compensation Left	G90	Absolute Distance Mode		

M-Code	Function
M00	Program Stop
M01	Option Stop
M02	Program End
M03	Rotate Spindle Clockwise
M04	Rotate Spindle Counter Clockwise
M05	Stop Spindle
M07	Mist Coolant On
M08	Flood Coolant On
M09	All Coolant Off
M30	Program End And Rewind
M47	Repeat Program From First Line
M48	Enable Speed And Feed Overrides
M49	Disable Speed And Feed Overrides
M98	Call Subroutine
M99	Return From Subroutine / Repeat

MANUAL PART PROGRAMMING

- TYPES OF MANUAL PROGRAMMING: POINT TO POINT, CONTOURING, 3-D.
- *(3-D programming, only with the help of a computer) .*

- WRITE THE PART PROGRAM IN A STANDARD FORMAT
- SPECIAL MANUSCRIPT AND FLEXO WRITER – TAPE, LISTING etc. *(Nowadays, these are is not required)*
- MOSTLY POINT TO POINT programming – SIMPLE
- COMPLICATED CONFIGURATION OF THE PATH – CALCULATIONS with the help of a COMPUTER.
- SEVERAL SPECIAL PURPOSE LANGUAGES FOR NC ROGRAMMING – SAY, APT.

BASIC CONCEPTS OF MANUAL PART PROGRAMMING

- WHO PREPARES THE TAPE / CD ? – PROGRAMMER –> SHOULD BE FAMILIAR WITH THE MANUFACTURING PROCESSES.
- OPTIMAL SEQUENCE OF OPERATIONS SHOULD BE KNOWN.
- PROGRAM SHOULD BE WRITTEN IN THE MANUSCRIPT.
- EACH LINE OF THE MANUSCRIPT TELLS WHAT IS BEING DONE ?
- TRANSFER OF CUTTING TOOL INCLUDING OTHER INSTRUCTIONS.
  - EXAMPLE :N – SEQUENCE #, G – PREPARATORY FUNCTION, X&Y – DIMENSIONAL WORDS,F (or f)- FEED RATE, S – SPINDLE SPEED,T – TOOL #, M – MISCELLANEOUS FUNCTION, EB – END OF BLOCK.
- X, Y – WORD ADDRESS.
- EB – READING COMPLETED & MOTION STARTS

FEED FUNCTION

- ‘f’ – RESTRICTED TO CONTOURING OR STRAIGHT - CUT.
- FEED RATES OF LINEAR OR CIRCULAR MOTION – INDEPENDENT OF SPINDLE SPEEDS – EXPRESSED AS inches/min OR mm/min.
- ‘MCU’ ACCCEPTS SPECIFIC METHOD OF EXPRESSING ‘FRN’ :

The part program is a sequence of instructions, which describe the work, which has to be done on a part, in the form required by a computer under the control of a numerical control computer program.

It is the task of preparing a program sheet from a drawing sheet. All data is fed into the numerical control system using a standardized format. Programming is where all the machining data are compiled and where the data are translated into a language which can be understood by the control system of the machine tool.

The machining data is as follows :

(a) Machining sequence classification of process, tool start up point, cutting depth, tool path, etc.

(b) Cutting conditions, spindle speed, feed rate, coolant, etc.

(c) Selection of cutting tools.

While preparing a part program, need to perform the following steps :

(a) Determine the startup procedure, which includes the extraction of dimensional data from part drawings and data regarding surface quality requirements on the machined component.

(b) Select the tool and determine the tool offset.

(c) Set up the zero position for the workpiece.

(d) Select the speed and rotation of the spindle.

(e) Set up the tool motions according to the profile required.

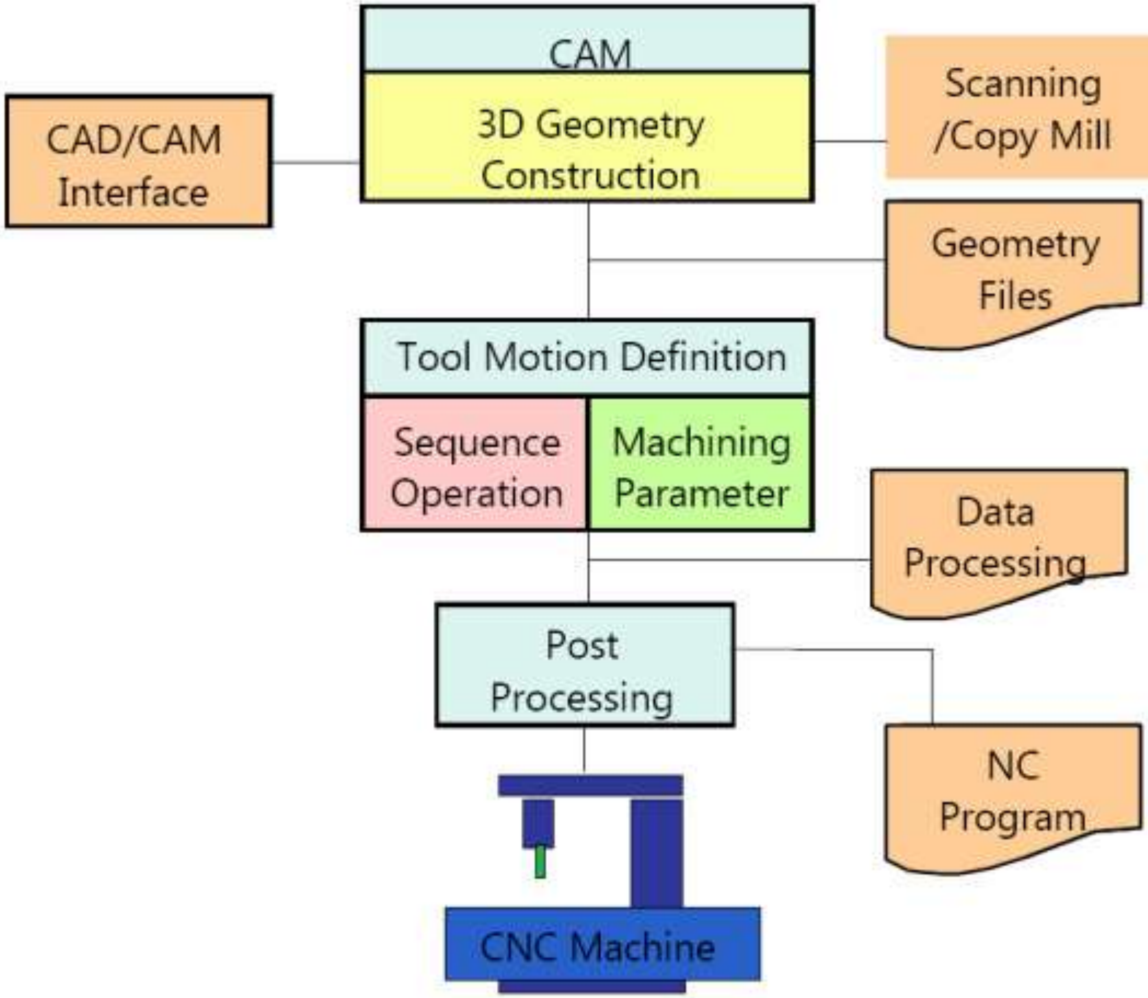
(f) Return the cutting tool to the reference point after completion of work.

(g) End the program by stopping the spindle and coolant.

The part programming contains the list of coordinate values along the X, Y and Z directions of the entire tool path to finish the component. The program should also contain information, such as feed and speed. Each of the necessary instructions for a particular operation given in the part program is known as an NC word. A group of such NC words constitutes a complete NC instruction, known as block. The commonly used words are N, G, F, S, T, and M.

The methods of part programming can be of two types depending upon the two techniques

(a) Manual part programming
(b) Computer aided part programming.



Interactive Graphic System in Computer Aided Part Programming

Block of Information

NC information is generally programmed in blocks of words. Each word conforms to the EIA standards and they are written on a horizontal line. If five complete words are not included in each block, the machine control unit (MCU) will not recognize the information; therefore the control unit will not be activated. It consists of a character N followed by a three digit number raising from 0 to 999.

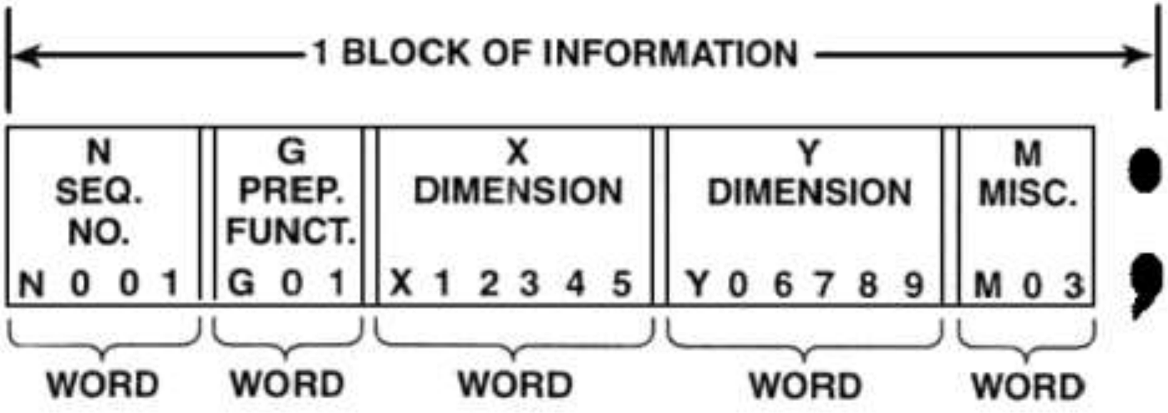


Figure 4.2 : A Block of Information

Using the example shown in Figure 4.2. The words are as follows :

N001 – represents the sequence number of the operation.

G01 – represents linear interpolation.

X12345 – will move the table in a positive direction along the *X*-axis.

Y06789 – will move the table along the *Y*-axis.

M03 – Spindle on CW and

; – End of block.

G-Codes (Preparatory Functions)

Code	Function
G00	Rapid positioning
G01	Linear interpolation
G02	Circular interpolation clockwise (CW)
G03	Circular interpolation counterclockwise (CCW)
G20	Inch input (in.)
G21	Metric input (mm)
G24	Radius programming
G28	Return to reference point
G29	Return from reference point
G32	Thread cutting
G40	Cutter compensation cancel
G41	Cutter compensation left
G42	Cutter compensation right
G43	Tool length compensation positive (+) direction
G44	Tool length compensation minus (-) direction
G49	Tool length compensation cancels
G 53	Zero offset or M/c reference
G54	Settable zero offset
G84	canned turn cycle
G90	Absolute programming
G91	Incremental programming

M-Codes (Miscellaneous Functions)

Code	Function
M00	Program stop
M02	End of program
M03	Spindle start (forward CW)
M04	Spindle start (reverse CCW)
M05	Spindle stop
M06	Tool change
M08	Coolant on
M09	Coolant off
M10	Chuck - clamping
M11	Chuck - unclamping
M12	Tailstock spindle out
M13	Tailstock spindle in
M17	Tool post rotation normal
M18	Tool post rotation reverse
M30	End of tape and rewind or main program end
M98	Transfer to subprogram
M99	End of subprogram

Word Address Format

This type of tape format uses alphabets called address, identifying the function of numerical data followed. This format is used by most of the NC machines, also called variable block format. A typical instruction block will be as below :

N20 G00 X1.200 Y.100 F325 S1000 T03 M09 <EOB>

or

N20 G00 X1.200 Y.100 F325 S1000 T03 M09;

The MCU uses this alphabet for addressing a memory location in it.

Tab Sequential Format

Here the alphabets are replaced by a Tab code, which is inserted between two words. The MCU reads the first Tab and stores the data in the first location then the second word is recognized by reading the record Tab. A typical Tab sequential instruction block will be as below :

>20 >00 >1.200 >.100 >325 >1000 >03 >09

Fixed Block Format

In fixed block format no letter address of Tab code are used and none of words can be omitted. The main advantage of this format is that the whole instruction block can be read at the same instant, instead of reading character by character. This format can only be used for positioning work only. A typical fixed block instruction block will be as below:

20 00 1.200 .100 325 1000 03 09 <EOB>

Absolute Zero Shift

The absolute zero shift can change the position of the coordinate system by a command in the CNC program. The programmer first sends the machine spindle to home zero position by a command in the program. Then another command tells the MCU how far from the home zero location, the coordinate system origin is to be positioned.

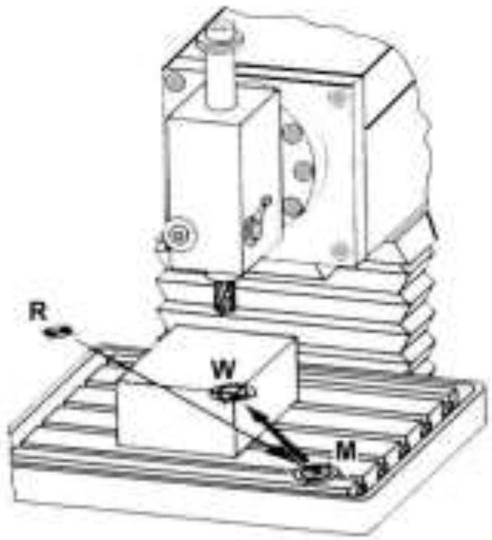


Figure 4.3 : Machine Tool Zero Point Setting

R = Reference point (maximum travel of machine) 

W = Part zero point workpice coordinate system 

M = Machine zero point (X0, Y0, Z0) of machine coordinate system 

The sample commands may be as follows :

N1 G28 X0 Y0 Z0 (sends spindle to home zero position or Return to reference point).

N2 G92 X3.000 Y4.000 Z5.000 (the position the machine will reference as part zero or Programmed zero shift).

4.3.9 Spindle Function

The spindle speed is commanded under an S address and is always in revolution per minute. It can be calculated by the following formula :

$$\text{Spindle Speed} = \frac{\text{Surface cutting speed in m/min} \times 1000}{\pi \times \text{Cutter Diameter in mm}}$$

4.3.10 Feed Function

The feed is programmed under an *F* address except for rapid traverse. The unit may be in mm per minute or in mm per revolution. The unit of the federate has to be defined at the beginning of the programme. The feed rate can be calculated by the following formula :

$$\text{Feet Rate} = \frac{\text{Chip Load}}{\text{Tooth} \times \text{No. of tooth} \times \text{Spindle speed}}$$

Tool Function The selection of tool is commanded under a T address. T04 represents tool number 4.

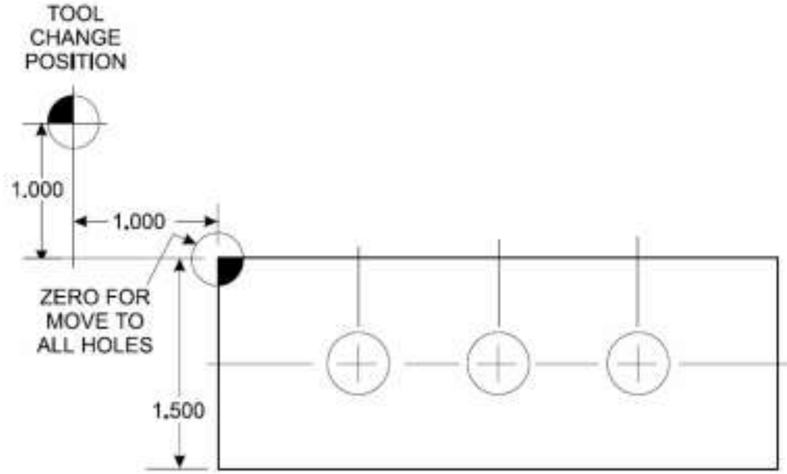


Figure 4.4 : Work Settings

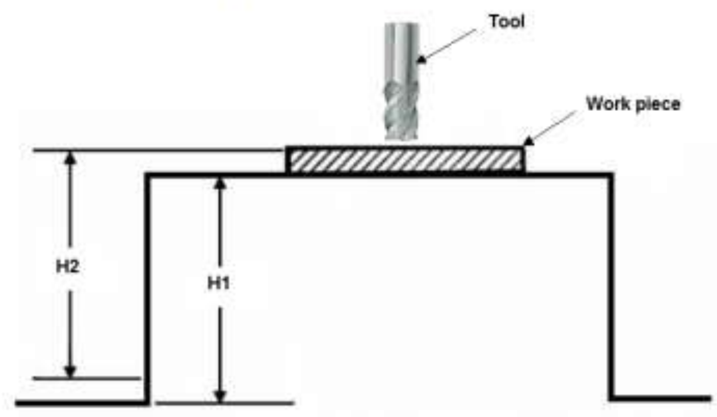


Figure 4.5 : Offsets

4.3.13 Rapid Positioning

This is to command the cutter to move from the existing point to the target point at the fastest speed of the machine.

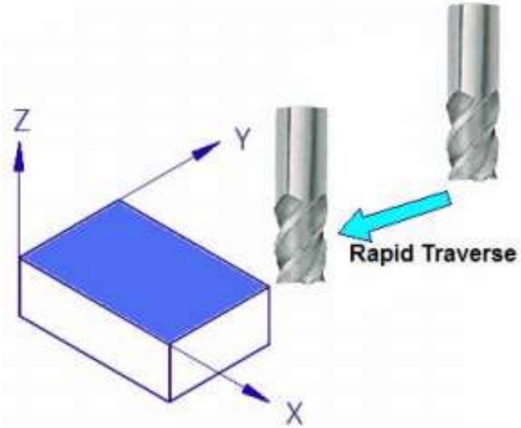


Figure 4.6 : Rapid Positioning

4.3.14 Linear Interpolation

This is to command the cutter to move from the existing point to the target point along a straight line at the speed designated by the *F* address.

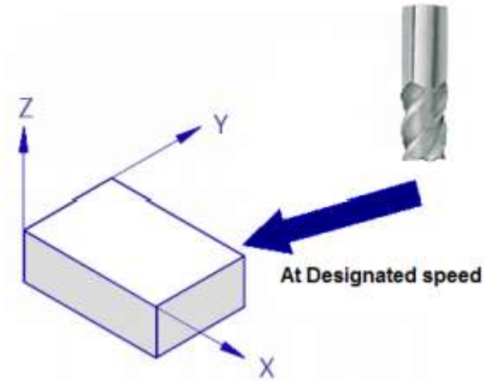


Figure 4.6 : Linear Interpolation

4.3.15 Circular Interpolation

This is to command the cutter to move from the existing point to the target point along a circular arc in clockwise direction or counter clockwise direction. The parameters of the center of the circular arc is designated by *I*, *J* and *K* addresses. I is the distance along the *X*-axis, *J* along the *Y*, and *K* along the *Z*. This parameter is defined as the vector from the starting point to the center of the arc.

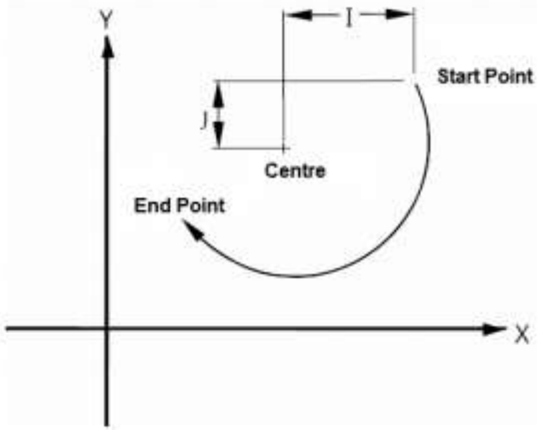


Figure 4.7 : Clockwise Circular Interpolation

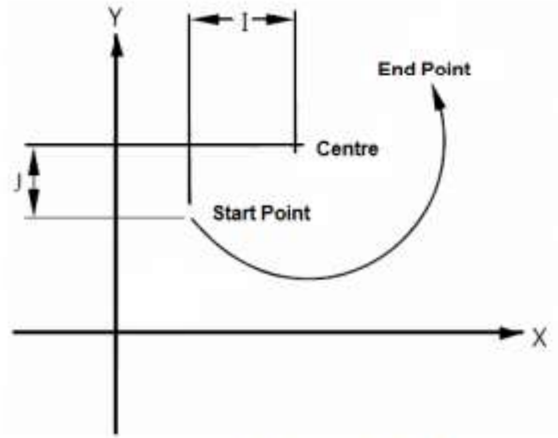


Figure 4.8 : Counter Clockwise Circular Interpolation

4.3.16 Circular Interpolation

In NC machining, if the cutter axis is moving along the programmed path, the dimension of the workpiece obtained will be incorrect since the diameter of the cutter has not be taken in to account. What the system requires are the programmed path, the cutter diameter and the position of the cutter with reference to the contour. The cutter diameter is not included in the programme. It has to be input to the NC system in the tool setting process.

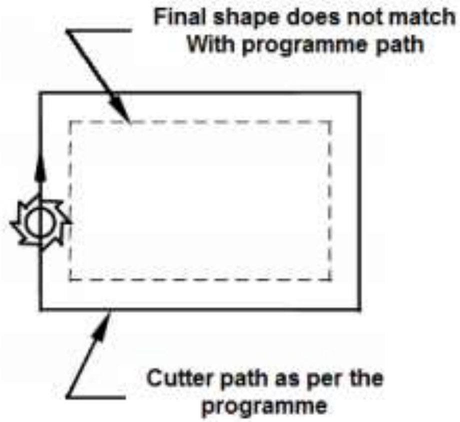


Figure 4.9 : Tool Path without Cutter Compensation

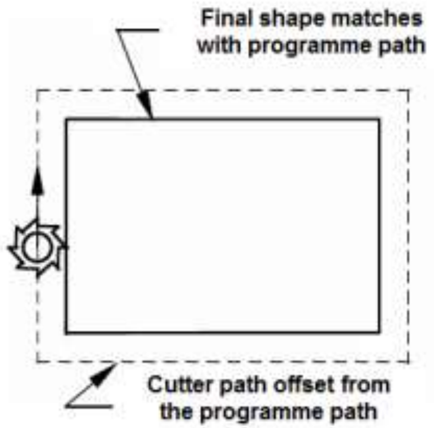


Figure 4.10 : Tool Path with Cutter Compensation

SYMBOLS USED

% – Main Programme (1 to 9999)

L – Sub program (1 to 999)/Home position

N – Sequence of block number.

Lf – Block end (EOB) means "; or *"

T – Tool number or Tool station number

D – Tool offset

S – Spindle speed

F – Feed

M – Switching function

G – Transverse commands

R – Parameters

I, J, K – Circle parameters

B/U/R – Radius

X/Y/Z – Axis coordinates

P – Passes.

Example

01 (All dimensions are in mm).

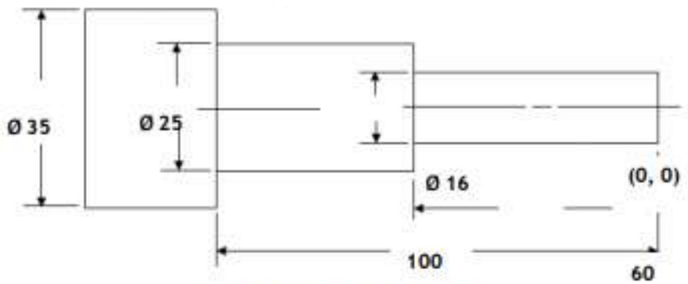


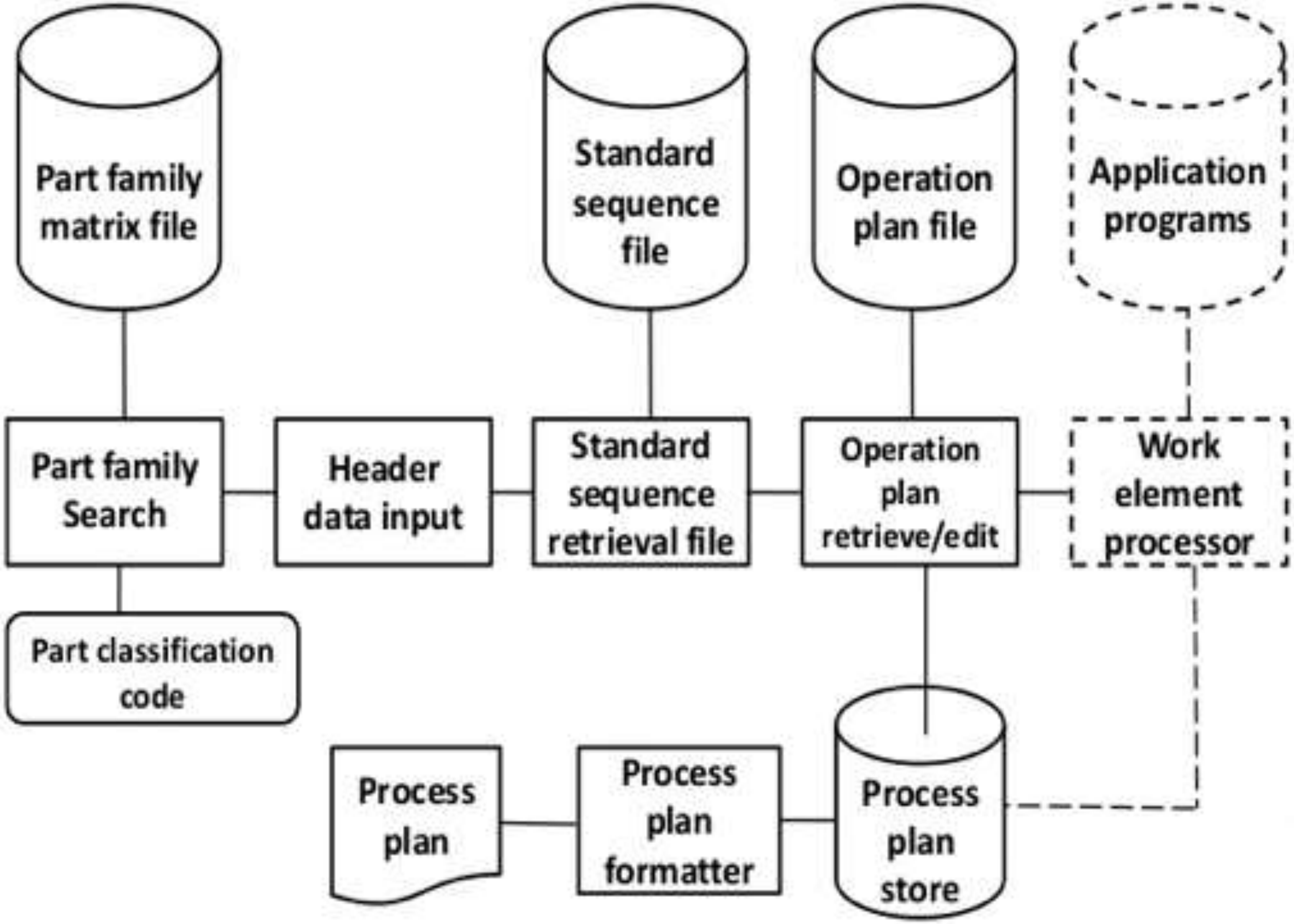
Figure 4.11 : Turning Operation

% 1000;	(Main programme)
N01 G54 G90 G71 G94 M03 S800;	(Parameters Setting)
N05 G01 X-12.5 Z0 F2;	(Facing the job)
N10 G00 Z1;	(Retrieval of tool)
N15 G00 X00;	(Tool clearance)
N20 G01 Z-100;	(Starting cut)
N25 G00 X1 Z1;	(Clearance position)
N30 G00 X-2;	(Position of cut)
N35 G01 Z-60;	(Cutting length)
N40 G00 X-1 Z1;	(Retrieval of tool)
N45 G00 X-3;	(Position of cut)
N50 G01 Z-60;	(Cutting length)
N55 G00 X-2 Z1;	(Retrieval of tool)
N60 G00 X-4;	(Position of cut)
N65 G01 Z-60;	(Cutting length)
N70 G00 X-3 Z1;	(Retrieval of tool)
N75 G00 X-4.5;	(Position of cut)
N80 G01 Z-60;	(Cutting length)
N85 G00 X5 Z5;	(Final position of tool)
N90 M02;	(End of programme)

COMPUTER AIDED MANUFACTURING - II

UNIT 5 COMPUTER AIDED MANUFACTURING - II 9 Hrs.

Computer Aided Process Planning (CAPP): Traditional process planning, Benefits of CAPP, Variant and Generative approaches. Computer integrated production system (CIPS): Traditional production planning, Benefits of CIPS, Master production Schedule, Material Requirement Planning, Inventory Management, Capacity planning, Shop floor control.


Part family
matrix file
Standard
sequence
file
Operation
plan file
Application
programs
Part family
Search
Header
data input
Standard
sequence
retrieval file
Operation
plan
retrieve/edit
Work
element
processor
Part classification
code
Process
plan
Process
plan
formatter
Process
plan
store

Flow of information

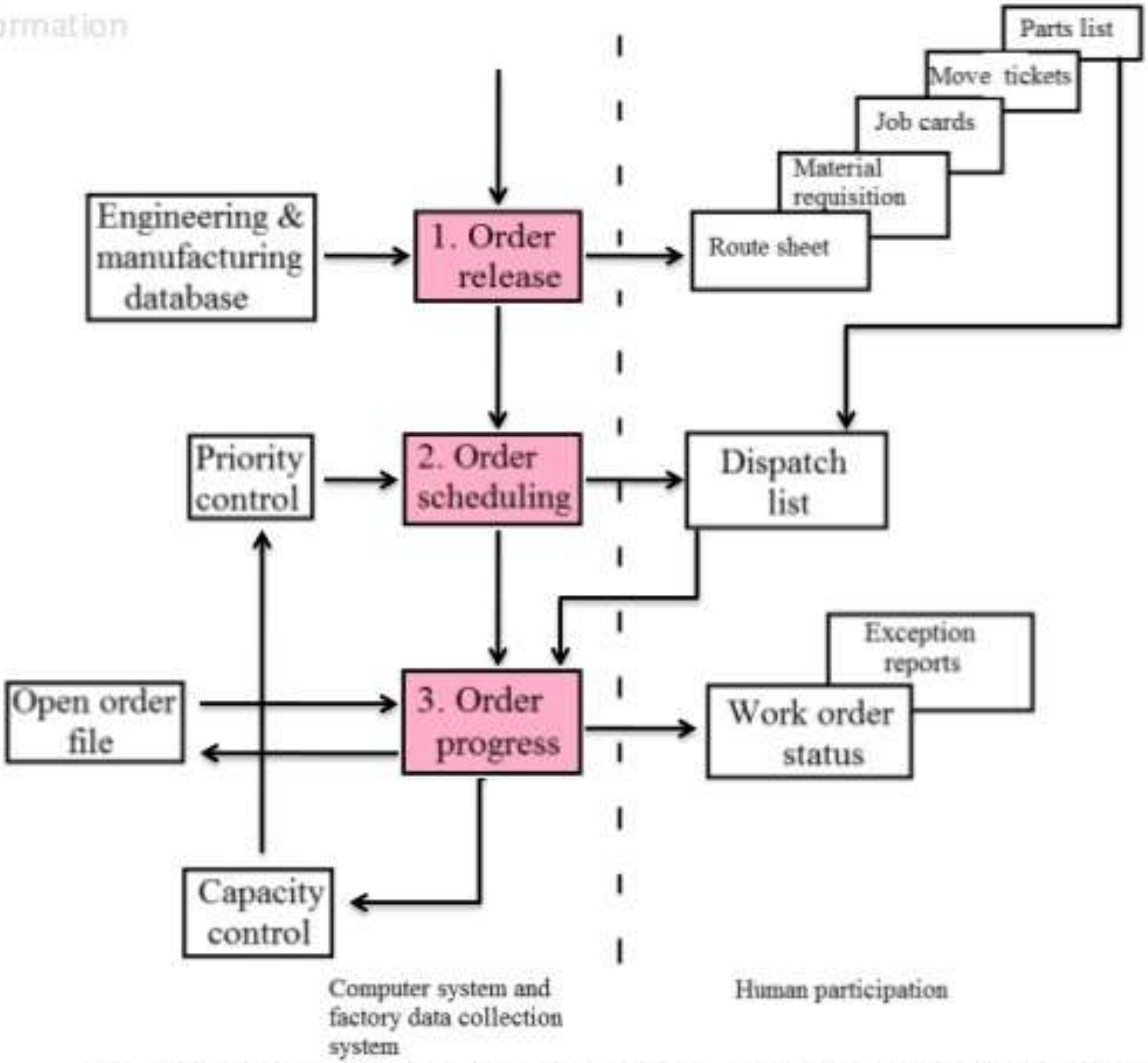
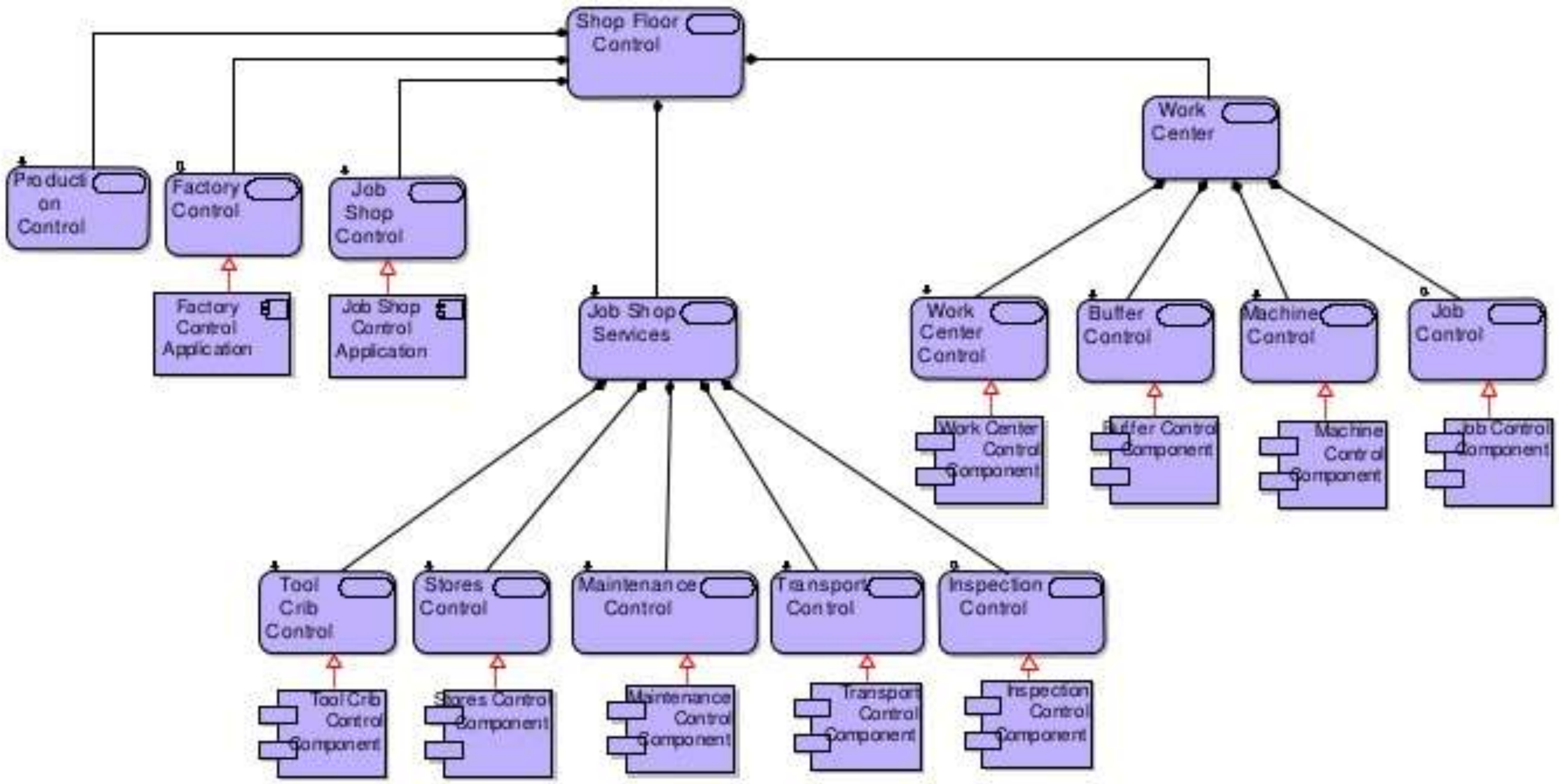


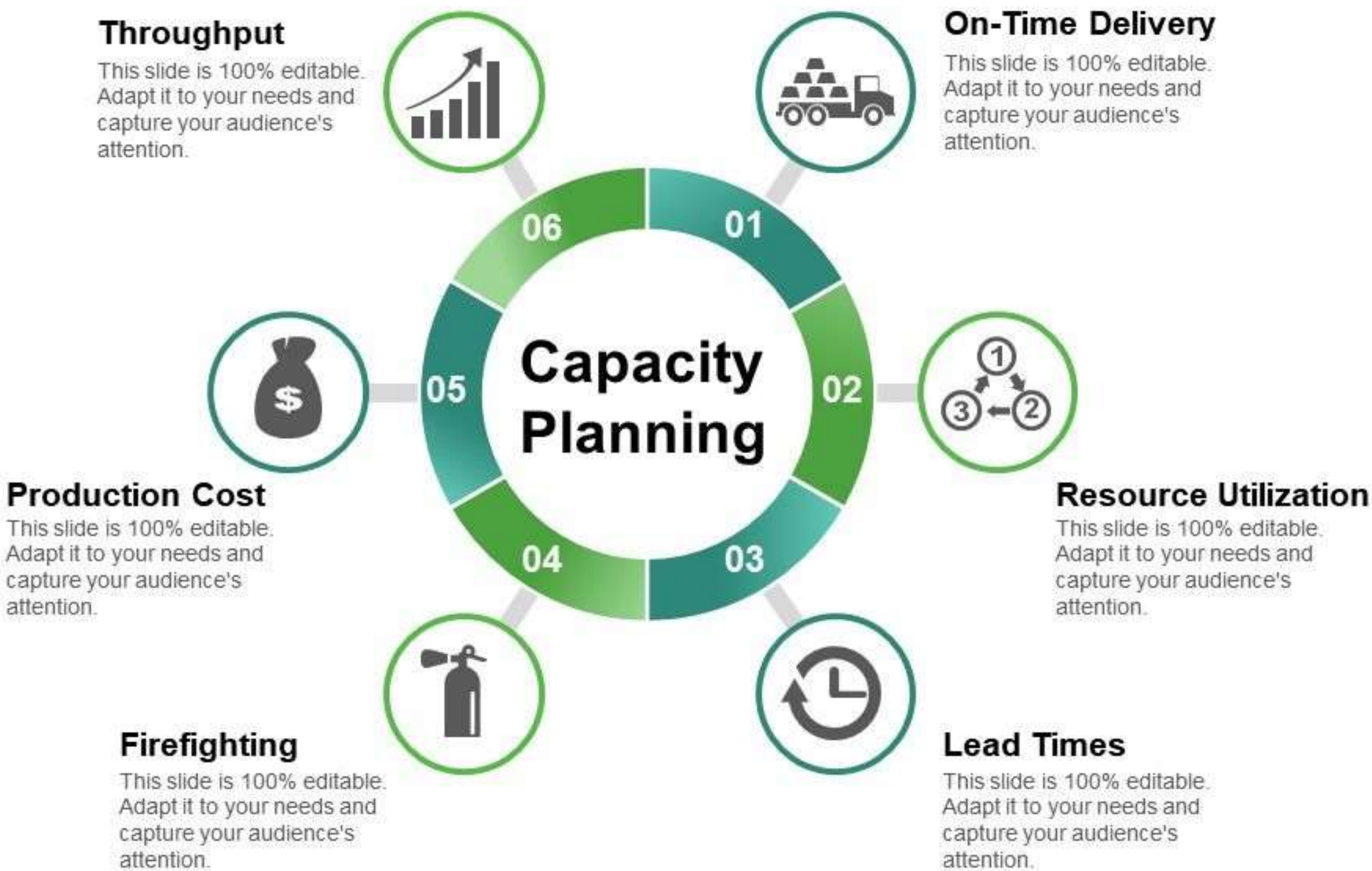
Fig. 1 The organization of a computerized shop floor control system

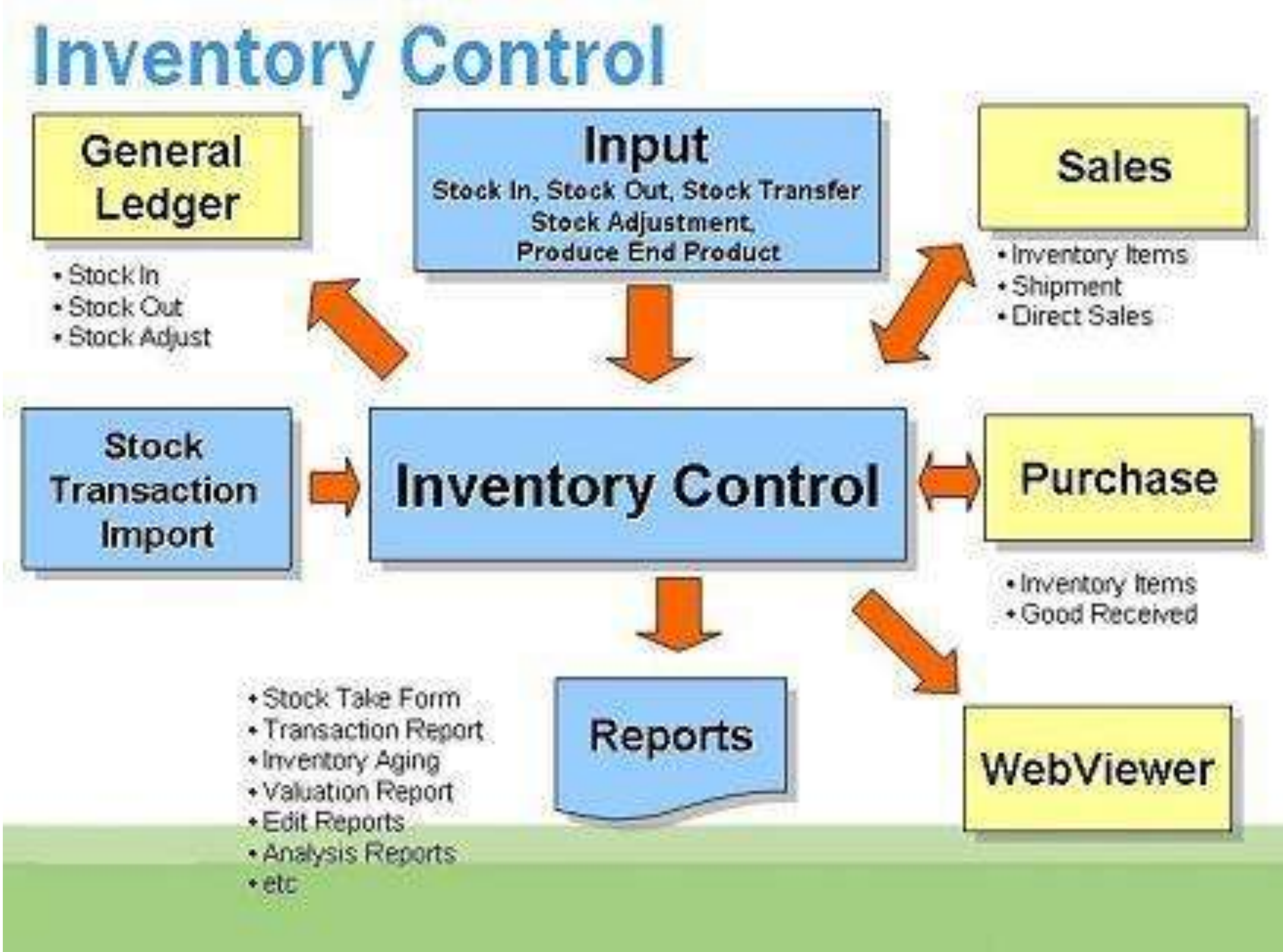
Shop Floor Application Services



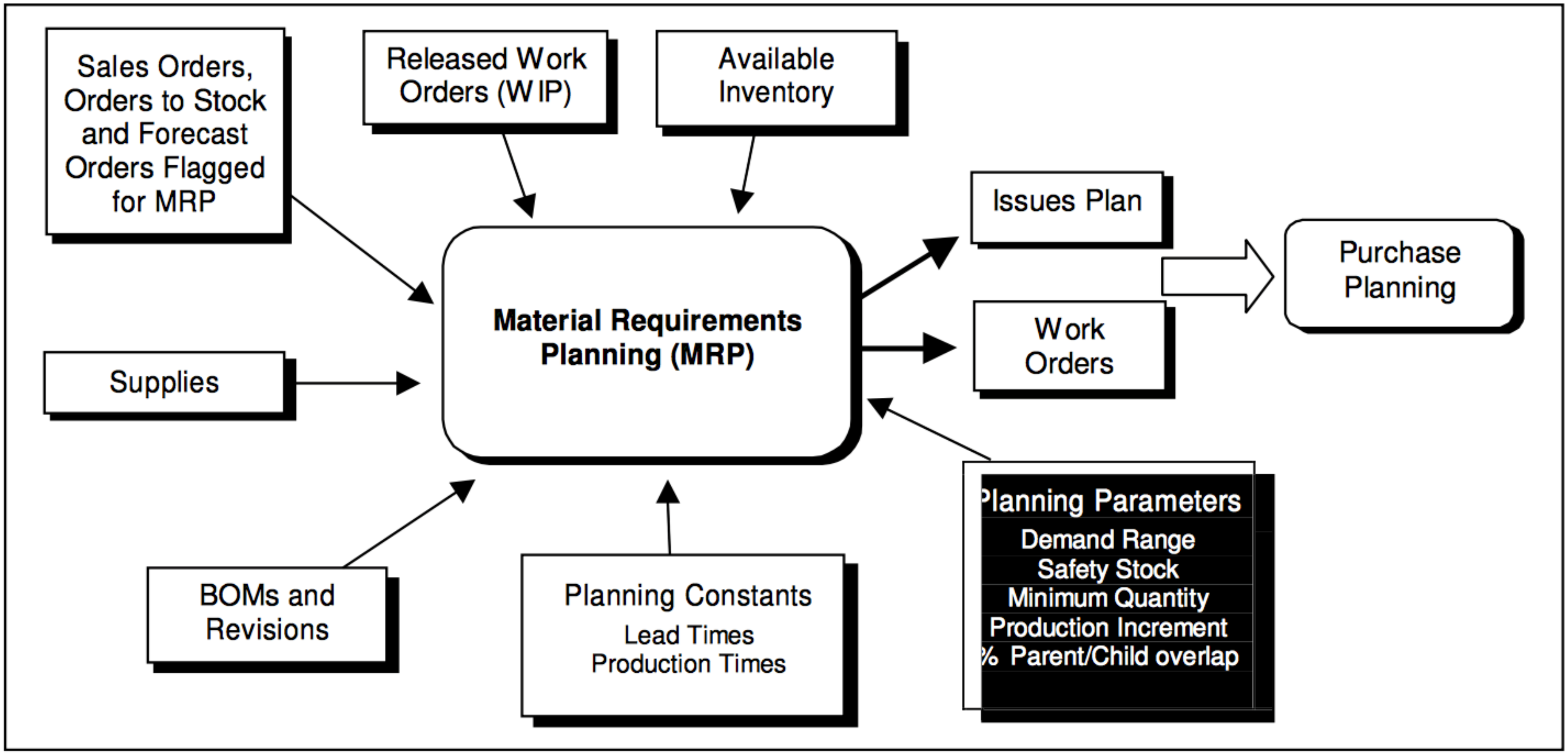

CAPACITY PLANNING
Determine if existing hardware is meeting the company's needs
Determine the company's future needs
Identify opportunities to consolidate
Determine whether the existing infrastructure can support anticipated growth
Implement Capacity Planning

Capacity Planning Resource Utilization Components With Arrows

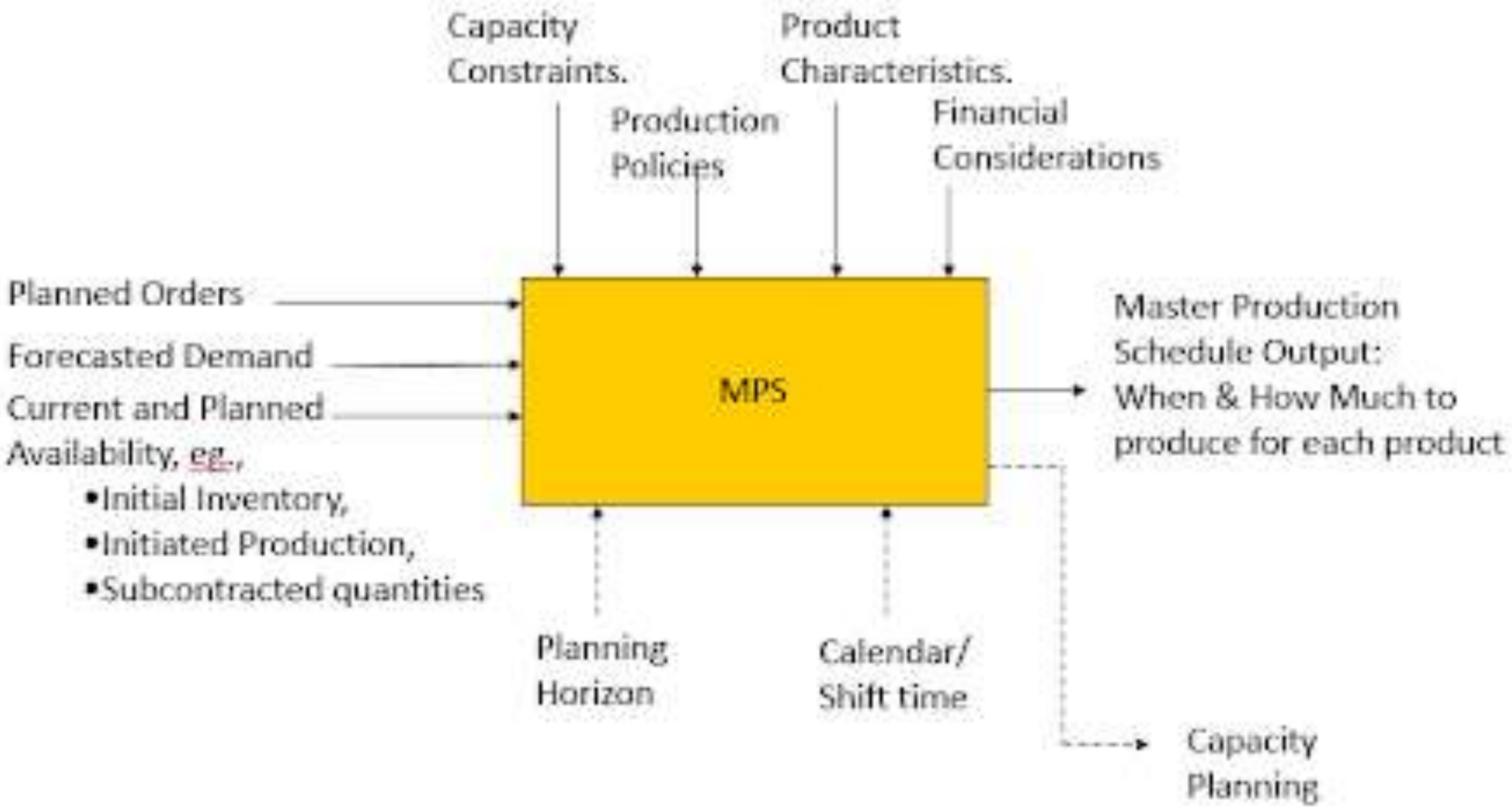



Inventory Control
General Ledger
• Stock In
• Stock Out
• Stock Adjust
Input
Stock In, Stock Out, Stock Transfer
Stock Adjustment,
Produce End Product
Sales
• Inventory Items
• Shipment
• Direct Sales
Stock Transaction Import
Inventory Control
Purchase
• Inventory Items
• Good Received
• Stock Take Form
• Transaction Report
• Inventory Aging
• Valuation Report
• Edit Reports
• Analysis Reports
• etc
Reports
WebViewer


Preventing Dead Stock or Perishability
Reducing Purchase Cost of Goods
Inventory Management Objectives
Optimizing Storage Cost
Enhancing Cash Flow
Maintaining Sufficient Stock


Sales Orders, Orders to Stock and Forecast Orders Flagged for MRP
Released Work Orders (WIP)
Available Inventory
Issues Plan
Purchase Planning
Material Requirements Planning (MRP)
Work Orders
Supplies
Planning Parameters
Demand Range
Safety Stock
Minimum Quantity
Production Increment
% Parent/Child overlap
BOMs and Revisions
Planning Constants
Lead Times
Production Times

The Master Production Scheduling



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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 5 – COMPUTER AIDED MANUFACTURING – II - SMEA1501

5.1. PROCESS PLANNING

Process planning involves determining the most appropriate manufacturing and assembly processes and the sequence in which they should be accomplished to produce a given part or product according to specifications set forth in the product design documentation. Process planning is usually accomplished by manufacturing engineers. (Other titles include industrial engineer, production engineer. and process engineer.) The process planner must be familiar with the particular manufacturing processes available in the factory and be able to interpret engineering drawings. Based on the planner's knowledge, skill, find experience, the processing steps arc developed in the most logical sequence to make each part.

Following is a list of the many decisions and details usually included within the scope of process planning.

- Interpretation of design drawings. The part or product design must be analyzed (materials, dimensions, tolerances, surface finishes, etc.) at the start of the process planning procedure.
- Processes and sequence. The process planner must select which processes are required and their sequence. A brief description of ail processing steps must be prepared.
- Equipment selection. In general, process planners must develop plans that utilize existing equipment in the plant. Otherwise, the component must be purchased, or an investment must be made in new equipment.
- Tools, dies, molds, flxtures, and gages. The process planner must decide what tooling is required for each processing step. The actual design and fabrication of these tools is usually delegated to a tool design department and tool room, or an outside vendor specializing in that type of tool is contracted.
- Work standards. Work measurement techniques are used to set time standards for each operation.
- Cutting tools and cutting conditions. These must be specified for machining operations, often with reference to standard handbook recommendations

For individual parts, the processing sequence is documented on a form called a route sheet. (Not all companies use the name route sheet; another name is "operation sheet.") Just as engineering drawings are used to specify the product design, route sheets are used to spec ify the process plan. They are counterparts. one for product design, the other for manufacturing. A typical route sheet, illustrated in Figure 25.1, includes the following information: (1) all operations to be performed on the work part, listed in the order in which they should be performed; (2) a brief description of each operation indicating the processing to be accomplished, with references to dimensions and tolerances on the part drawing; (3) the specific machine, on which the work is to be done; and (4) any special tooling, such as dies, molds, cutting tools. jigs or fixtures, and gages. Some companies also include setup times, cycle time standards, and other data. It is called a route sheet because the processing sequence defines the route that the part must follow in the factory.

Some of the guidelines in preparing a route sheet are listed.

- Operation numbers for consecutive processing steps should be listed as 10, 20, 30, etc, This allows new operations to be inserted if necessary.
- A new operation and number should be specified when a work part leaves one workstation and is transferred to another station

- A new operation and number should be specified if a part is transferred to another work holder (e.g., jig or fixture), even if it is on the same machine tool
- A new operation and number should be specified if the workpart is transferred from one worker to another, as on a production line

A typical processing sequence to fabricate an individual part consists of:
(I) basic process,
(2) secondary processes,
(3) operations to enhance physical properties, and
(4) finishing opera/jam.

A basic process determines the starting geometry of the work part. Metal casting. plastic molding, and rolling of sheet metal arc examples of basic processes. The starting geometry must often be refined by secondary processes, operations that transform the starting geometry into the geometry (or close to the final geometry).The secondary processes that might be used are closely correlated to the basic process that provides the starting geometry. When sand casting is the basic process, machining operations are generally the secondary processes. When a rolling mill produces sheet metal, stamping operations such as punching and bending are the secondary processes. when plastic injection molding is the basic process, secondary operations are often unnecessary, because most of the geometric features that would otherwise require machining can be created by the molding operation. Plastic molding and other operations that require no subsequent secondary processing are called net shape processes. Operations that require some but not much secondary processing (usually machining) are referred to as near net shape processes. Some impression die forgings are in this category. These parts can often be shaped in the forging operation (basic process) so that minimal machining (secondary processing) is required.

Once the geometry has been established, the next step for some parts is to improve their mechanical and physical properties. Operations to enhance properties do not alter the geometry of the part; instead. They alter physical properties. Heat treating operations on metal parts are the most common example. Similar heating treatments are performed on glass to produce tempered glass. For most manufactured parts, this property enhancing operations arc not required in the processing sequence. Finally ,finishing operations usually provide a coating on the work part (or assembly) surface. Examples include electroplating, thin film deposition techniques, and painting. The purpose of the coating is to enhance appearance, change color, or protect the surface from corrosion. abrasion, and .>0 forth. Finishing operations are not required on many parts: for example, plastic moldings rarely require finishing. When finishing is required, it is usually the final step in the processing sequence.

In addition to the route sheet, a more detailed description of each operation is usually prepared. This is filed in the particular production department office where the operation is performed. It lists specific details of the operation, such as cutting conditions and tooling (if the operation is machining) and other instructions that may be useful to the machine operator. The descriptions often include sketches of the machine setup.

5.2. COMPUTER AIDED PROCESS PLANNING

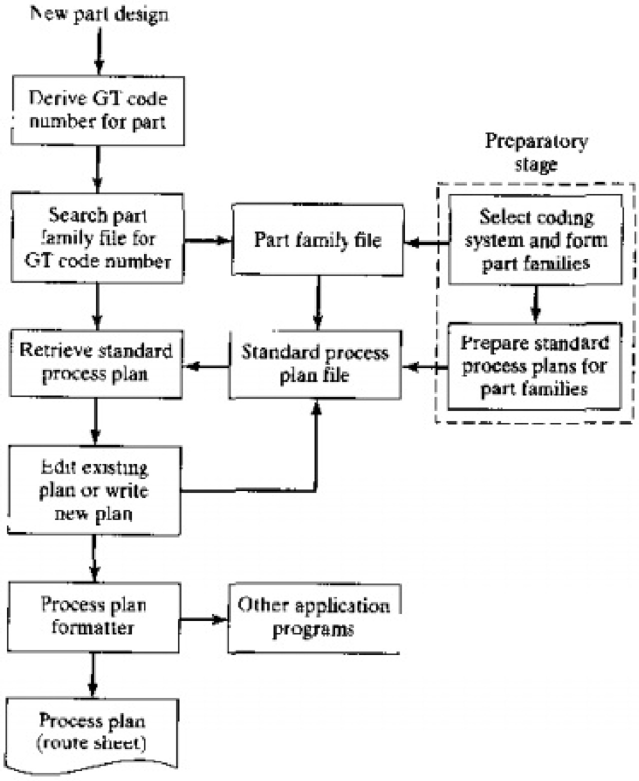
There is much interest by manufacturing firms in automating the task of process planning using computer-aided process planning (CAPP) systems. The shop trained people who are familiar with the details of machining and other processes are gradually retiring, and these people will be unavailable in the future to do process planning. An alternative way of accomplishing this function is needed, and CAPP systems are providing this alternative.

CAPP is usually considered to be part of computer-aided manufacturing (CAM). However, this lends to imply that CAM is a standalone system. In fact, a synergy results when CAM is combined with computer-aided design to create a CAD/CAM system. In such a system, CAPP becomes the direct connection between design and manufacturing.

Computer-aided process planning systems are designed around two approaches. These approaches are called: (1) retrieval CAPP systems and (2) generative CAPP systems.

5.2.1. RETRIEVAL CAPP

A retrieval CAPP system, also called a variant CAPP system, is based on the principles of group technology (GT) and parts classification and coding. In this type of CAPP, a standard process plan (route sheet) is stored in computer files for each part code number. The standard route sheets are based on current part routings in use in the factory or on an ideal process plan that has been prepared for each family. It should be noted that the development of the data base of these process plans requires substantial effort.



General procedure for using one of the retrieval CAPP systems.

Fig 5.1. Retrieval CAPP

Before the system can be used for process planning, a significant amount of information must be compiled and entered into the CAPP data files. This is what Chang et al., refer to as the "preparatory phase:' It consists of the following steps: (1) selecting an appropriate classification and coding scheme for the company, (2) forming part families for the parts produced hy the company; and (3) preparing standard process plans for the part families. It should be mentioned that steps (2) and (3) continue as new parts are designed and added to the company's design data base. After the preparatory phase has been completed, the system is ready for use, For a new component for which the process plan is to be determined. the first step is to derive the GT code number for the part. With this code number, a search is made of the part family, file to determine if a standard route sheet exists for/he given part code. If the file contains a process plan for the part it is retrieved (hence. the word "retrieval" for this CAPP system) and displayed for the user. The standard process plan is examined to determine whether any modifications are necessary. It might be that although the new part has the same code number. there are minor differences in the processes required to make it. The user edits the standard plan accordingly. This capacity to alter an existing process plan is what gives the retrieval system its alternative name: variant CAPP system. The process planning session concludes with the process plan formatter, which prints alit the route sheet in the proper format. The formatter may call other application programs into use: for example, to determine machining conditions for the various machine tool operations in the sequence. to calculate standard times (or the operations (e.g., for direct labor incentives). or to compute cost estimates for the operations. One of the commercially available retrieval CAPP systems is MultiCapp, from OIR the Organization for Industrial Research. It is an online computer system that permits the user to create new plans. or retrieve and edit existing process plans, as we have explained above.

5.2.2. GENERATIVE CAPP

Generative CAPP systems represent an alternative approach to automated process planning. Instead of retrieving and editing an existing plan contained in a computer data base, a generative system creates the process plan based on logical procedures similar to the procedures a human planner would use. In a fully generative CAPP system, the process sequence is planned without human assistance and without a set of predefined standard plans. The problem of designing a generative CAPP system is usually considered part of the field of expert systems, a branch of artificial intelligence. An expert system is a computer program that is capable of solving complex problems that normally require a human with years of education and experience.

There are several ingredients required in a fully generative process planning system. First. the technical knowledge of manufacturing and the logic used by successful process planners must be captured and coded into a computer program. In an expert system applied to process planning, the knowledge and logic of the human process planners is incorporated into a so called "knowledge base. The second ingredient in generative process planning is a computer-compatible description of the part to be produced. This description contains all of the pertinent data and information needed to plan the process sequence, Two possible ways of providing this description are: (l) the geometric model of the part that is developed on a CAD system dur10g product design and (2) a GT code number of the part that defines the part features in significant detail. The third ingredient in a generative CAPP system is the capability to apply the process knowledge and planning logic contained in the knowledge base to a given part description. In other words, the CAPP system uses its knowledge base to solve a specific problem-planning the process for a new part. This problem-solving procedure is referred to as the "inference engine’ in the terminology of expert systems. By using its knowledge base and inference engine, the CAPP system synthesizes a new process plan from scratch for each new part it is presented.

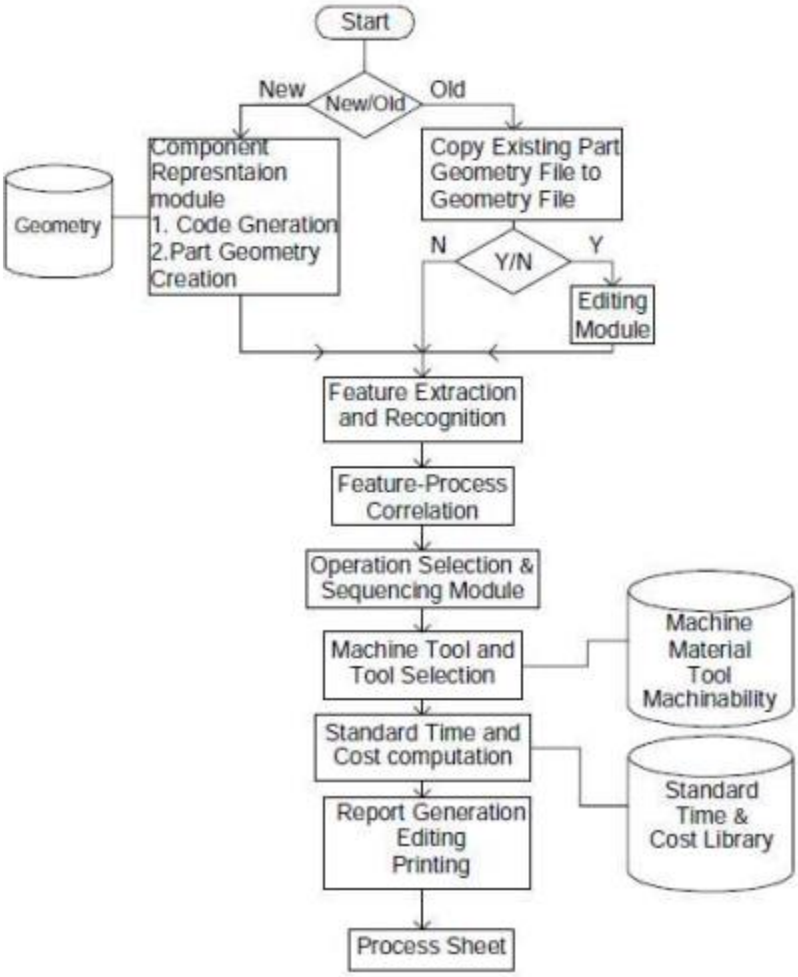


Fig 5.2. Generative CAPP

5.2.3. BENEFITS OF CAPP

The benefits derived from computer -automated process planning include the following:

- Process rationalization and standardization. Automated process planning leads to more logical and consistent process plans than when process planning is done completely manually. Standard plans tend to result in lower manufacturing costs and higher product quality.
- Increased productivity of process planners. The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners.
- Reduced lead time for process planning. Process planners working with a CAPP system can provide route sheets in a shorter lead time compared to manual preparation.
- Improved legibility. Computer-prepared route sheets are neater and easier to read than manually prepared route sheets
- Incorporation o other application programs The CAPP program can be interfaced With other application programs, such as cost estimating and work standards.

5.3. AGGREGATE PLANNING AND MASTER PRODUCTION SCHEDULE

Aggregate planning is a high-level corporate planning activity. The aggregate production indicates production output levels for the major product lines of the company.

The aggregate plan must be coordinated with the plans of the sales and marketing departments. Because the aggregate production plan includes products that are currently in production, it must also consider the present and future inventory levels of those products and their component parts. Because new products currently being developed will also be included in the aggregate plan. the marketing plans and promotions for current products and new products must be reconciled against the total capacity resources available to the company.

	Week									
Product line	1	2	3	4	5	6	7	8	9	10
M model line	200	200	200	150	150	120	120	100	100	100
N model line	80	60	50	40	30	20	10			
P model line							70	130	25	100

(a) Aggregate production plan

	Week									
Product line models	1	2	3	4	5	6	7	8	9	10
Model M3	120	120	120	100	100	80	80	70	70	70
Model M4	80	80	80	50	50	40	40	30	30	30
Model N8	80	60	50	40	30	20	10			
Model P1								50		100
Model P2							70	80	25	

(b) Master production schedule

(a) Aggregate production plan and (b) corresponding MPS for a hypothetical product line.

Fig 5.3. APP & MPS

The production quantities of the major product lines listed in the aggregate plan must he converted into a very specific schedule of individual products, known as the master production schedule (MPS).lt is a list or the products to be manufactured, when they should be completed and delivered, and in what quantities. The master schedule must be based on an accurate estimate of demand and a realistic assessment of the company's production capacity. products included in the MPS divide into three categories: (1) firm customer orders, (2) forecasted demand, and (3) spare parts. Proportions in each category vary for different companies, and in some cases one or more categories are omitted. Companies producing assembled products will generally have to handle all three types.

5.4. MATERIAL REQUIREMENTS PLANNING (MRP)

Material requirements planning (MRP) is a computational technique that converts the master schedule for end products into a detailed schedule for the raw materials and components used in the end products. The detailed schedule identifies the quantities of each raw material and component item. It also indicates when each item must be ordered and delivered to meet the master schedule for final products. MRP is often thought of as a method of inventory control. Even though it is an effective tool for minimizing unnecessary inventory investment, MRP is also useful in production scheduling and purchasing of material. Whereas demand for the firm's end products must often be forecasted, the raw materials and component parts should not be forecasted. Once the delivery schedule for end products i; established, the requirements for components and raw materials can be directly calculated.

For example. even though demand for automobiles in a given month can only he forecasted. once the quantity is established and production is scheduled, we know that five tires will be needed to deliver the car (don't forget the spare).MRP is the appropriate technique for determining quantities of dependent demand items. These items constitute the inventory of manufacturing: raw materials, work-in-process (WIP), component parts, and subassemblies. That is why MRP is such a powerful technique in the planning and control of manufacturing inventories. we first examine the inputs to the MRP sys· tern. We then describe how MRP works, the output reports generated by the MRP computations and finally the benefits and pitfalls that have been experienced with MRP systems in industry.

5.4.1. Inputs to MRP

To function. the MRP program must operate on data contained in several files. These files serve as inputs to the MRP processor They are:

(I) MPS,

(2) bill of materials file and other engineering and manufacturing data.

(3) inventory record file.

The MPS lists what end product, and how many of each are to be produced and when they are to be ready for shipment. Manufacturing firms generally work toward monthly delivery schedules, but the master schedule in our figure uses weeks as the time periods.

The bill of materials (BOM)file is used to compute the raw material and component requirements for end products listed in the master schedule. It provides information on the product structure by listing the component parts and subassemblies that make up each product.

The inventory record file is referred to as the item master file in a computerized inventory system. The types of data contained in the inventory record are divided into three segments: (1) Item master data. This provides the item's identification (part number) and other data about the part such as order quantity and lead times. (2) Inventory status. This gives a time phased record of inventory status. In MRP, it is important to know not only the current level of inventory, but also any future changes that will occur against the inventory. Therefore, the inventory status segment lists the gross requirements for the item, scheduled receipts, on hand status, and planned order releases, (3) Subsidiary data. Thc third file segment provides subsidiary data such as purchase orders, scrap or rejects, and engineering changes.

Period		1	2	3	4	5	6	7
Item: **Raw material M4**								
Gross requirements								
Scheduled receipts				40				
On hand	50	50	50	90				
Net requirements								
Planned order releases								

Initial inventory status of material

Fig 5.4. MRP

5.4.2. How MRP Works

The MRP processor operates on data contained in the MPS, the 80M file, and the inventory record file. The master schedule specifies the period-by-period list of final products required. The 80M defines what materials and components are needed for each product. And the inventory record file contains data on current and future inventory status of each product, component, and material. The MRP processor computes how many of each component and raw material are needed each period by "exploding" the end product requirements into successively lower levels in the product structure. Several complicating factors must be taken into account during the 'MRP computations. First. the quantities of components and subassemblies listed in the solution of Example 26.1 do not account for any of those items that may already be stocked in inventory or arc expected to be received a, future orders. Accordingly, the computed quantities must be adjusted for any inventories on hand or on order, a procedure called netting. For each time bucket, net requirements = gross requirements less on-hand inventories and less quantities on order. Second. quantities of common use items must be combined during parts explosion to determine the total quantities required for each component and raw material in the schedule. Common use items arc raw materials and components that are used on more than one product. MRP collects these common use items from different products to effect economics in ordering the raw materials and producing the components. Third. lead times for each item must be taken into account. The lead time for a job is the time that must be allowed to complete the job from start to finish. There are two kinds of lead times in MRP: ordering lead times and manufacturing lead times. Ordering lead time for an item is the time required from initiation of the purchase requisition 10 receipt of the item from the vendor. If the item is a raw material that is stocked by the vendor.fhe ordering lead time should be relatively short, perhaps a few days or a few weeks. If the item is fabricated, the lead time may be substantial, perhaps several months. Manufacturing lead time is the time required to produce the item in the company's own plant, from order release to completion, once the raw materials for the item are available. The scheduled delivery of end products must be translated into time phased requirements for components and materials by factoring in the ordering and manufacturing lead times.

5.4.3. MRP Outputs and Benefits

The MRP program generates a variety of outputs that can be used in planning and managing plant operations. The outputs include:

(I) planned order releases. which provide the authority to place orders that have been planned by the MRP system

(2) report of planned order releases in future period

(3) rescheduling notices, indicating changes in due dates for open orders

(4) cancelation notices, indicating that certain open orders have been canceled because of changes in the MPS

(5) reports on inventory status

(6) performance reports of various types. indicating costs. Item usage, actual versus planned lead times.

(7) exception reports. showing deviations from the schedule, orders that are overdue, scrap.

(8) inventory forecasts. indicating projected inventory levels in future periods.

Many benefits are claimed for a well designed MRP system. Benefits reported by users include the following

(1) reduction in inventory,

(2) quicker response to changes in demand than is possible with a manual requirements planning system.

(3) reduced setup and product changeover costs,

(4) better machine utilization,

(5) improved capacity to respond to changes in the master Schedule,

(6) as an aid in developing the master schedule.

5.5. INVENTORY CONTROL

Inventory control is concerned with achieving an appropriate compromise between two opposing objectives:

(1) minimizing the cost of holding inventory.

(2) maximizing service to customers. On the one hand, minimizing inventory cost suggests keeping inventory to a minimum in the extreme, zero inventory. On the other hand, maximizing customer service implies keeping large stocks on hand from which the customer can choose and immediately take possession.

The types of Inventory of greatest interest in PPC arc raw materials purchased components, in-process inventory (WIP) and finished products. The major costs of holding inventory are

(1) investment costs,

(2) storage costs,

(3) cost of possible obsolescence or spoilage.

The three costs are referred to collectively as carrying costs or holding costs:

Companies can minimize holding costs by minimizing the amount of inventory on hand. However, when inventories are minimized, customer service may suffer inducing customers to take their business elsewhere. This also has a cost, called the stock-out cost. Most companies want to minimize stock-out cost and provide good customer service. Thus, they are caught on the horns of an inventory control dilemma: balancing carrying costs against the cost of poor customer service.

5.5.1. Order Point Inventory Systems

Order point systems are concerned with two related problems that must be solved when managing inventories of independent demand items: (1) how many unit ordered? And (2) when should the order be placed? The first problem is often solved using economic order quantity formulas. The second problem can be solved using reorder point methods.

5.5.2. Economic Order Quantity Formula.

The problem of deciding on the most appropriate quantity to order or produce arises when the demand rate for the item is fairly constant, and the rate at which the item is produced is significantly greater than its demand rate. This is the typical make-to-stock situation.

Reorder Point Systems. Determining the economic order quantity is not the only problem that must be solved in controlling inventories in make-to-stock situations, the other problem is deciding when to reorder. One of the most widely used methods is the reorder point system. In a reorder point system, when the inventory level for a given stock item falls to some point specified as the reorder point, then an order is placed to restock the item. The reorder point is specified at a sufficient quantity level 10 minimize the probability of a stock-out between when the reorder point is reached and the new order is received. Reorder point triggers can be implemented using computerized inventory control systems that continuously monitor the inventory level as demand occurs and automatically generate an order for a new batch when the level declines below the reorder point.

Work-in-Process Inventory Costs: Work-in-process (WIP) represents a significant inventory cost for many manufacturing firms. In effect, the company is continually investing in raw materials, processing those materials, and then delivering them to customers when processing has been completed. The problem is that processing takes time, and the company pays a holding cost between start of production and receipt of payment from the customer for goods delivered.

5.6. CAPACITY PLANNING

A realistic master schedule must be consistent with the production capabilities and limitations of the plant that will produce the product. Accordingly the firm must know its production capacity and must plan for changes in capacity to meet changing production requirements specified in the master schedule. In Chapter 2, we defined production capacity and formulated ways for determining the capacity of a plant Capacity planning is concerned with determining what labor and equipment resources are required to meet the current MPS as well as long-term future production needs of the firm. Capacity planning also serves to identify the limitations of the available production resources so that an unrealistic Master schedule is not planned.

Capacity planning is typically accomplished in two stages, first, when the MRS is established: and second, when the MRP computations are done. In the MPS stage, a rough-cut capacity planning (REEP) calculation is made to assess the feasibility of the master schedule. Such a calculation indicates whether there is a significant violation of production capacity in the MPS. On the other hand, if the calculation

shows no capacity violation, neither does it guarantee that the production schedule can be met. This capacity calculation is malic at the MRP schedule is prepared Called capacity requirements planning (CRP). This detailed calculation determines, whether there is sufficient production capacity in the individual departments and work cells to complete the specific parts and assemblies that have been scheduled by MRP. If the schedule is not compatible with capacity, then adjustments must be made either in plant capacity or in the master schedule.

Capacity adjustments can be divided into short term adjustments and long-term adjustments. A capacity adjustment for the short term includes:

- Employment levels. Employment in the plant can be increased or decreased in response to changes in capacity requirements,
- Temporary workers. Increases in employment level can also be made by using workers from a temporary agency. When the busy period is passed, these workers move to positions at other companies where their services are needed.
- Number of work shifts. The number of shifts worked per production period can be increased or decreased.
- Labour hours. The number of labour hours per shift can be increased or decreased, through the use of overtime or reduced hours.
- Inventory stockpiling. This tactic might be used to maintain steady employment levels during slow demand periods
- Order backlogs. Deliveries of the product to the customer could be delayed during busy periods when production resources are insufficient to keep up with demand.
- Subcontracting. This involves the letting of jobs to other shops during busy periods OR the taking in of extra work during slack periods

Capacity planning adjustments for the long term include possible changes in production capacity that generally require long lead times. These adjustments include the following types of decisions

- New equipment Investments. This involves investing in more machines or more productive machines to meet increased future production requirements, or investing in new types of machines to match future changes in product design.
- New plant construction. Building a new factory represents a major investment for the company. However, it also represents a significant increase in production capacity for the firm.
- Purchase of existing plants from other companies.
- Acquisition of existing companies. This may be done to increase productive capacity. However, there are usually more important reasons for taking over an existing company, for example, to achieve economies of scale that result from increasing market share and reducing staff.

- Plant closings. This involves the closing of plants that will not be needed in the future

5.7. SHOP FLOOR CONTROL

Shop floor control deals with managing the work-in-process. This consists of the release of production orders to the factory, controlling the progress of the orders through the various work stat ons, and getting the current information of the status of the orders. This can be shown in the form of a factory information system. . The input to the shop floor control system is the collection of production plans. These can be in the form of master schedule, manufacturing capacity planning and ERP data. The factory production operations are the processes to be controlled.

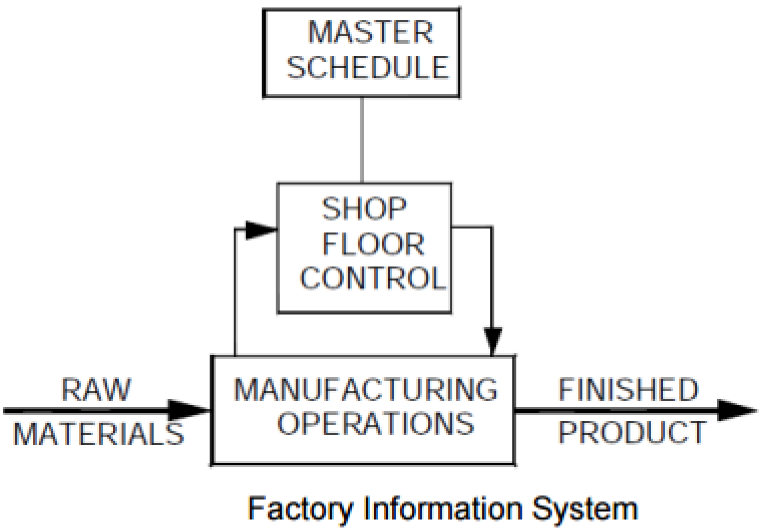


Fig 5.4. Factory information system

A typical shop floor control system consists of three phases. In a computer integrated manufacturing system these phases are managed by computer software. These three phases connected with the production management. In today's implementation of shop floor control, these are executed by a combination of computers and human resources. The following sections describe the important activities connected with this task.

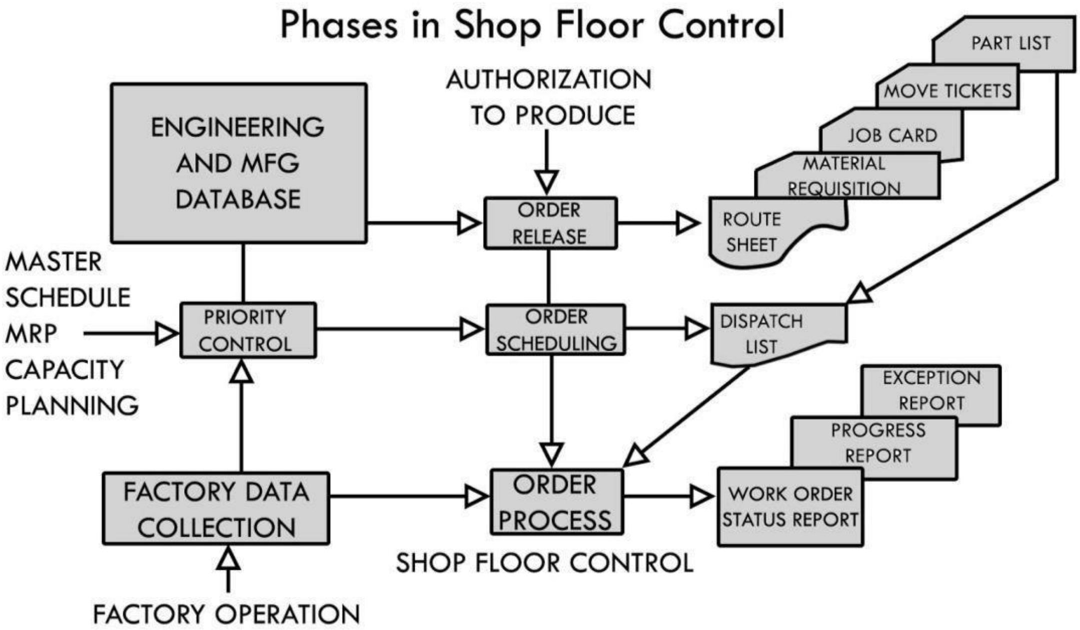


Fig 5.5. Shop floor control system

5.7.1. Order Release

The order release in shop floor control provides the documentation needed to process a production order. In a typical factory which works on manual processing of data these documents move with the production order and are used to track the progress through the shop. In a CIM factory, more automated methods are used to track the progress of the production orders. The order release is connected with two inputs. Authorization proceeds through the various planning functions (MRP, capacity planning). These provide timing and scheduling information. The engineering and manufacturing database provides the product structure and process planning information needed to prepare the various documents that accompany the order through the shop.

The documents in the shop floor order may consists of the following documents

(i) Route Sheet

(ii) Material requisition to draw necessary materials from the stores

(iii) Job cards or other means to report direct labour time given to the order.

(iv) Instructions to material handling personnel to transport parts between the work centres in the factory

(v) Parts list for assembly, in the case of assembly operations.

5.7.2. Order Scheduling

This module assigns the production orders to various work centres, machine tools, welding stations, moulding machines etc., in the plant. It follows directly from the order release module. Order scheduling executes the dispatch function in production planning and control. The order scheduling module prepares a dispatch list that indicates which production order should be accomplished at the various work centres. It provides the information on the relative priorities of the various jobs by showing the due dates for each job. By following the dispatch list in making work assignments and allocating resources to different jobs the master schedule can be best achieved.

The order schedule module addresses to two important activities in shop floor production control.

(I)Machine loading (ii) Job sequencing. Allocating the orders to the work centres is termed as machine loading or shop loading, which refers to the loading of all machines in the plant. In most cases each work centre will have a queue of orders waiting to be processed. This queue problem can be solved by job sequencing. This involves determining the order in which the jobs will be processed through a given work centre. To determine this sequence, priorities are given to jobs in the queue and the jobs are processed according to the priorities. Several queuing models are available in operations management to solve this problem. This control of priorities is an important input to the order scheduling module. Rules to establish the priorities are: (i) Earliest due date: These are given high priority (ii) Shortest processing time: Shorter processing time orders are given high priority. (iii) Least slack time: Orders with least slack time are given high priority. Fluctuations in market demand, equipment breakdown, cancellation of the order by customer and defective raw material or delay in the receipt of materials affect the priority. The priority control plan reviews the relative priorities of the orders and adjusts the dispatch list accordingly.

5.7.3. Order Progress

The order progress module in the shop floor control system monitors the status of the various orders in the plant work-in-process and other characteristics that indicate the progress and performance of production. The function of the order progress module is to provide the information that is useful in managing the factory based on the data collected from the factory.

The order progress report includes:

(i) Work order status reports: These reports indicate the status of the production orders. Typical information in the report includes the current work centre where each order is located, processing hours remaining before completion of each order, whether the job is on-time or behind schedule, and priority level.

(ii) Progress report: A progress report records the performance of the shop during the period of master schedule and reports the number of operations completed and not completed during the time period.

(iii) Exception reports: These reports bring out the deviations from the production schedule (ex. overdue jobs).

The above reports are useful to production management in making the decisions about allocation of resources, authorization of the overtime hours, and other capacity issues, and in identifying areas of problems in the plant that adversely affect the implementation of the master production schedule.

5.8. FACTORY DATA COLLECTION (FDC)

There are several of data collection techniques to gather data from the shop floor. Some of the data are keyed by the employees and the rest are recorded automatically. Later the data is compiled on a fully automated system that requires no human intervention. These methods are collectively called as shop floor data collection systems. These data collection systems consist of various paper documents, terminals and automated devices located through the plant in a plant. The shop floor data collection system serves as an input to the order progress module in shop floor. Examples of the data collection in shop floor are:

(i) To supply data to the order progress module in the shop floor control system.

(ii) To provide up to date information to the production supervisors and production control personnel.

(iii) To enable the management to monitor implementation of master schedule. To carry out this, the factory data collection system inputs the data to the computer system in the plant.

The shop floor data collection systems can be classified into two groups. (i) On-line data collection systems (ii) Off-line data collection systems.

5.8.1. On-Line Data Collection Systems

In an on-line system, the data are directly entered to the computer and are available to the order progress module. The advantage lies in the fact that the data file representing 72 the status of the shop is always at the current state. As and when the changes in the order progress module are reported they can be fed to computer and in turn to the status file. In this way the production personnel are provided with most up-to-data information.

5.8.2. Off-Line (Batch) Data Collection Systems

In this the data are collected temporarily in a storage device or a stand-alone computer system to be entered and processed by plant computer in a batch mode. In this mode there is delay in the entry and processing of the data. The delay may vary depending upon the situation. So this system cannot provide real time information of shop floor status. The advantage of this system is that it is easier to install and implement.

Data collection techniques include manual procedures and computer terminals located on the shop floor. The manual data collection methods require the production workers to fill out paper forms indicating order progress data. These forms are compiled using a combination of clerical and computerized methods. The manual data collection methods rely on the co-operation and clerical accuracy of the employees to record a data property on a proper document. Errors may creep in this type of method. The common forms of errors that can be checked and rectified are wrong dates, incorrect order numbers and incorrect operation numbers. These can be detected and corrected. There are, however, other errors which are difficult to identify. Another problem is that there may be a delay in submitting the order progress for compiling. The reason is that there will be always a time lapse between when occurrence of events and recording of events. These problems necessitate the location of the data collection equipment in the factory itself. The various input techniques include manual input by push-button pads or keyboards. Error checking routines can be incorporated to detect the syntax errors in the input. The data entry methods also include more automated technologies, such as bar code reader, magnetic card readers etc. An important type of equipment used in shop floor data entry is keyboard based systems. There are various types of such systems. They are discussed in the following sections.

- Centralized Terminal A single terminal is located centrally in the shop floor. This requires the employees to go to the terminal and input the data. So employee’s time will be wasted and in a big shop, this becomes inconvenient.
- Satellite Terminals These are multiple data collection centers located throughout the shop floor. In this arrangement a balance is to be struck between the minimization of the investment cost and maximization of the convenience of the employees in the plant.
- Work Centre Terminals The most convenient arrangements to the employees are to have a data collection terminal at each work centre. This reduces the time to go to the central terminal. This can be applied when the amount of data to be collected is very large.

- Automatic Data Collection System The recent trend in industry towards use of more automation necessitates putting in human participation is unavoidable in many cases. The advantages of the automatic data collection methods are:
  (i) The accuracy of data collected increases
  (ii) The time required by the workers to make the data entry can be reduced.
  The basic elements in data collection systems are:
  (i) Machine readable media
  (ii) Terminal configuration
  (iii) Software for data collection.

- Machine Readable Media Typical machine readable media include:
  (i) Bar Code Technology
  (ii) Optical Character Recognition (OCR)
  (iii) Magnetic Ink Character
  (iv) Voice Recognition (VR)

PROCESS PLANNING

Process planning is defined as conversion of design data to work instruction

Process planning is defined as systematic determination of methods by which a product is to be manufactured economically and competitively.

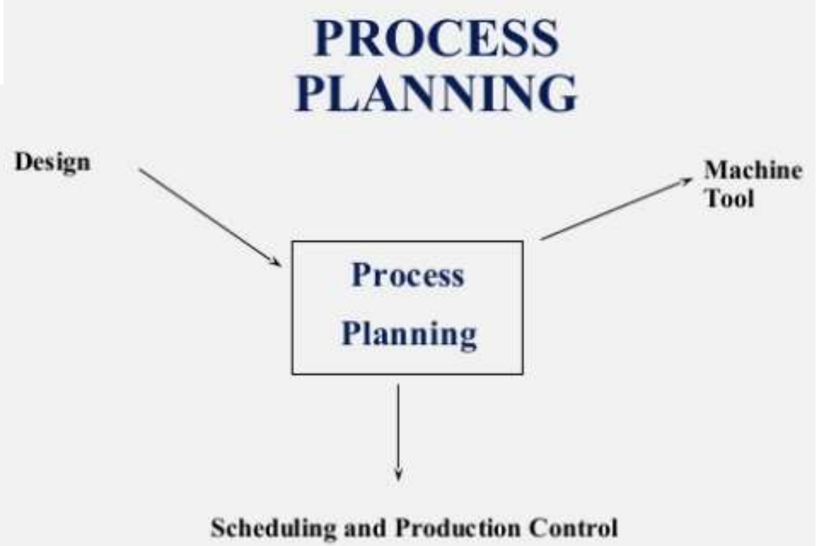
It consists of

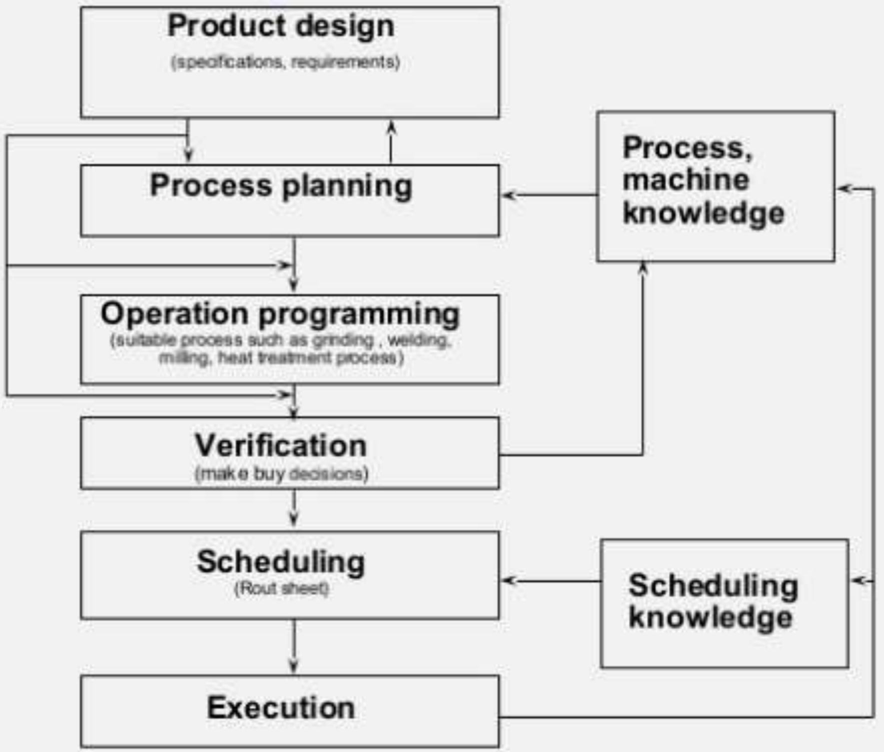
- Devising (arrange),
- Selecting
- Specifying process
- machine tools

to convert raw material to finished products

Process planning is also called:

- manufacturing planning,
- material processing,
- machine routing.
- Process plan is also called as
  - ✓ operation sheet
  - ✓ route sheet
- The detailed plan contains:
  - ✓ Route (printed sheet)
  - ✓ Processes (welding , drilling , milling , lathe operations, etc.,)
  - ✓ process parameters
  - ✓ machine and tool selections
  - ✓ (lathe, shaping m/c & drill bit, single point tool etc.,)
  - ✓ Fixtures (milling fixture , drilling fixture)
  - ✓ Machining time
- Detail of how the plan is depends on the application.
- Operation Plan sequence & Summary of a process plan.





Detailed Process Plan

ROUTE SHEET

Name of the part/component _ _ _ _ _ _ _ _
Component No._ _ _ _ _ _ _ _
Drg. No._ _ _ _ _ _ _ _

Order No._ _ _ _ _ _ _ _
Specifications_ _ _ _ _ _ _ _
Material _ _ _ _ _ _ _ _
Scrap allowance _ _ _ _ _ _ _ _

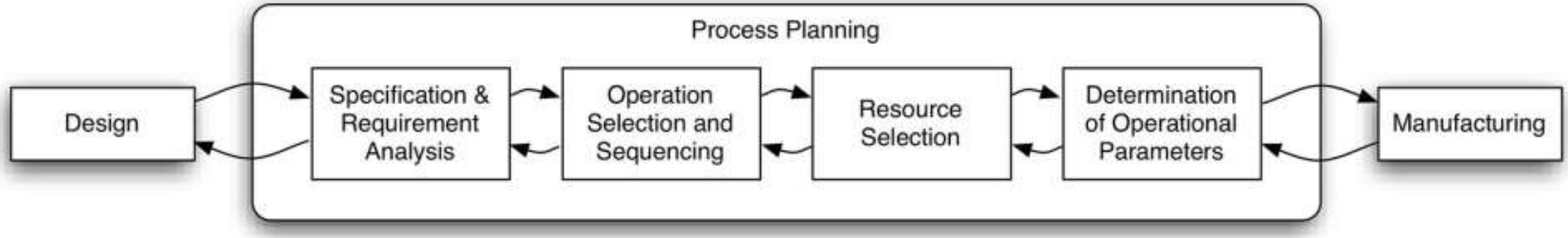
S. No.	Deptt. No.	Operation No.	Operation	Specifications		Manpower Required	Time per Piece	Due Dates	
				Machine	Tools, jigs & Fixtures			Start	End

Process Planning Activities

- **Analyse** (Part ,dimension requirements) [DRAWING INTERPRETATION]
- ↓
- **Determine** (operation sequence) [MATERIAL EVALUATION AND PROCESS SELECTION]
- ↓
- **Select** (equipment) [SELECTION OF MACHINES . TOOLING and WORK HOLDING DEVICE]
- ↓
- **Calculate** (processing times) [SETTING PROCESS PARAMETERS]
- ↓
- **Select** (QA/Inspection methods) [SELECTING QUALITY ASSURANCE METHOD]
- ↓
- **Estimate** (manufacturing cost) [COST ESTIMATING]
- ↓
- **Document** (Process Plan) [PREPARING PROCESS PLANNING DOCUMENTATION]
- ↓
- **Communicate** (manufacturing Engineer with shop floor)

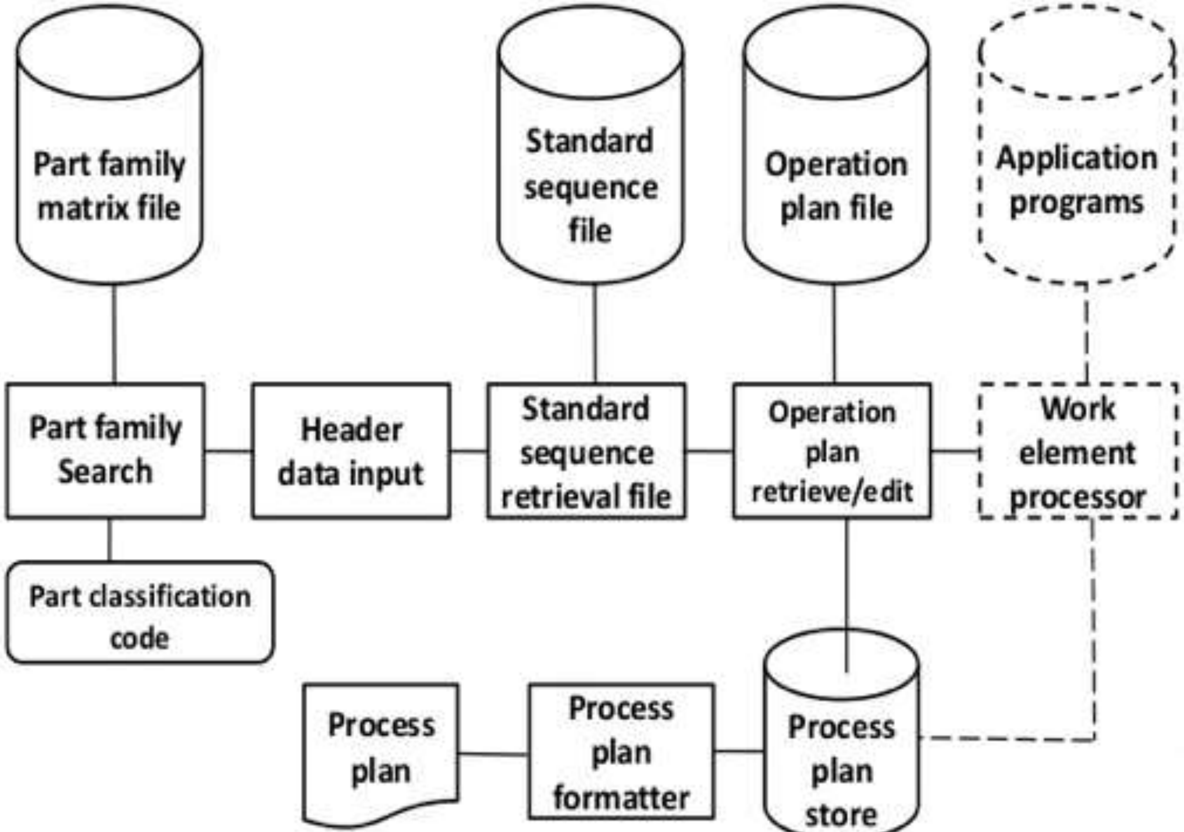
PROCESS PLANNING APPROACHES

- MANUAL
- COMPUTER-AIDED
  - VARIANT (Retrieval)
    - GT based
    - Computer aids for editing
    - Parameters selection
  - GENERATIVE
    - Some kind of decision logic
    - Decision tree/table
    - Artificial Intelligence
      Objective-Oriented
      Still experience based



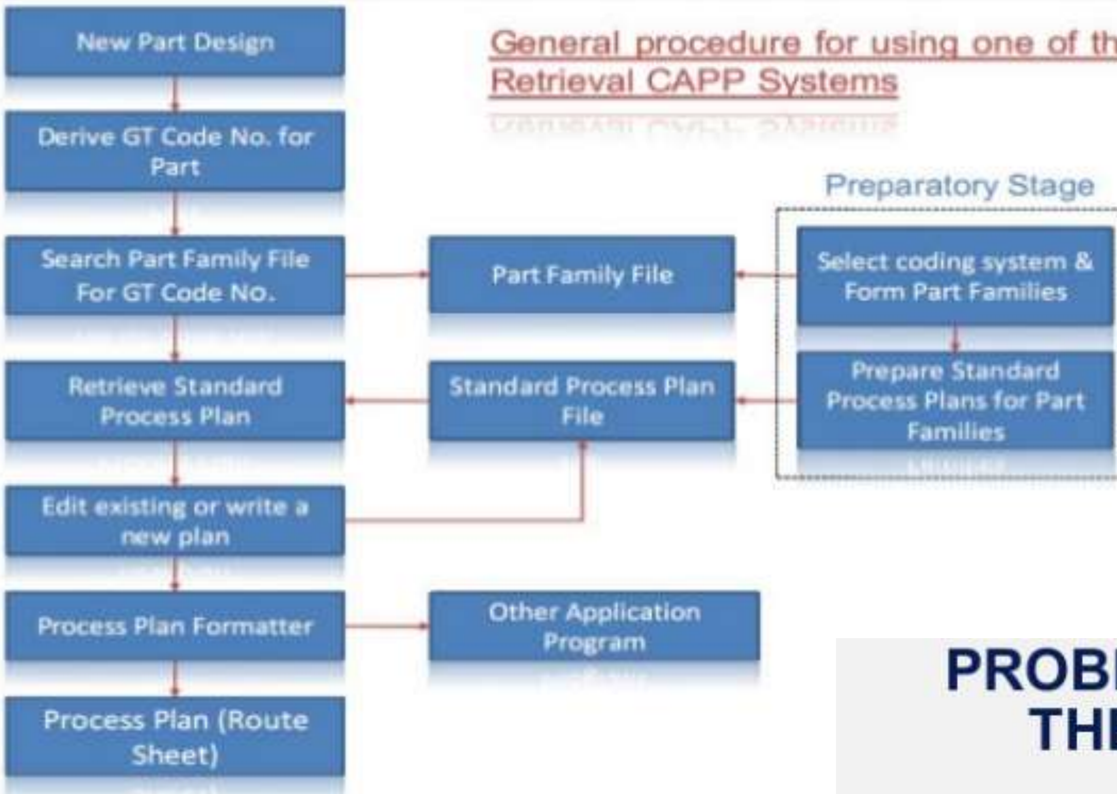
Generative process planning captures the logic, Judgments, & experiences of a process planner & incorporates them in to computer program which automatically generates the process plan from scratch, automatically & without human assistance

Retrieval type CAPP system use parts classification & code & group technology as a foundation. The parts, produced in the plant are grouped in to part families, Distinguished according to their manufacturing characteristics



Variant Process Planning

General procedure for using one of the Retrieval CAPP Systems



ADVANTAGES OF THE VARIANT APPROACH

1. Once a standard plan has been written, a variety of components can be planned.
2. Comparatively simple programming and installation (compared with generative systems) is required to implement a planning system.
3. The system is understandable, and the planner has control of the final plan.
4. It is easy to learn, and easy to use.

PROBLEMS ASSOCIATED WITH THE VARIANT APPROACH

1. The components to be planned are **limited to similar components** previously planned.
2. Experienced process planners are still required to modify the standard plan for the specific component.
3. Details of the plan cannot be generated.
4. Variant planning cannot be used in an entirely automated manufacturing system, without additional process planning.

GENERATIVE APPROACH

A system which automatically synthesizes a process plan **for a new component.**

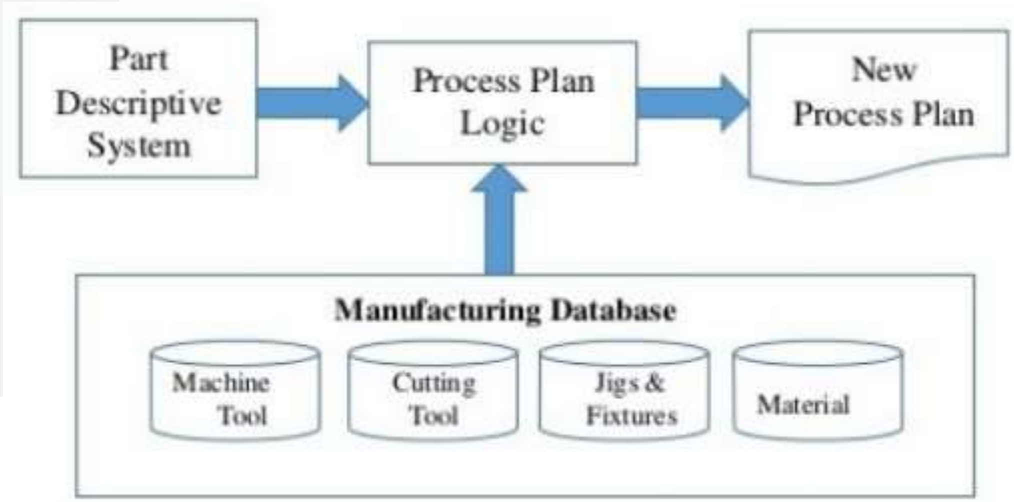
MAJOR COMPONENTS:

(i) part description

(ii) manufacturing databases

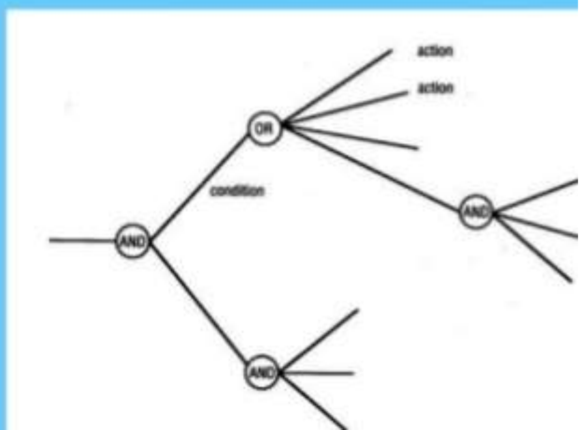
(iii) decision making logic and algorithms

Generative Approaches to CAPP



Generative Process Planning

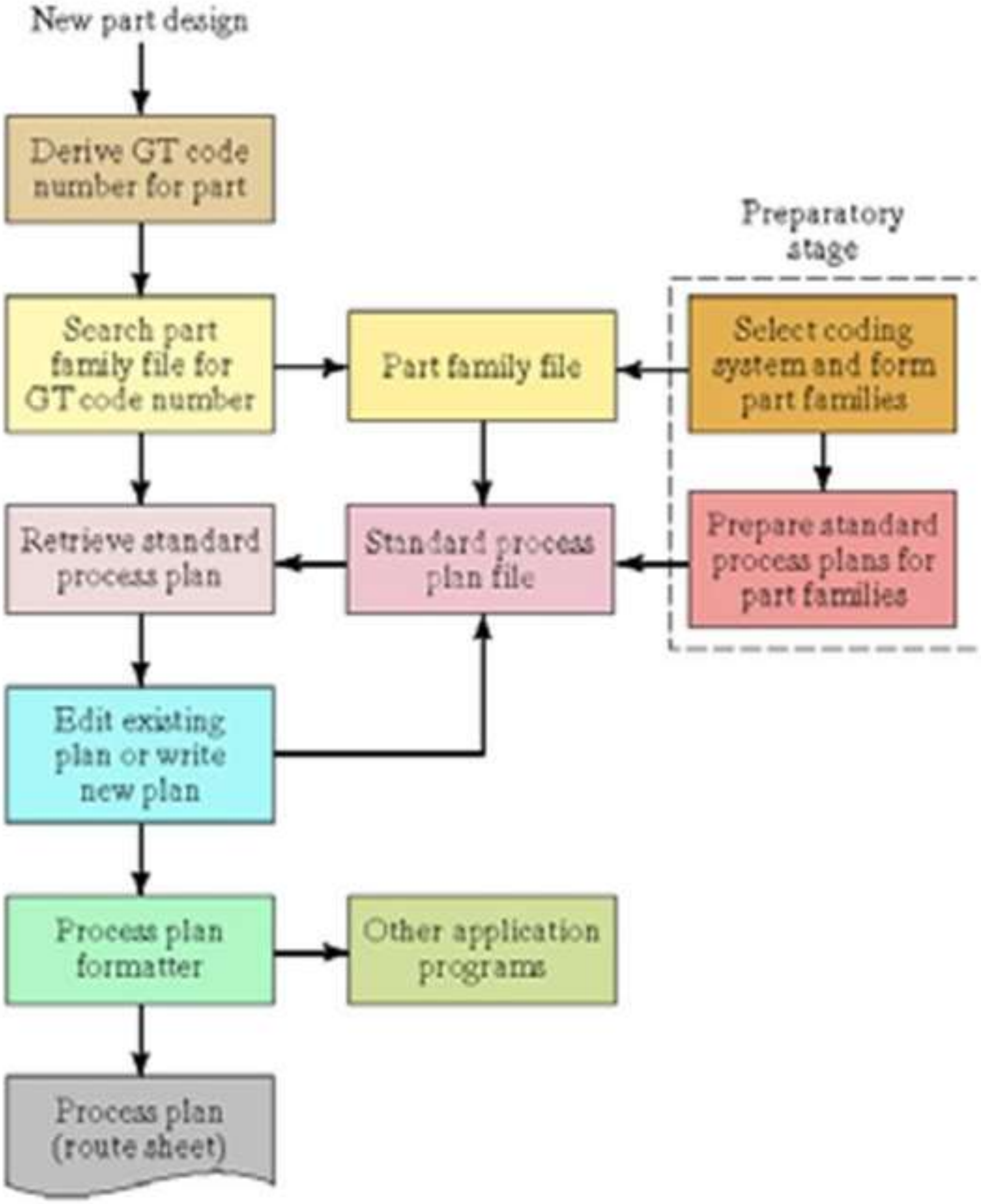
- Decision making logic and algorithms
  - Decision trees
  - Expert Systems:
  - AI based approaches



ADVANTAGES OF THE GENERATIVE APPROACH

1. Generate consistent process plans rapidly;
2. New components can be planned as easily as existing components;
3. It has potential for integrating with an automated manufacturing facility to provide detailed control information.

Operation of a retrieval type computer-aided process planning system



CIM

Computer integrated manufacture is concerned with providing computer assistance, control and high level integrated automation at all levels of manufacturing and other industry, by linking islands of automation into distributed processing system.

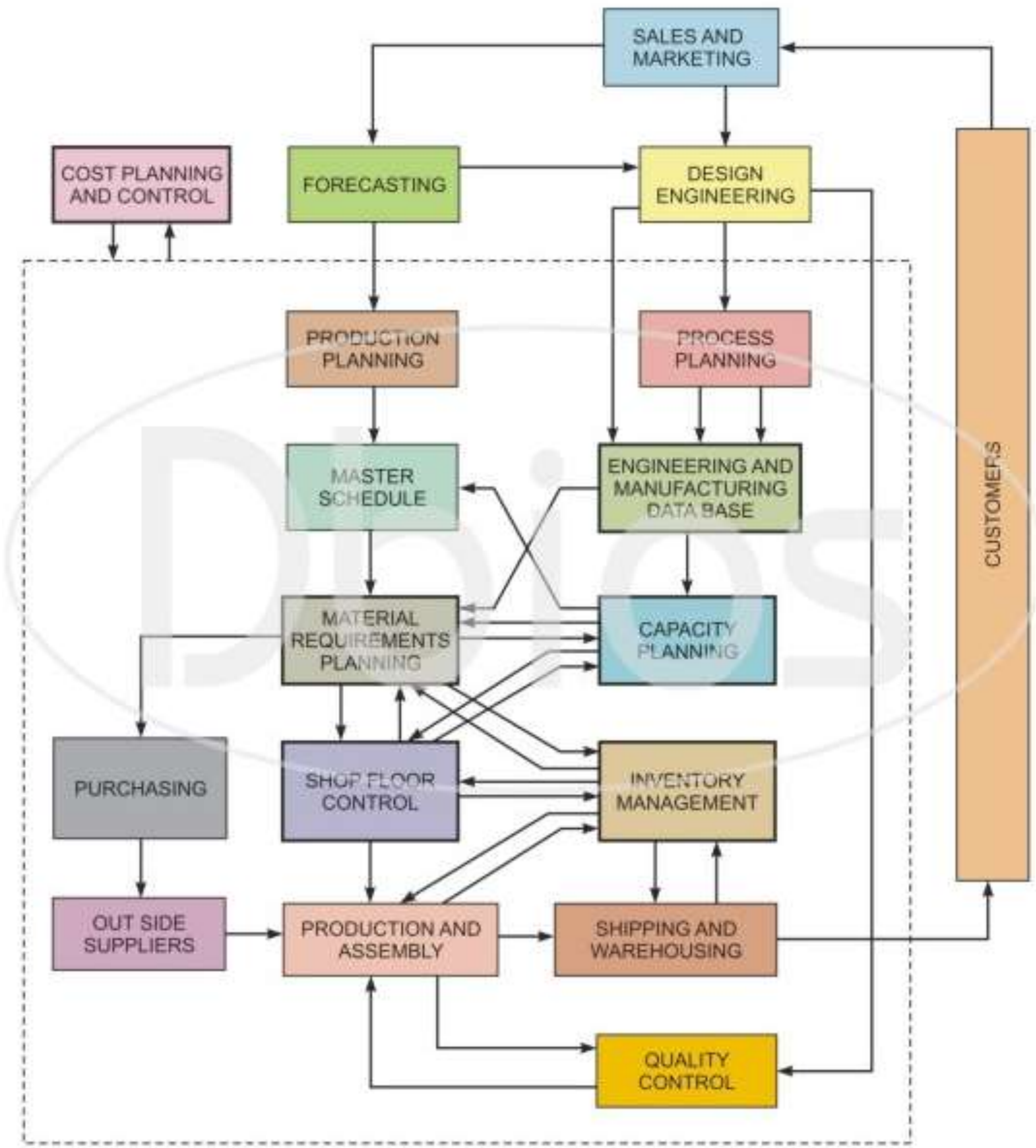
Definition of Automation

Automation is a technology concerned with the application of mechanical, electronic, and computer based systems to operate and control production.

This technology includes

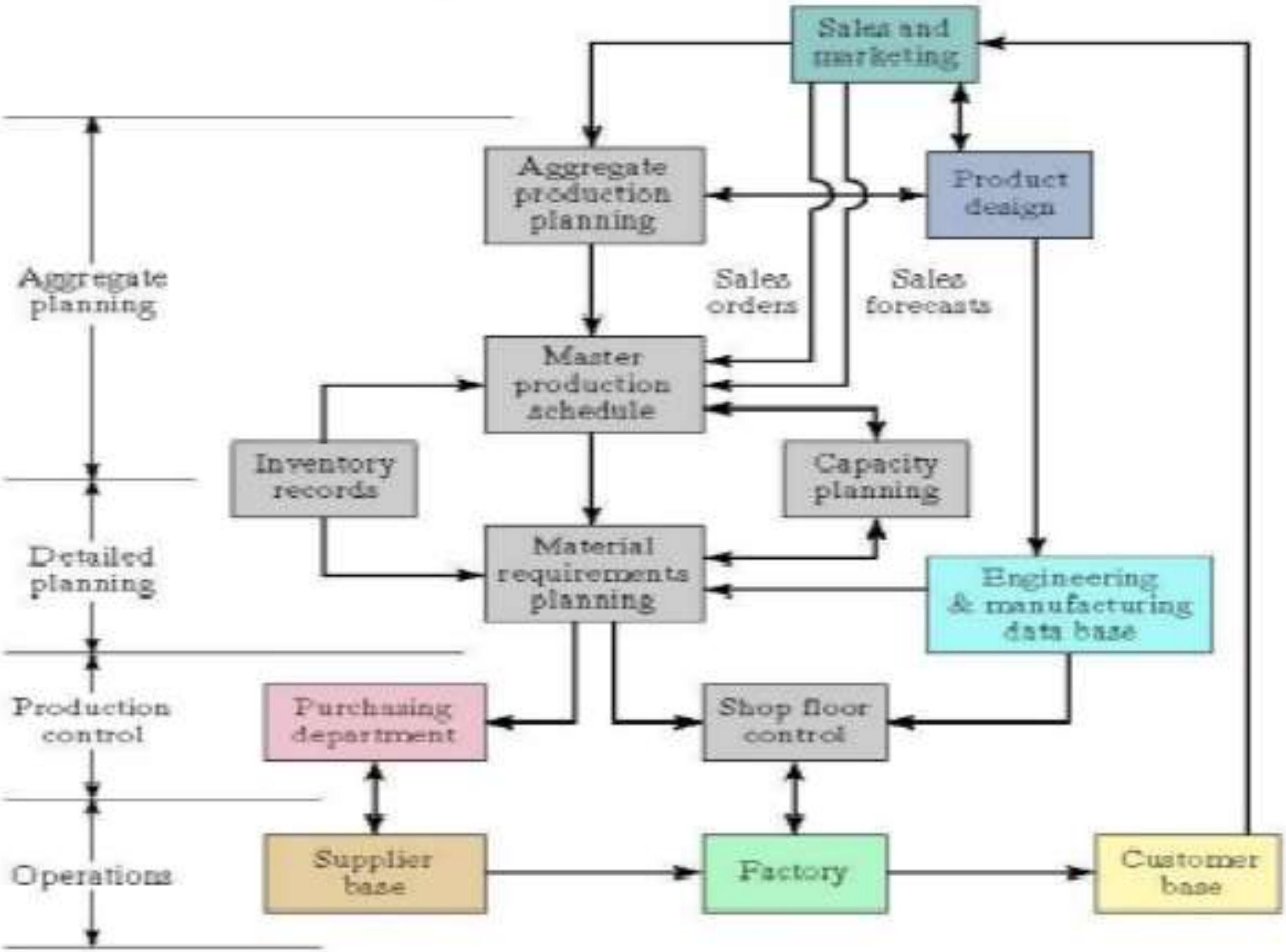
- Automatic machines tools to process parts
- Automatic assembly machines
- Industrial robots
- Automatic material handling and storage systems
- Automatic inspection systems for quality control

COMPUTER AIDED MANUFACTURING - II

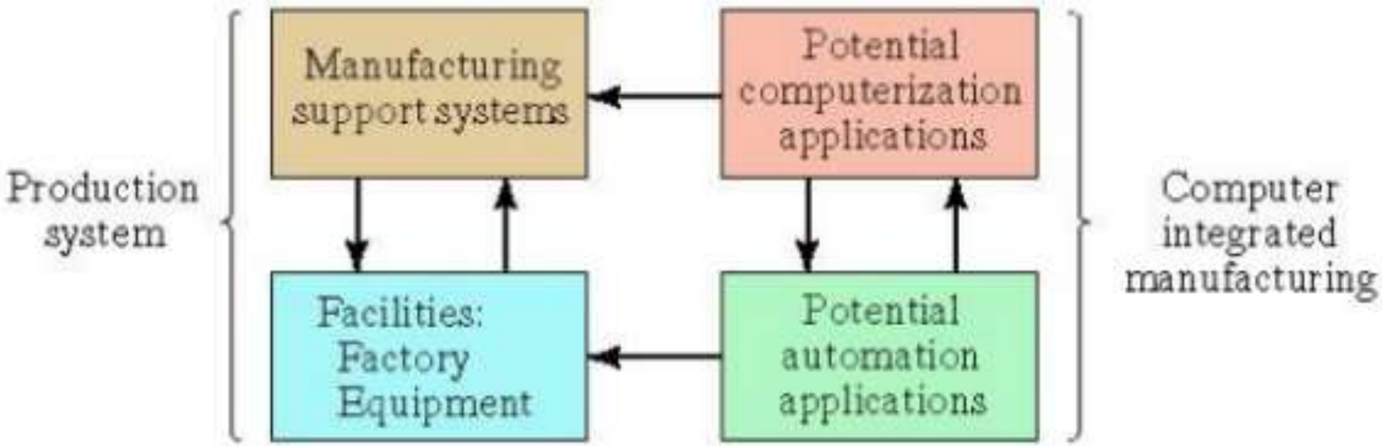


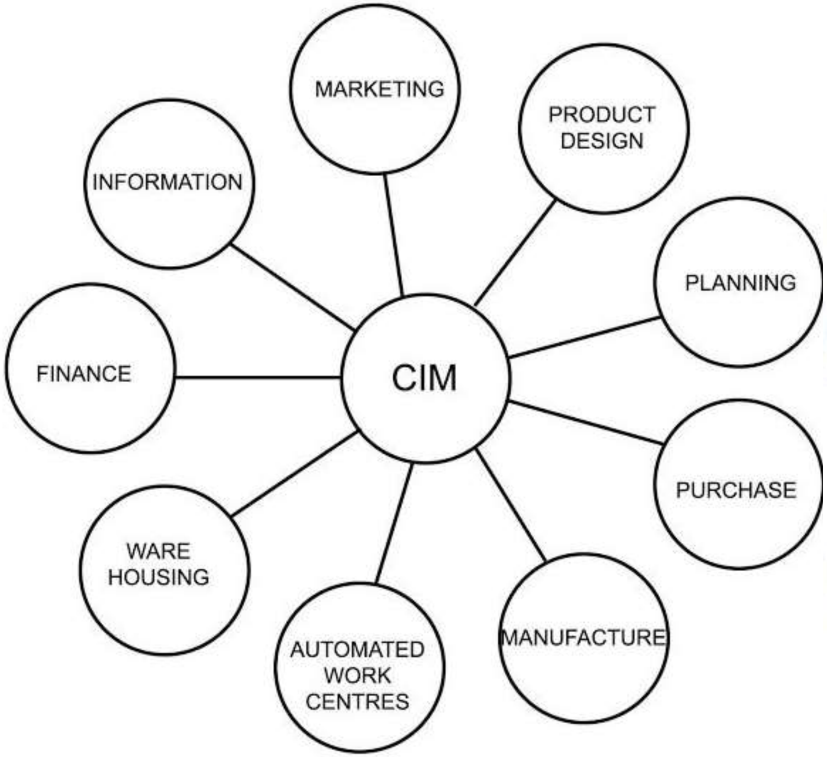
CYCLE OF ACTIVITIES IN A COMPUTER-INTEGRATED PRODUCTION MANAGEMENT SYSTEM

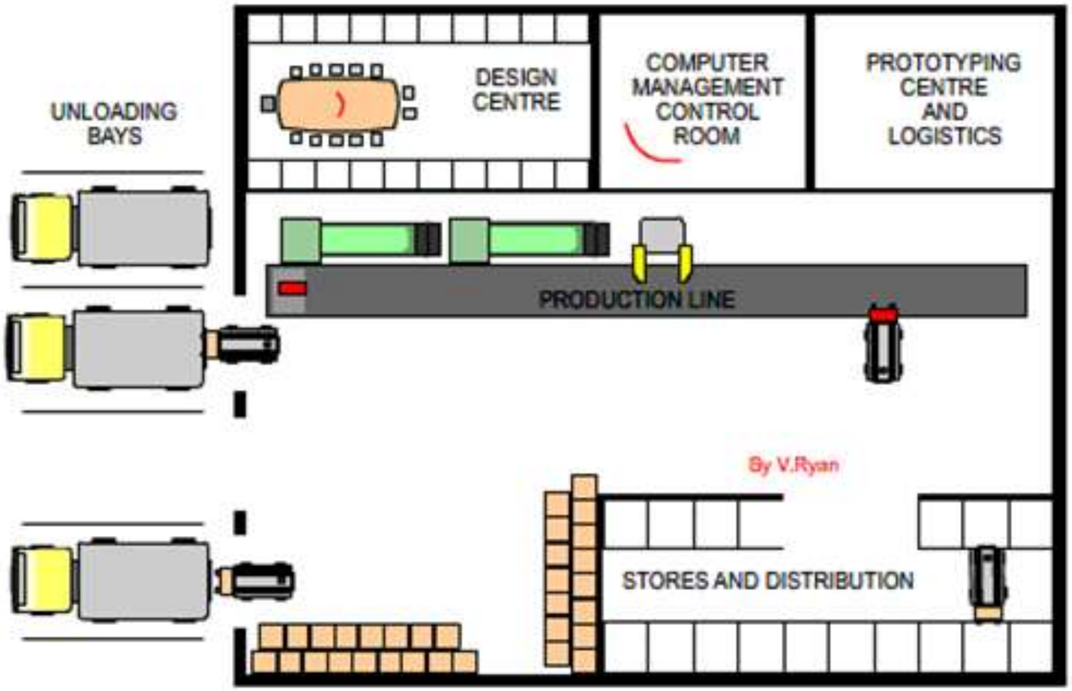
Production Planning & Control System



Computer Integrated Manufacturing

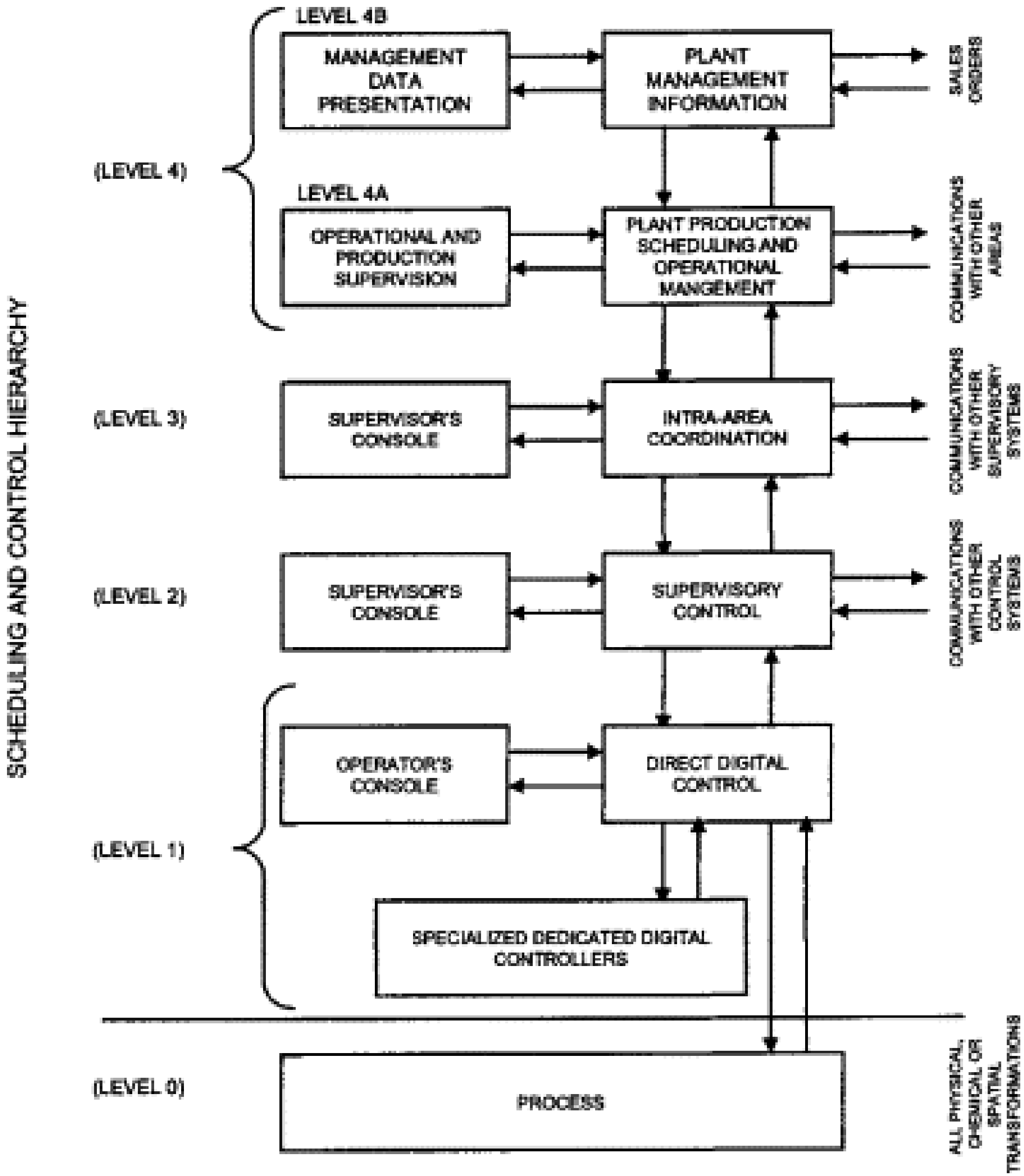






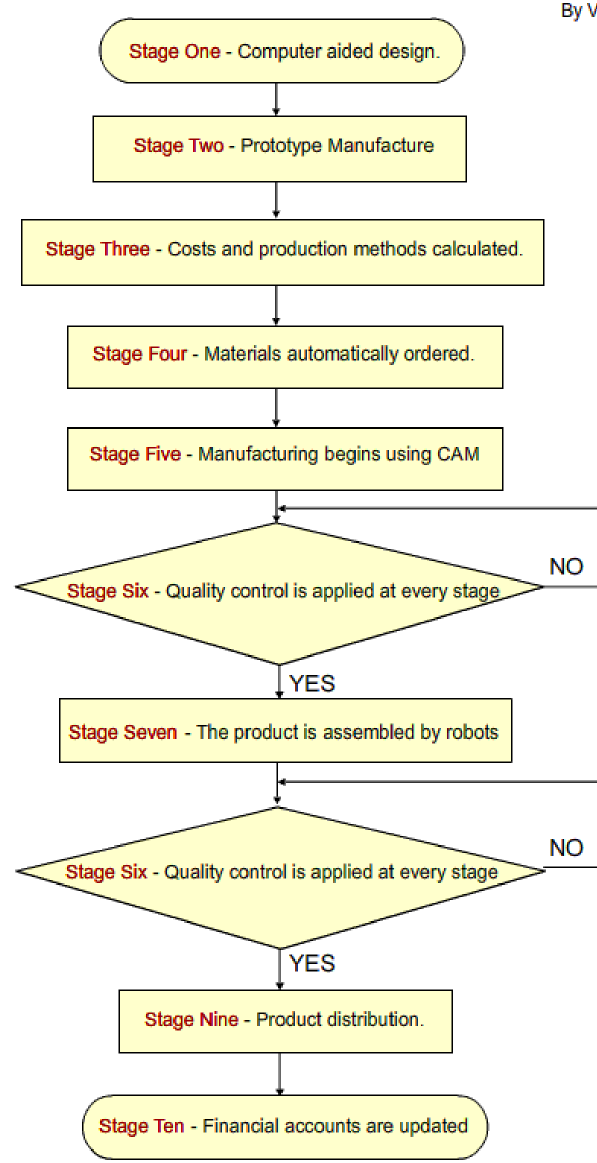
CIM

COMPUTER AIDED MANUFACTURING - II

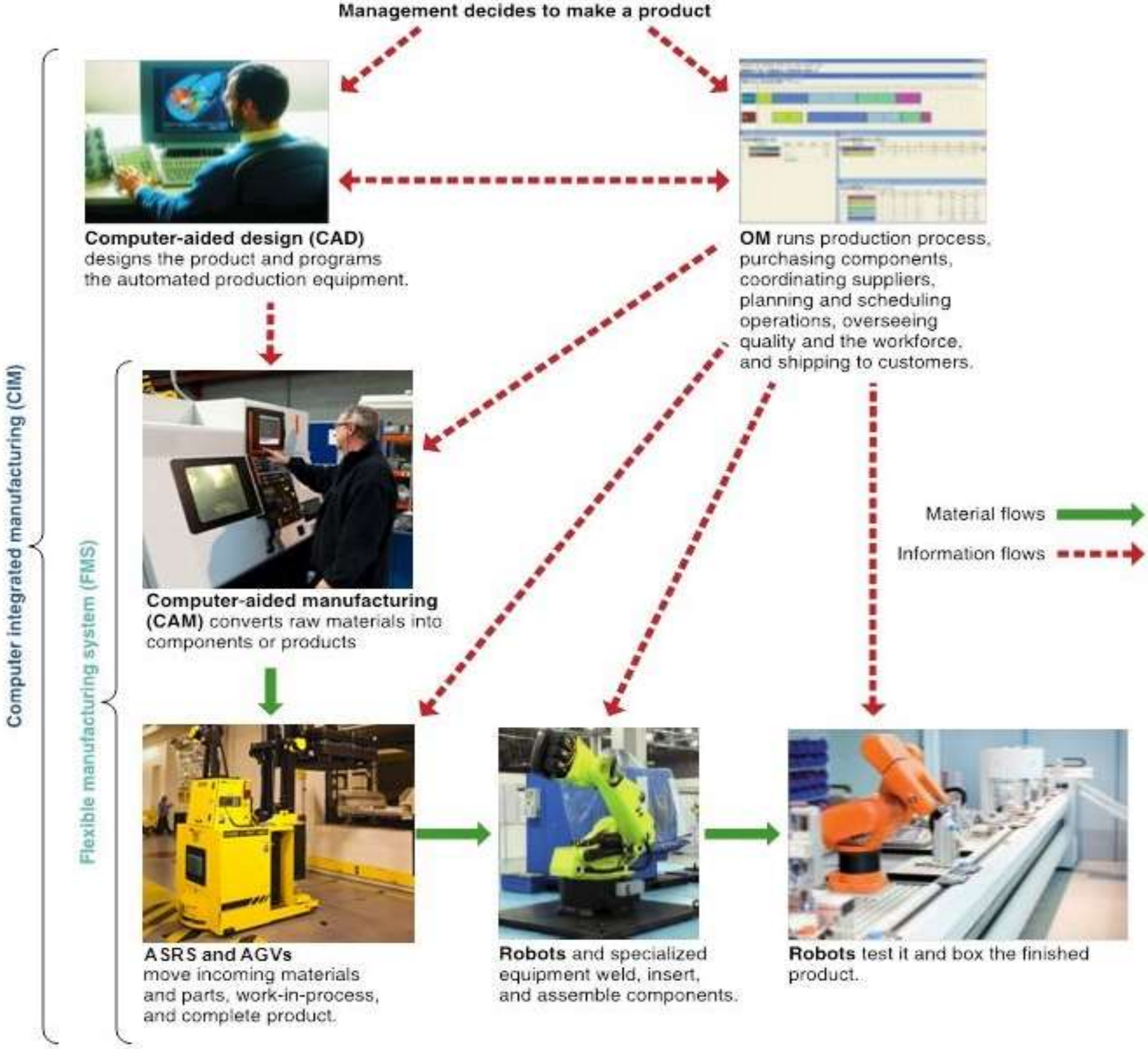


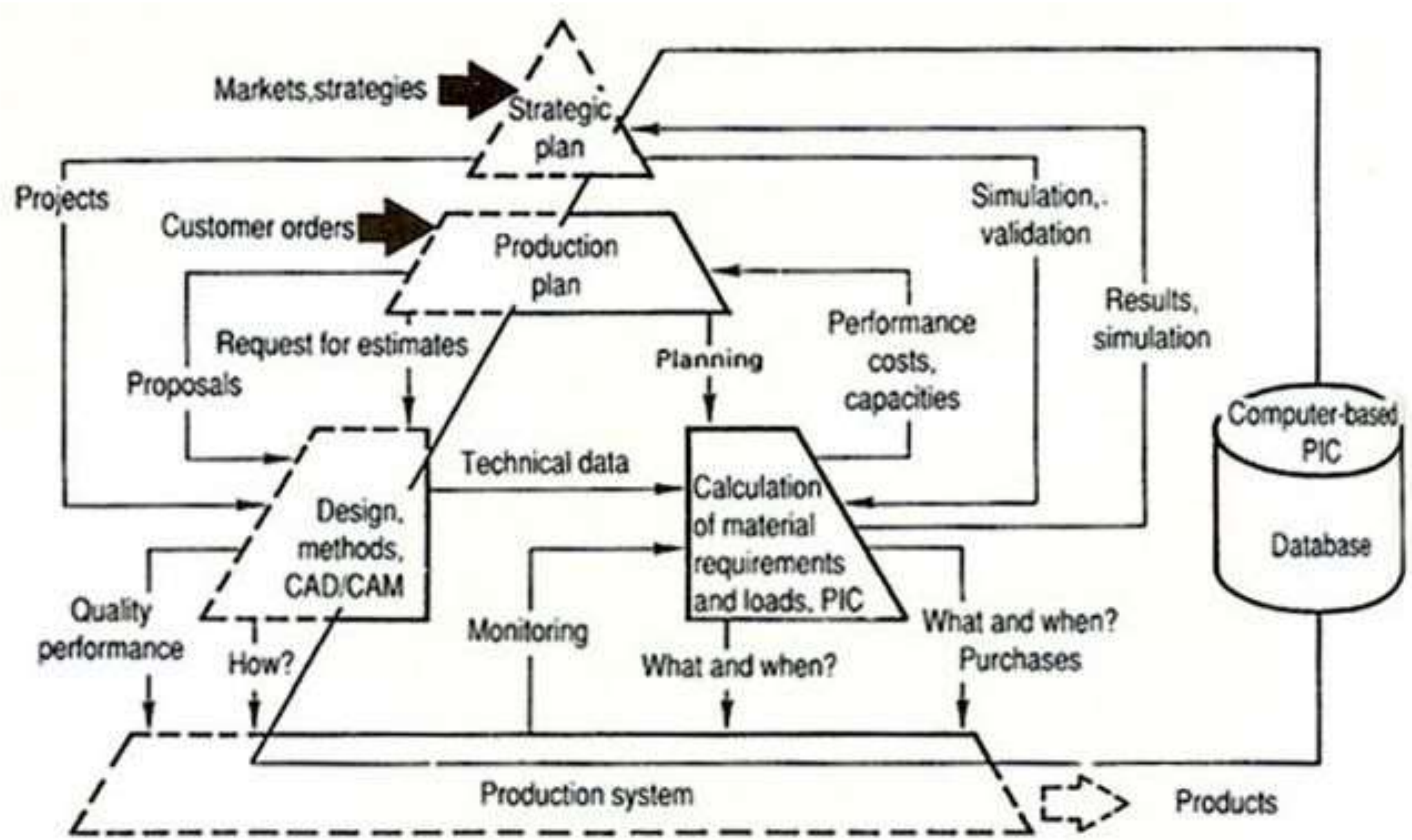
THE COMPUTER SYSTEM CONTROLS EVERY ASPECT FROM DESIGN TO MANUFACTURE TO STORAGE AND DISTRIBUTION

By V.Ryan



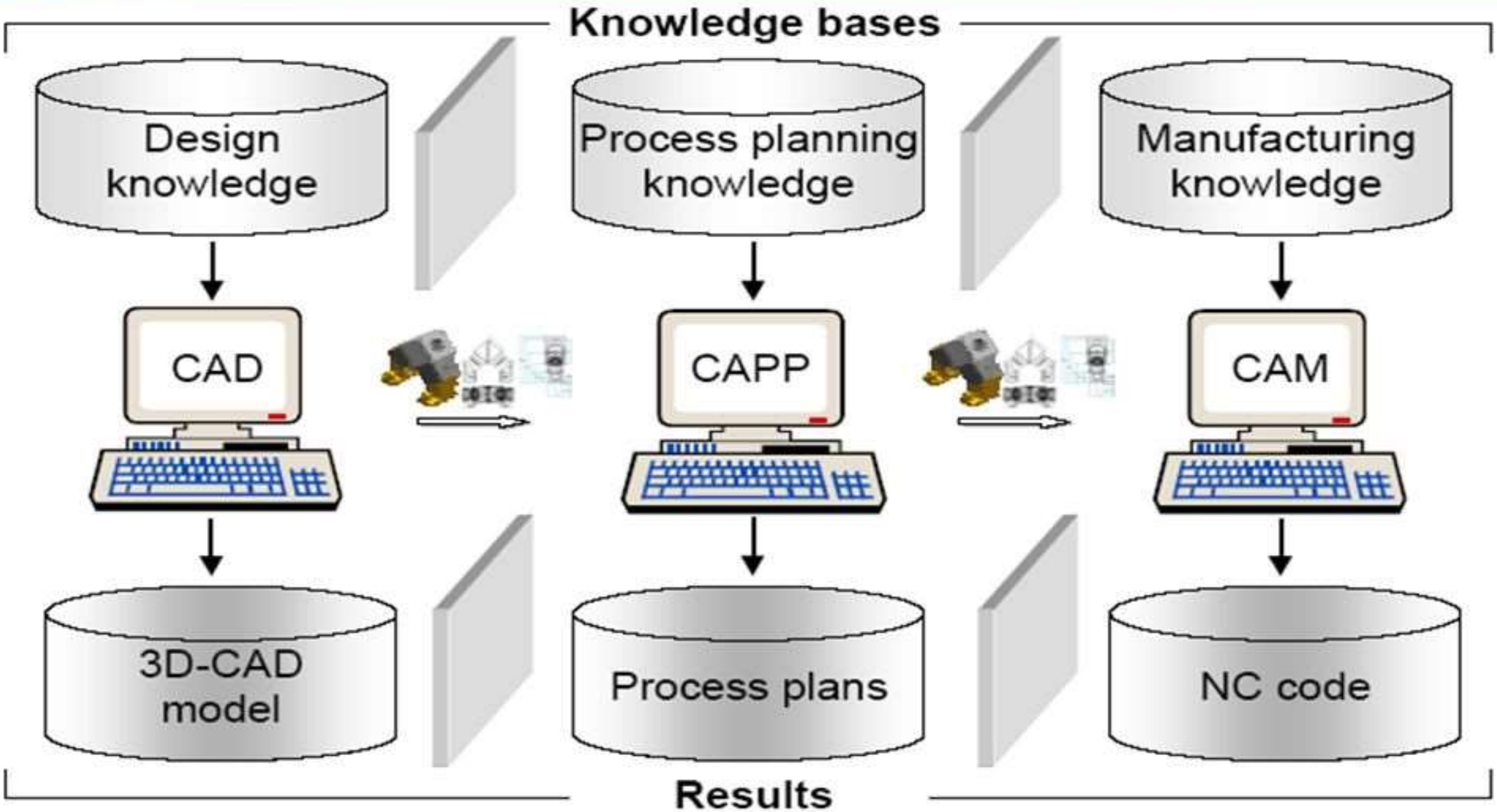
COMPUTER AIDED MANUFACTURING - II




Markets,strategies
Strategic plan
Projects
Customer orders
Production plan
Simulation, validation
Results, simulation
Performance costs, capacities
Request for estimates
Planning
Proposals
Computer-based PIC
Database
Technical data
Design, methods, CAD/CAM
Calculation of material requirements and loads. PIC
Quality performance
How?
Monitoring
What and when?
What and when? Purchases
Production system
Products

Introduction to Computer Aided Manufacturing - CAM

Computer Aided Manufacturing involves the use of computer programs specifically designed to create the geometry and tool paths needed for parts to be machined. These tool paths can then be automatically processed into a program specific for the CNC machine to be used.



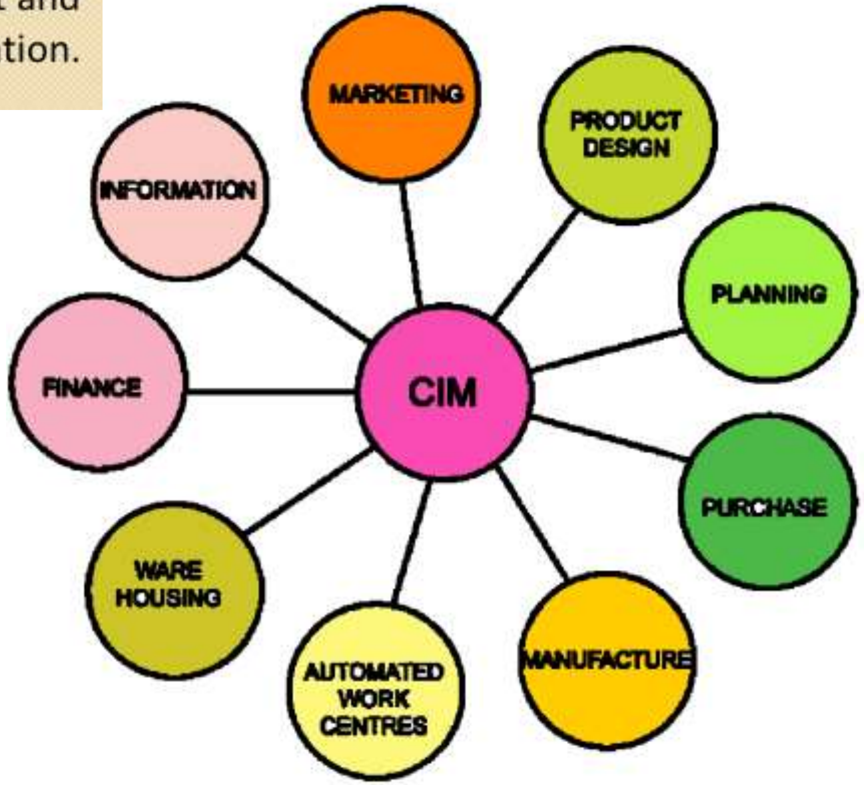
COMPUTER AIDED MANUFACTURING - II

Advantages

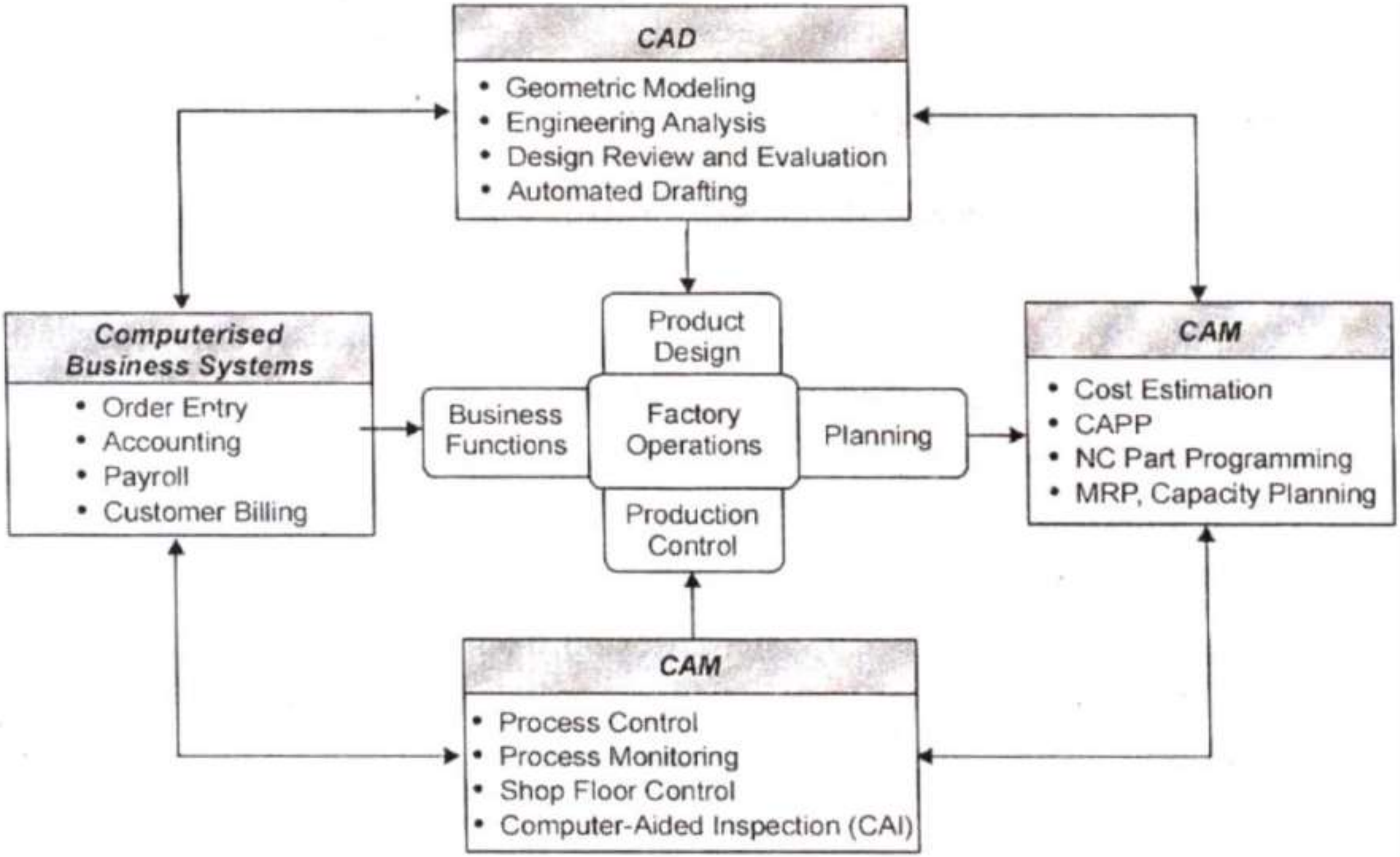
- Responsiveness to shorter product life cycles
- Better process control emphasizes product quality and uniformity.
- Supports and co-ordinates exchange of information
- Designs components for machines.
- Decreases the cost of production and maintenance

Disadvantages

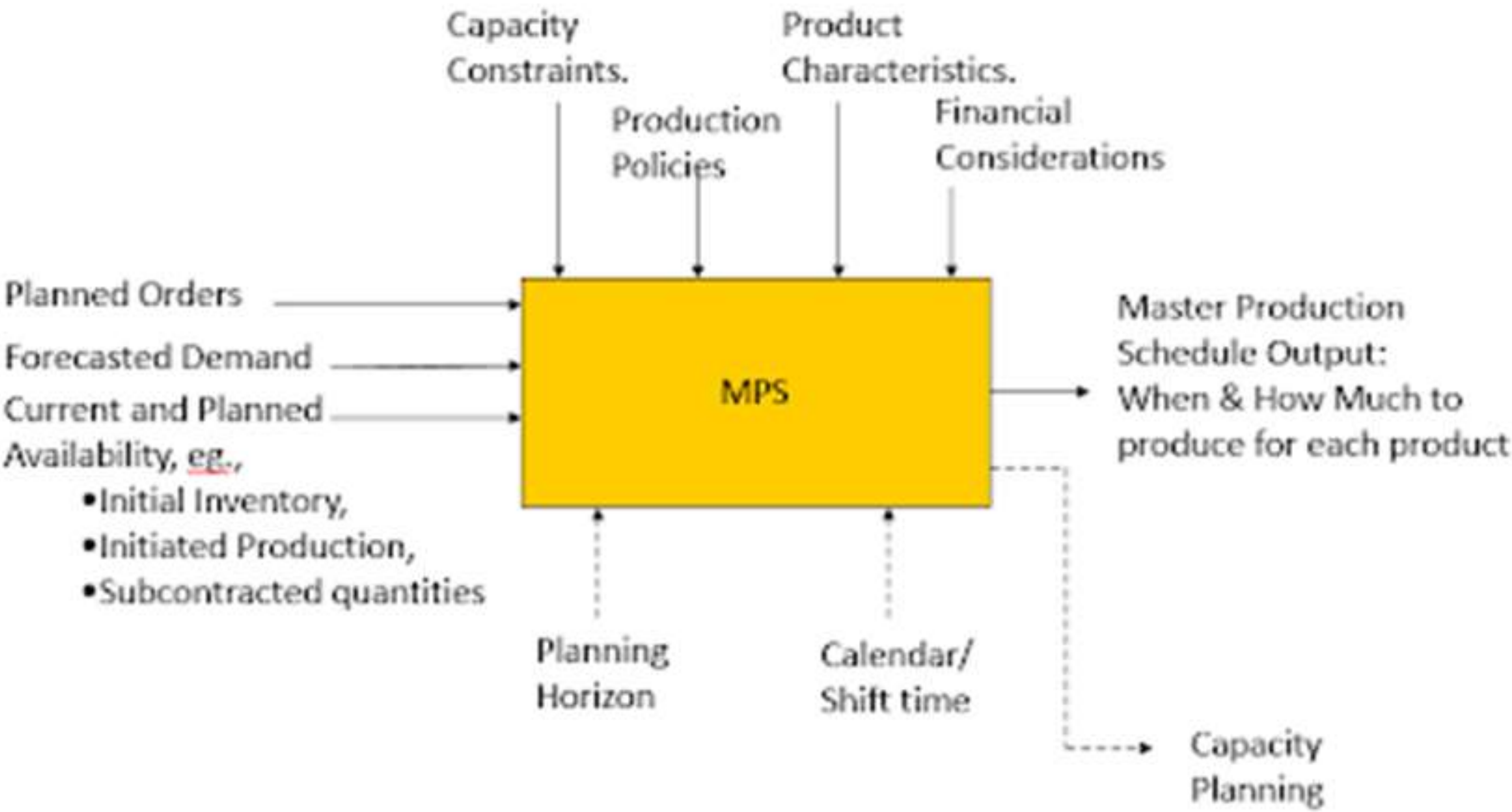
- Unfamiliar technologies used.
- Requires major change in corporate culture.
- Reduction in short term profit.
- Perceived risk is high.
- High maintenance cost and expensive implementation.



COMPUTER AIDED MANUFACTURING - II



The Master Production Scheduling



Flow of information

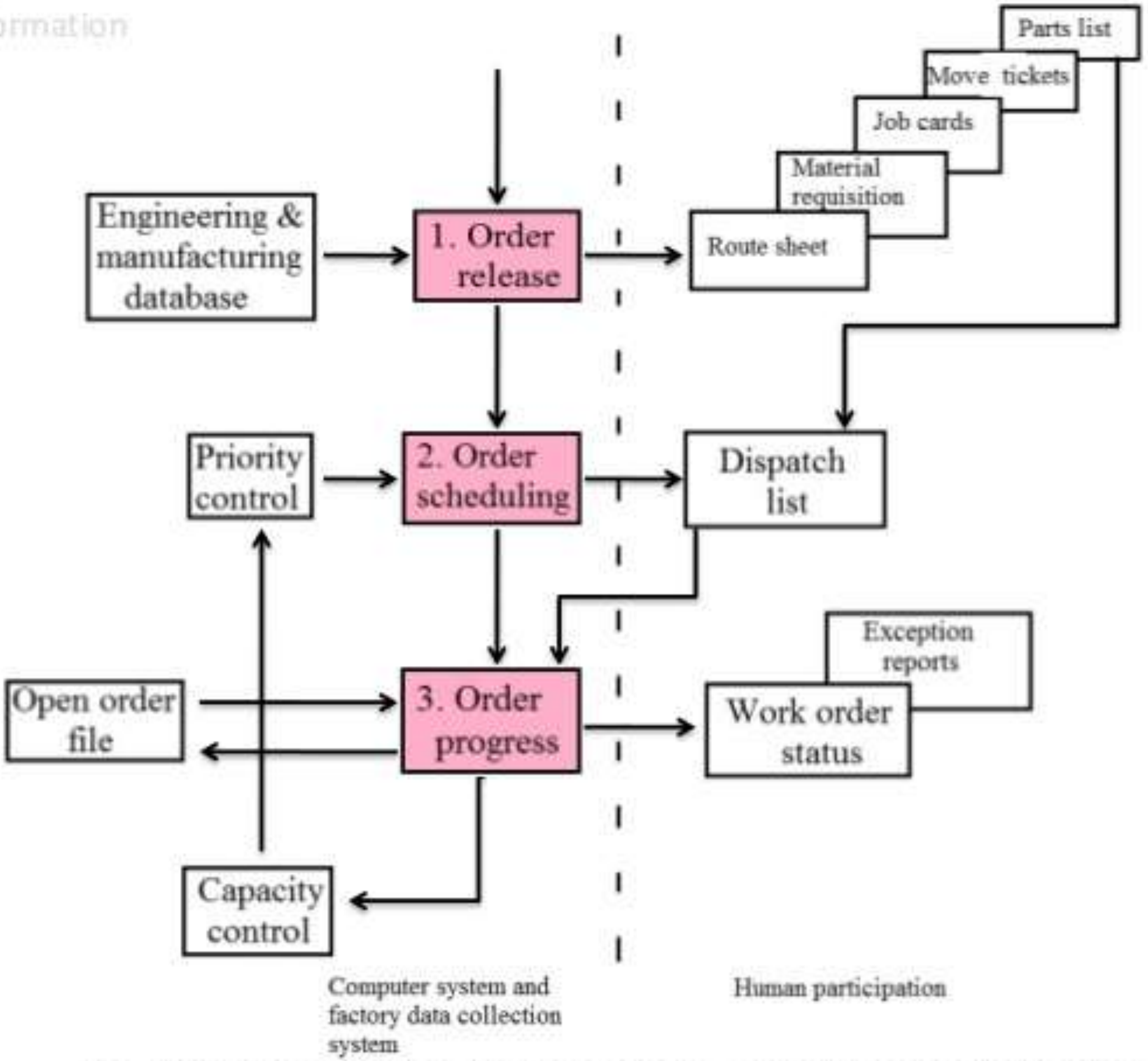
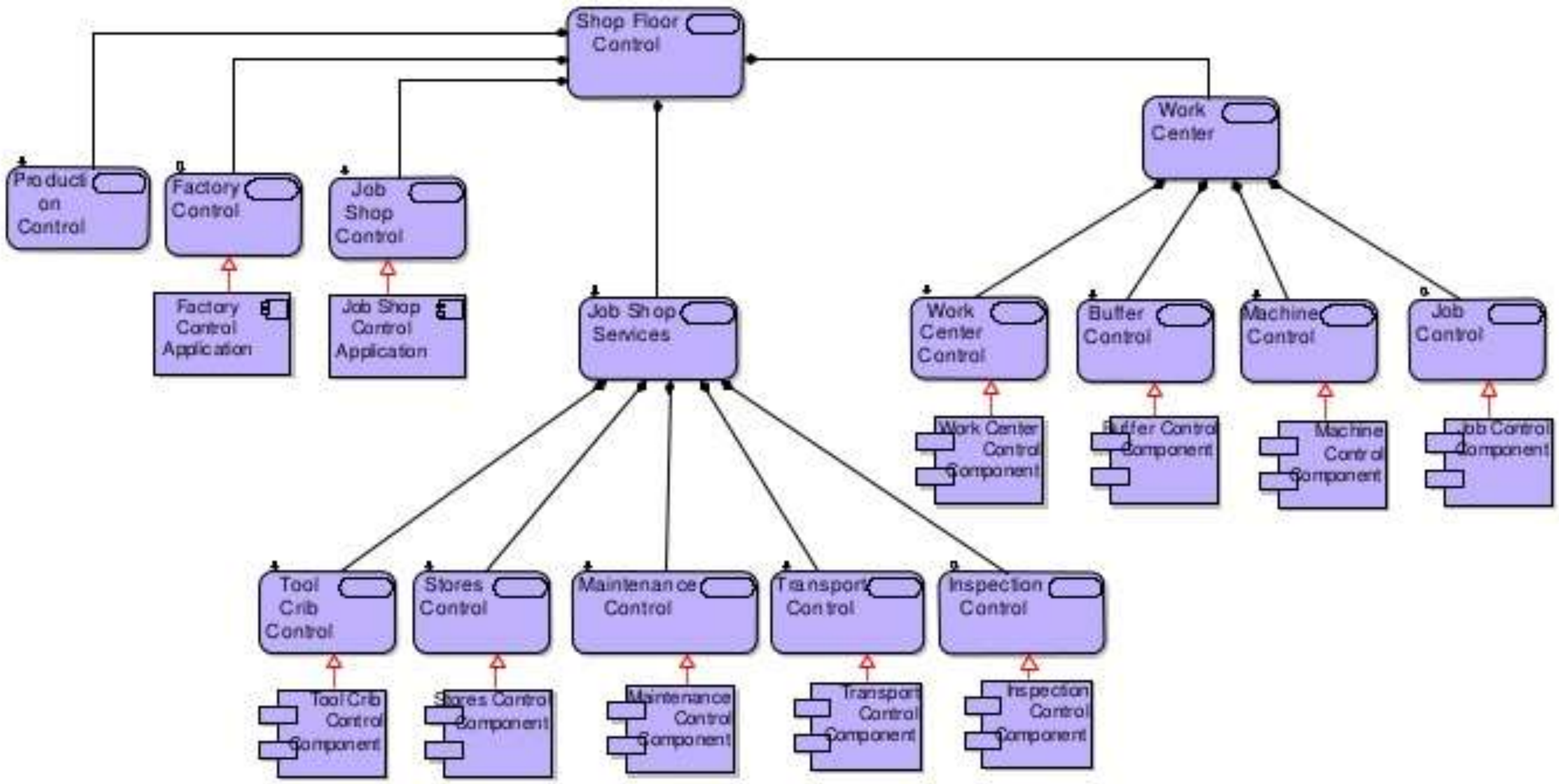
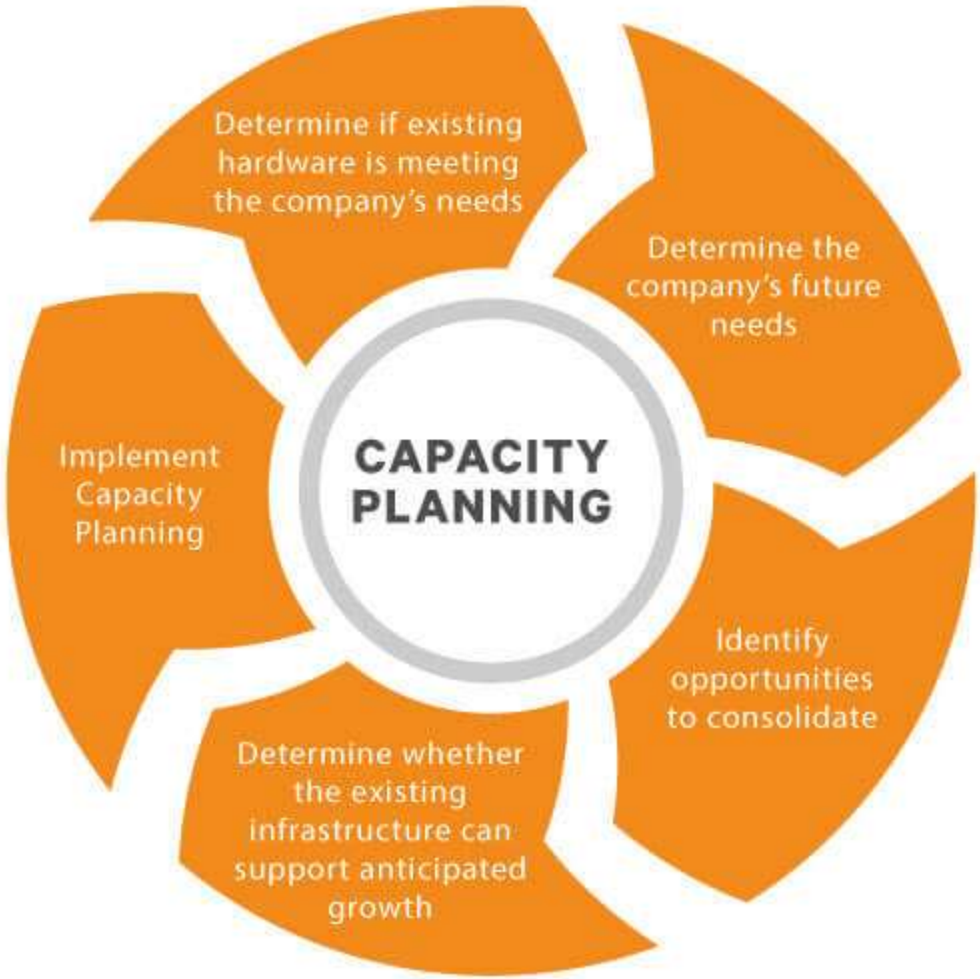


Fig. 1 The organization of a computerized shop floor control system

Shop Floor Application Services




Determine if existing hardware is meeting the company's needs
Determine the company's future needs
CAPACITY PLANNING
Identify opportunities to consolidate
Determine whether the existing infrastructure can support anticipated growth
Implement Capacity Planning


Capacity Planning Resource Utilization Components With Arrows
Capacity Planning
01
On-Time Delivery
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
02
Resource Utilization
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
03
Lead Times
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
04
Firefighting
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
05
Production Cost
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
06
Throughput
This slide is 100% editable. Adapt it to your needs and capture your audience's attention.
$
1
2
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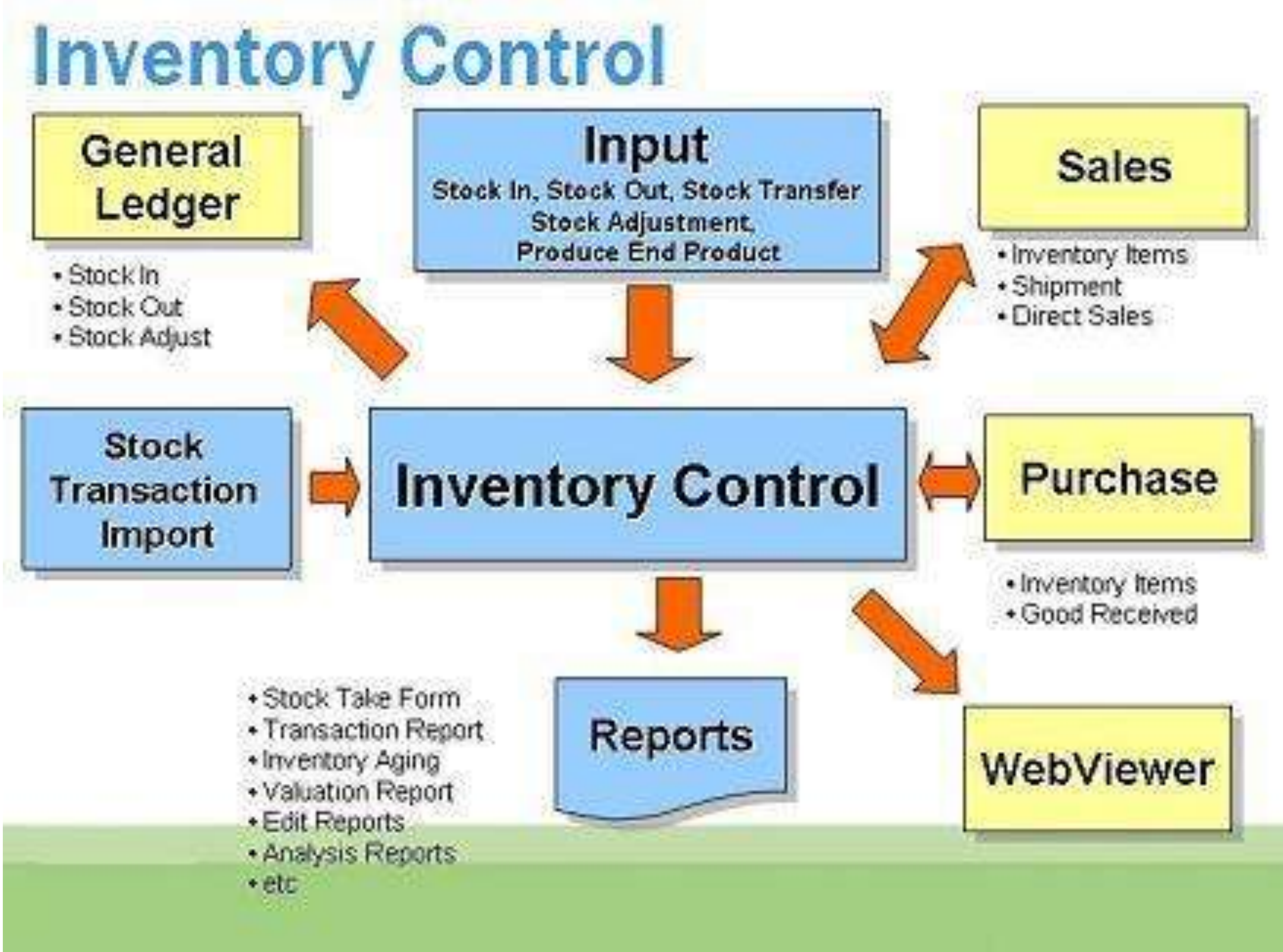
Inventory Control
General Ledger
• Stock In
• Stock Out
• Stock Adjust
Input
Stock In, Stock Out, Stock Transfer
Stock Adjustment,
Produce End Product
Sales
• Inventory Items
• Shipment
• Direct Sales
Stock Transaction Import
Inventory Control
Purchase
• Inventory Items
• Good Received
• Stock Take Form
• Transaction Report
• Inventory Aging
• Valuation Report
• Edit Reports
• Analysis Reports
• etc
Reports
WebViewer


Preventing Dead Stock or Perishability
Optimizing Storage Cost
Maintaining Sufficient Stock
Enhancing Cash Flow
Reducing Purchase Cost of Goods
Inventory Management Objectives

COMPUTER AIDED MANUFACTURING - II