Course Material of

PCME-302 CAD/CAM

ICD (6th Semester)

Prepared By

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Lecture 1

INTRODUCTION TO CAD/CAM

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Need for CAD/CAM

- Design and manufacturing forms the core of engineering.
- To remain competitive in global economy
- New products with enhanced features at competitive costs
- Short lead times and short product lives
- Reduction in product life cycle
- Mass customization – Customer specific changes to satisfy diverse requirements – High flexibility in the manufacturing system
- Reduction in manufacturing cost and delivery time
- Increasing consumer awareness about quality

NEED TO STUDY CAD/CAM

- Training courses typically offered by CAD/CAM vendors & manuals and documentation which are typically provided with the CAD/CAM systems tend to concentrate on the user interface and the syntax associated with it.
- Understanding the basic concepts and principles underlying the system helps the user in understanding the various jargon and terminology encountered in the system documentation as well as enabling the user to deal with system errors more intelligently.
- Failure of such understanding often results in user frustration and a significant decline in productivity and utilization of the system relative to manual procedures.
- Learning one system is sufficient to learn another one at a faster pace.
- Learning the basic concepts does not only speed up the training curve of users but it also helps them utilize the technology productively.

Developments in computers

- Developments in microelectronics – microprocessors, VLSI
- Availability of computers with enhanced memory and faster computing speed at affordable prices
- Development of graphics workstations with powerful graphic facilities
- Development of interactive graphics and analysis software - Easy to use and powerful

Computer Aided Design

- Use of computer systems to assist in creation, modification, analysis and optimization of a design.
- Computer assistance while a designer converts his or her ideas and knowledge into a mathematical and graphical model represented in a computer.

Computer Aided Manufacturing

- Use of computers systems to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with plant's production resources.

1. Computer monitoring and control - Computer is connected directly to the manufacturing process e.g. NC/CNC machines, chemical processing etc.
2. Manufacturing support applications – Use of computers in process planning, scheduling, shop floor control, work study, tool design, quality control etc.

CAD-CAM and AUTOMATION

- Automation is technology concerned with the application of complex mechanical, electrical, electronic , hydraulic, pneumatic or computer based system in the operation and control of production.
- Types of manufacturing

1. Continuous process industries – Sugar industry, chemical industry etc.
2. Mass production industries – Automobiles, Consumer goods etc.
3. Batch production industries – machines, aircrafts etc.
4. Job production industries – Prototypes, heat exchangers , chemical reactors etc.

- Automation is focused on reducing unit production time and to some extent time associated with planning and setting up for each batch of production.
- CAD/CAM is focused on reducing time for designing the product and all other activities which are accomplished once for each product and time associated with planning and setting up for each batch of production

CAD/CAM

- CAD/CAM involves all the processes of conceptualizing , designing, analyzing, prototyping and actual manufacturing with computer's assistance.
- Latest techniques of geometric modeling (Feature base or parametric modeling) and manufacturing like rapid prototyping (RP) have bridged the gap between product conceptualization and product realization.

CAD/CAM

- CAD/CAM - Key to improve manufacturing productivity and the best approach for meeting the critical design requirements.
- CAD/CAM software provides engineers with the tools needed to perform their technical jobs efficiently and free them from the tedious and time-consuming tasks that require little or no technical expertise.
- CAD/CAM software speeds the design process, therefore increasing productivity, innovation and creativity of designers.
- CAD/CAM is the only mean to meet the new technological design and production requirements of increased accuracy and uniformity

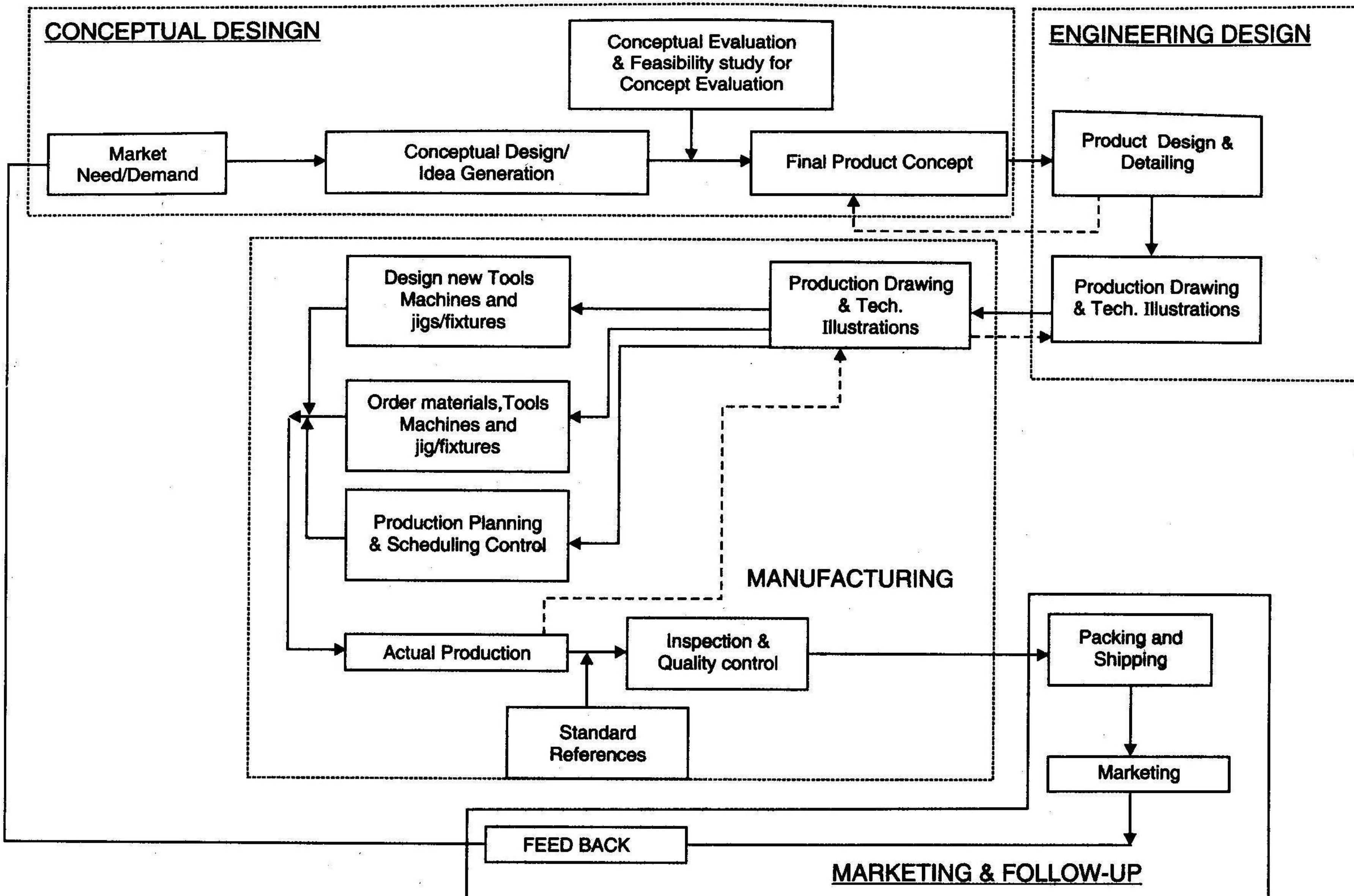


Figure 1. 1 : Conventional Product Design & Development Cycle

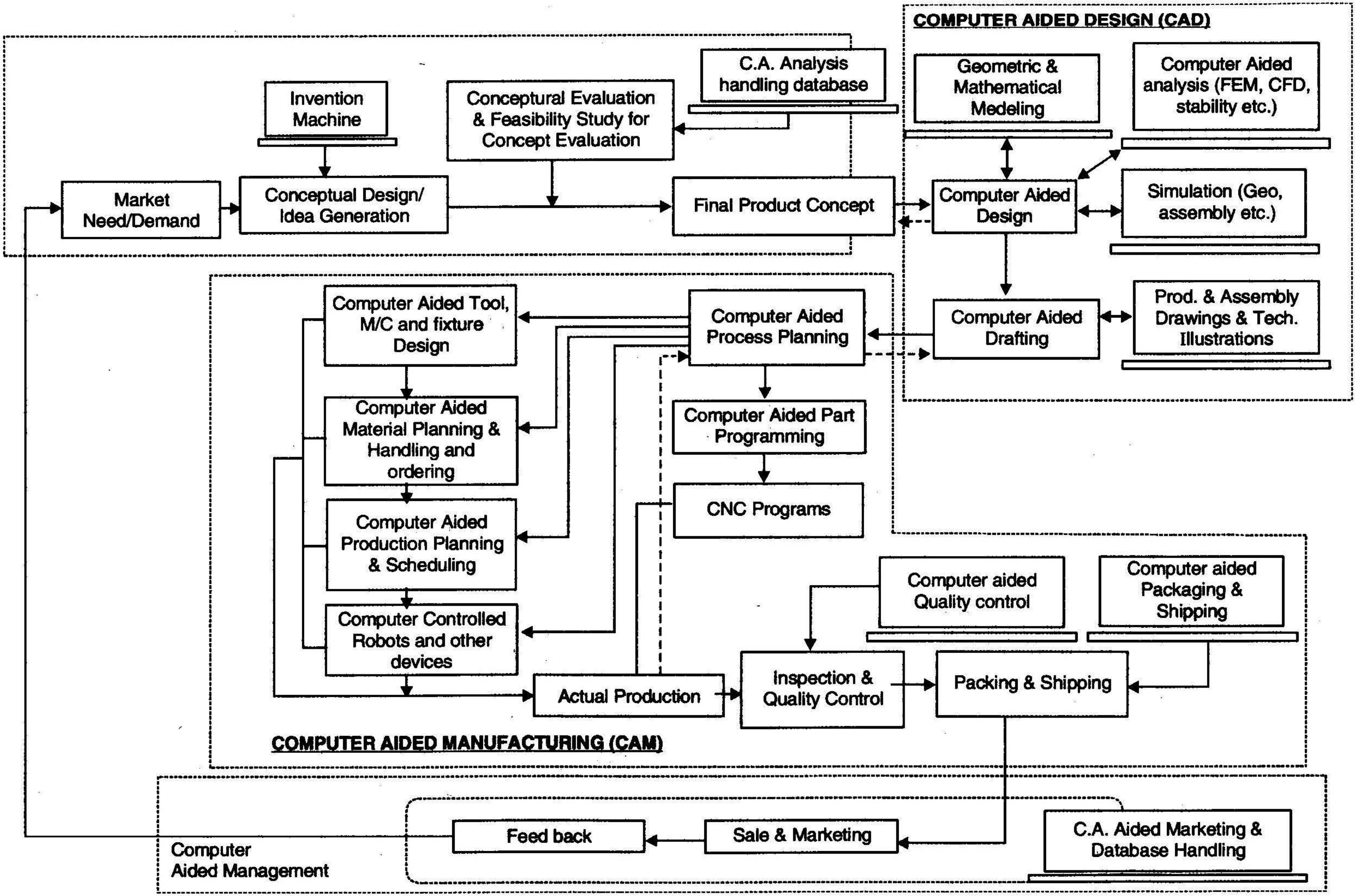


Figure 1. 2 : Product Design & Development Cycle with Computers

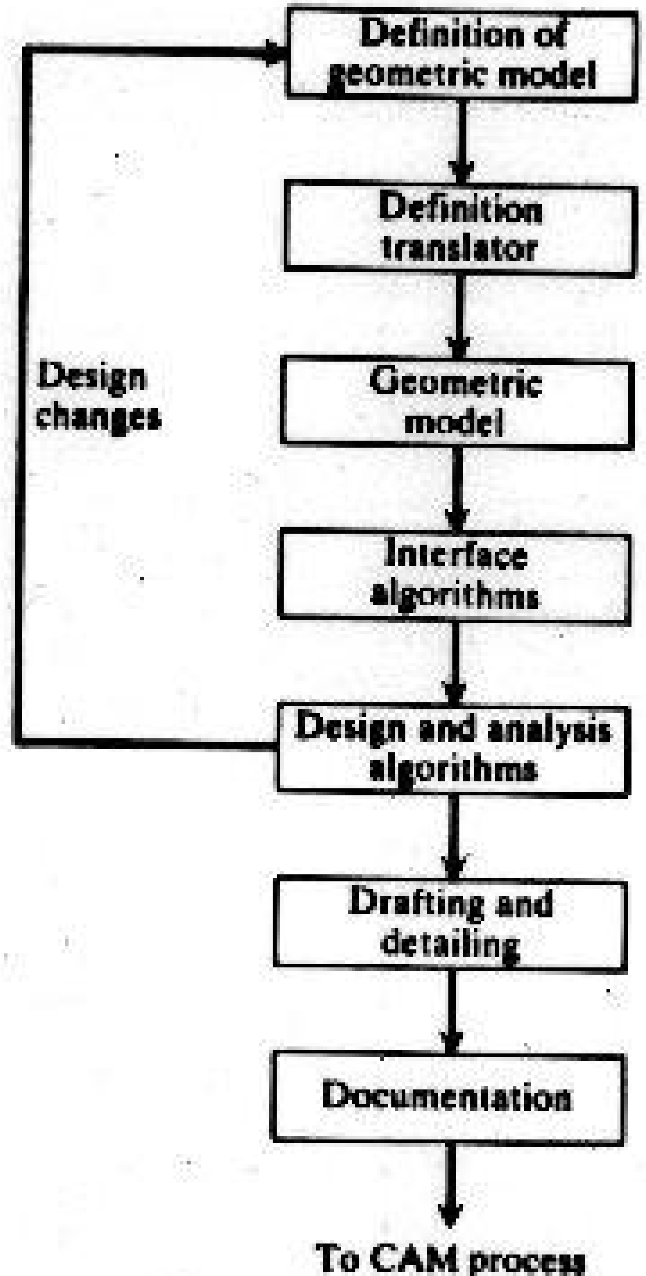
Product life cycle

- 2 main process: Design + Manufacturing
- 2 sub-process of design: Synthesis + Analysis
- The end goal of the synthesis is a conceptual design of the prospective product
- The analysis evaluate the performance of the expected product
- Computer prototypes: Less expensive and faster to generate

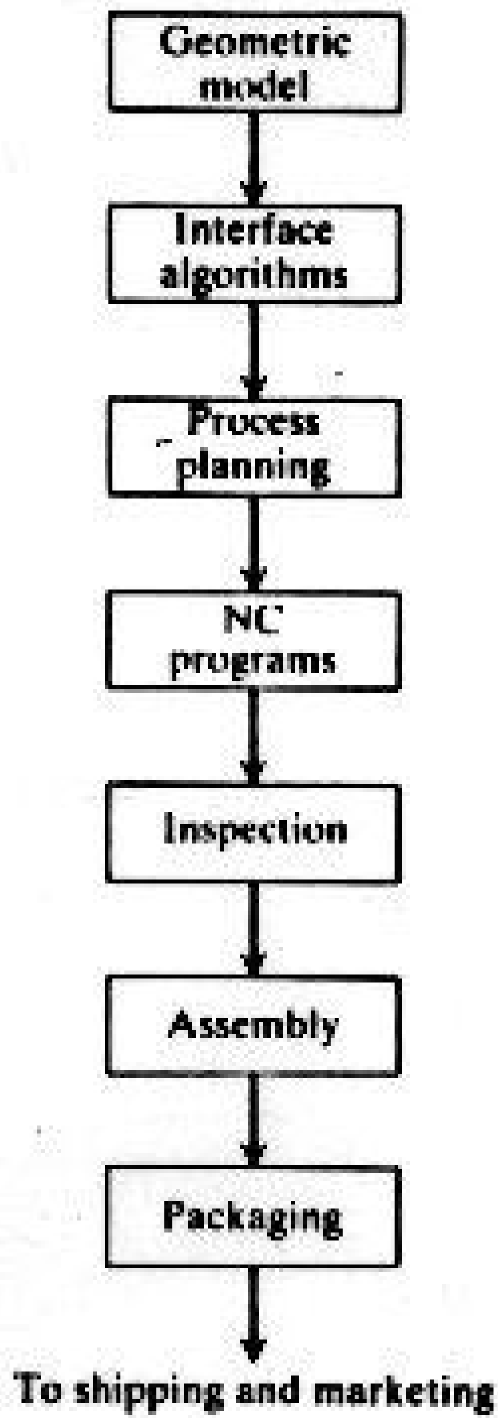
Product life cycle

- Manufacturing process begins with the
  - process planning.
- Process planning is the backbone of the manufacturing process.
- The outcome of the process planning is a production plan, tools procurement, material order, and machine programming.

A typical CAD process



A typical CAM process

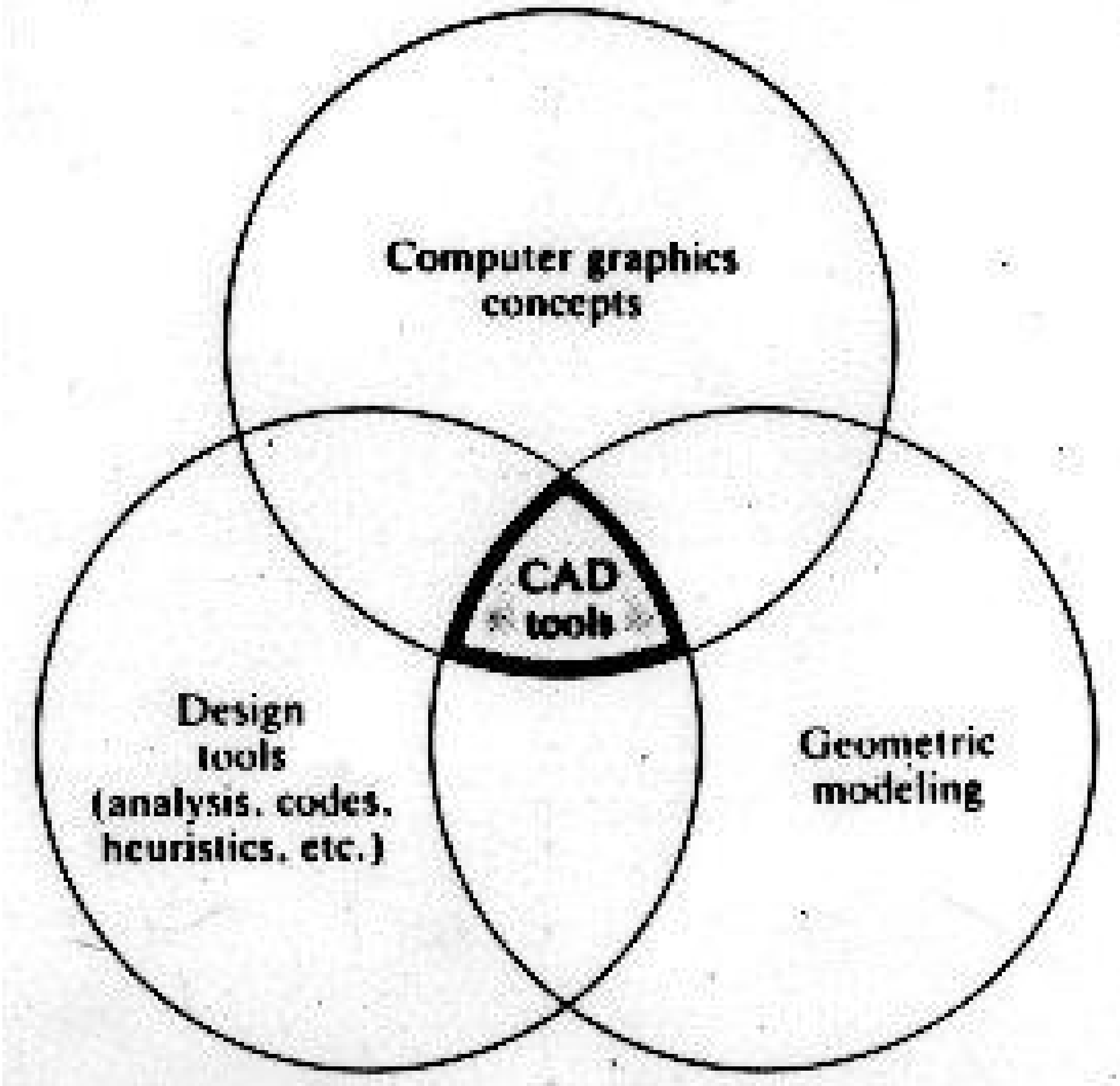


History of CAD/CAM

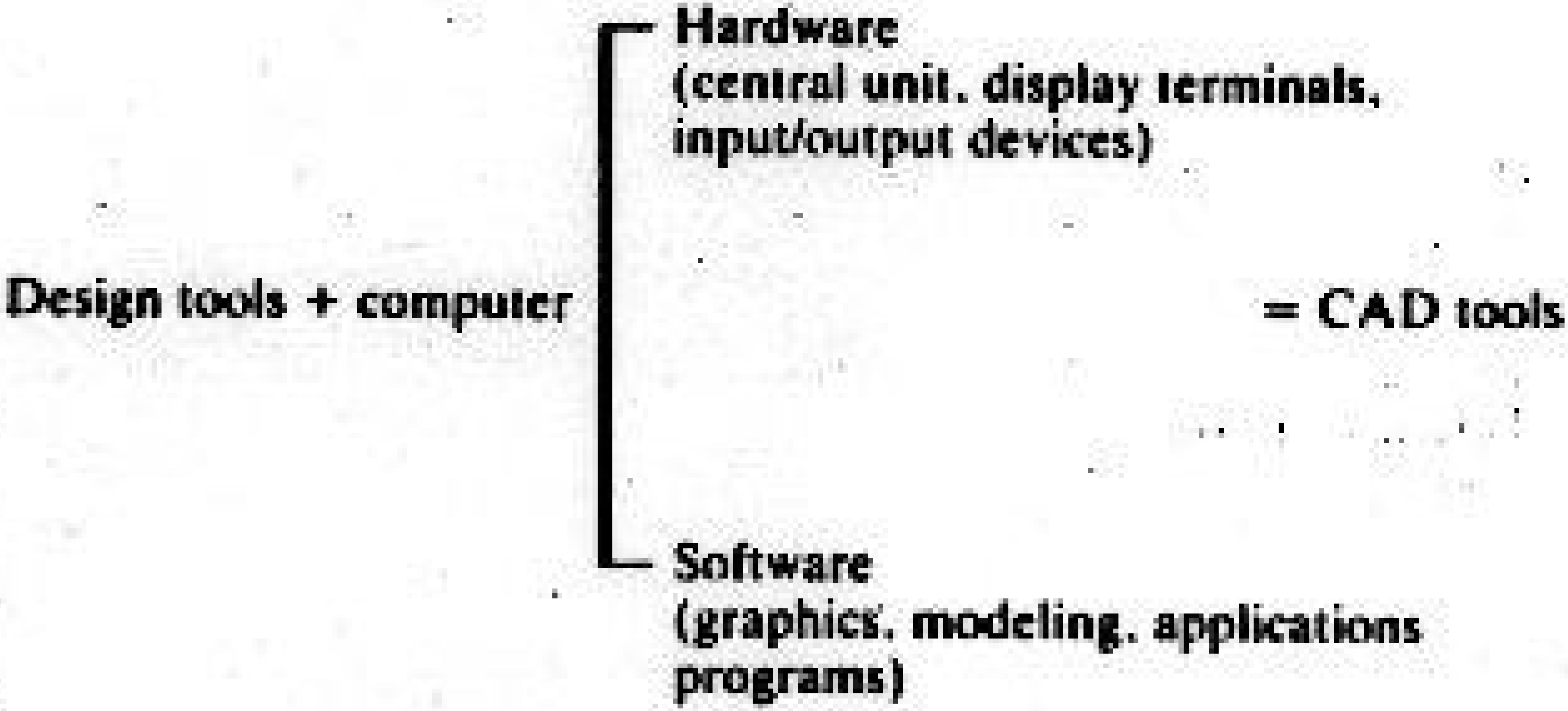
- **1950s: Start of interactive computer graphics,**
  - CRT (Cathode Ray Tube), NC (Numerical Control), APT (Automatically Programmed Tools)
- **1960s: Critical research period for interactive computer graphics**
  - Sketchpad by Ivan Sutherland,
  - Lockheed initiated CADAM,
  - Storage tube-based turnkey system
- **1970s: Potential of interactive computer graphics was realized by industry,**
  - Golden era for computer drafting,
  - Wireframe modeling

History of CAD/CAM . . .

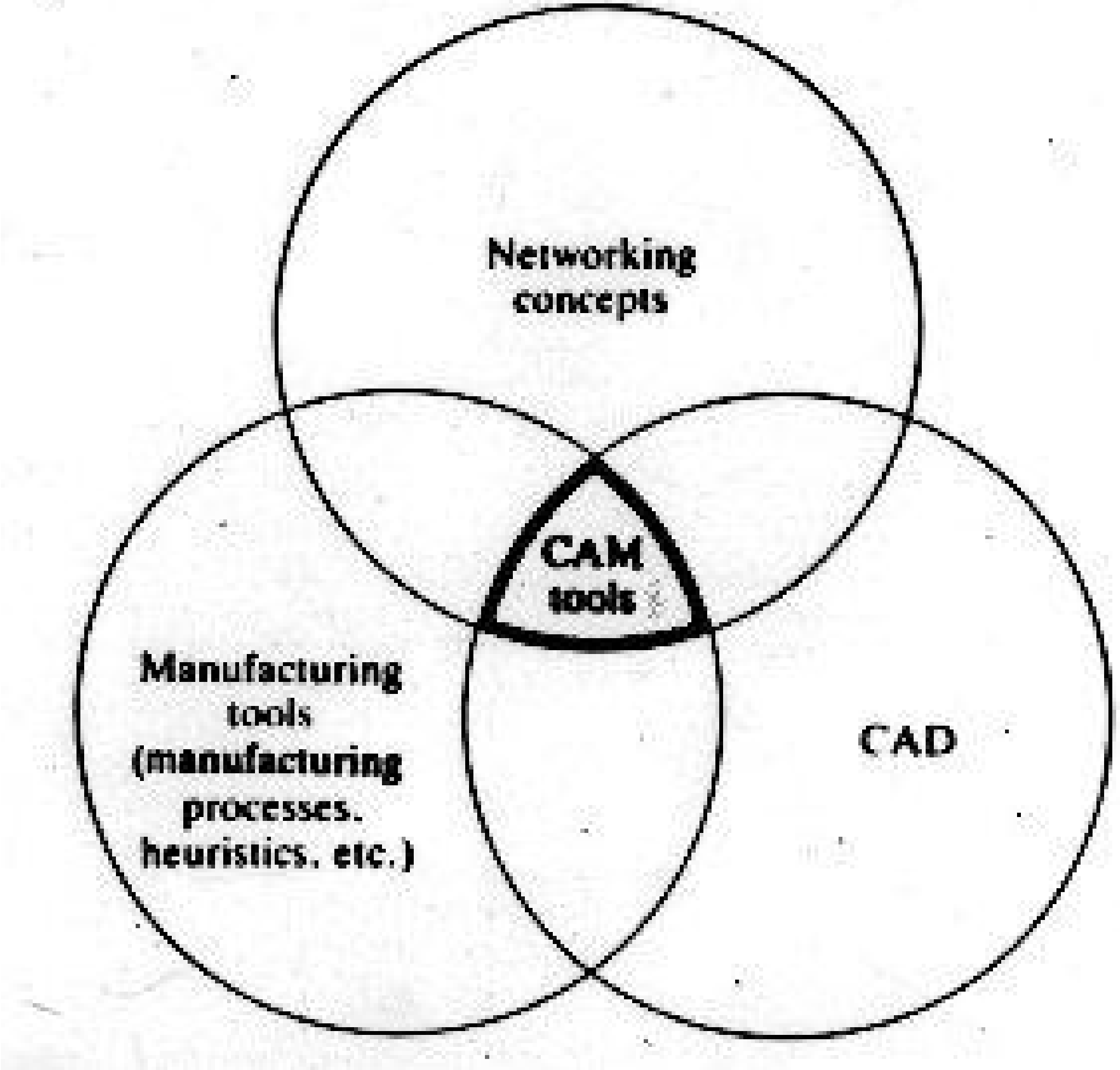
- **1980s: CAD/CAM heady years of research,**
  - Integration, Solid modeling, synthetic curves and surfaces
- **1990s: Management of CAD/CAM capabilities**
  - CIM, EDB, PDM, CALS, VR
  - Improvement in communication medium and networking
  - Reduced cost of hardware and software
- **2000s:** Wireless transmission, Reduced cost of high performance computing, Reverse engineering - Rapid prototyping



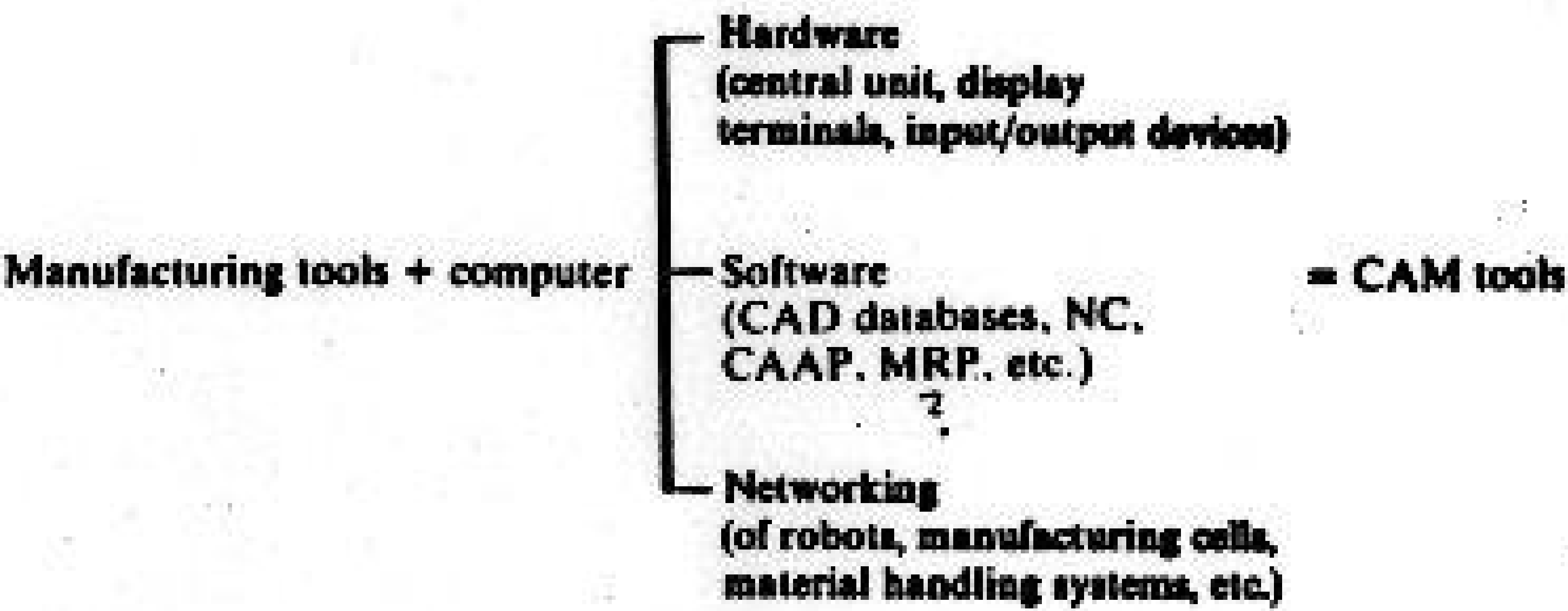
Definition of CAD tools based on constituents



Definition of CAD tools based on implementation



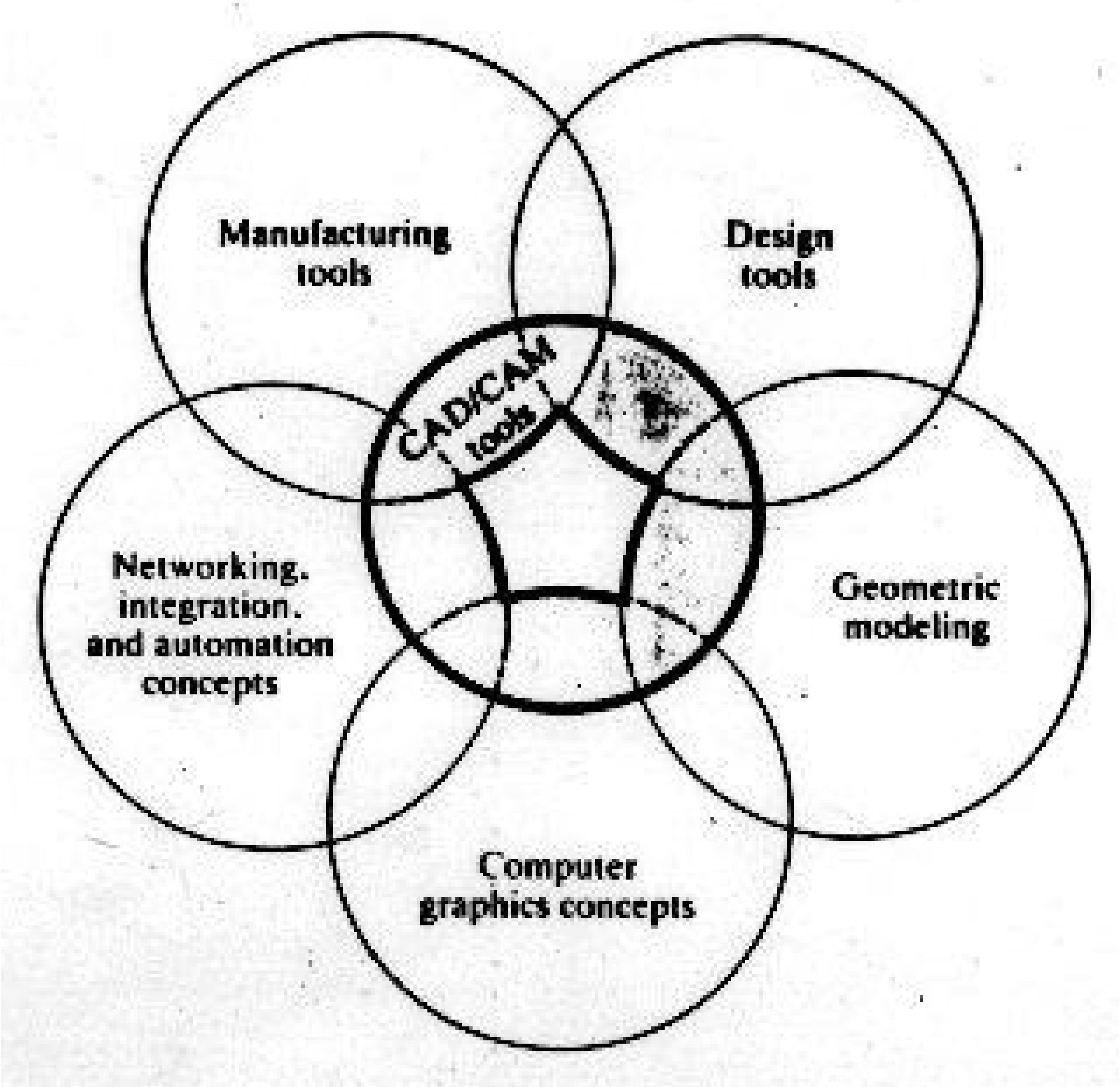
Definition of CAM tools based on constituents



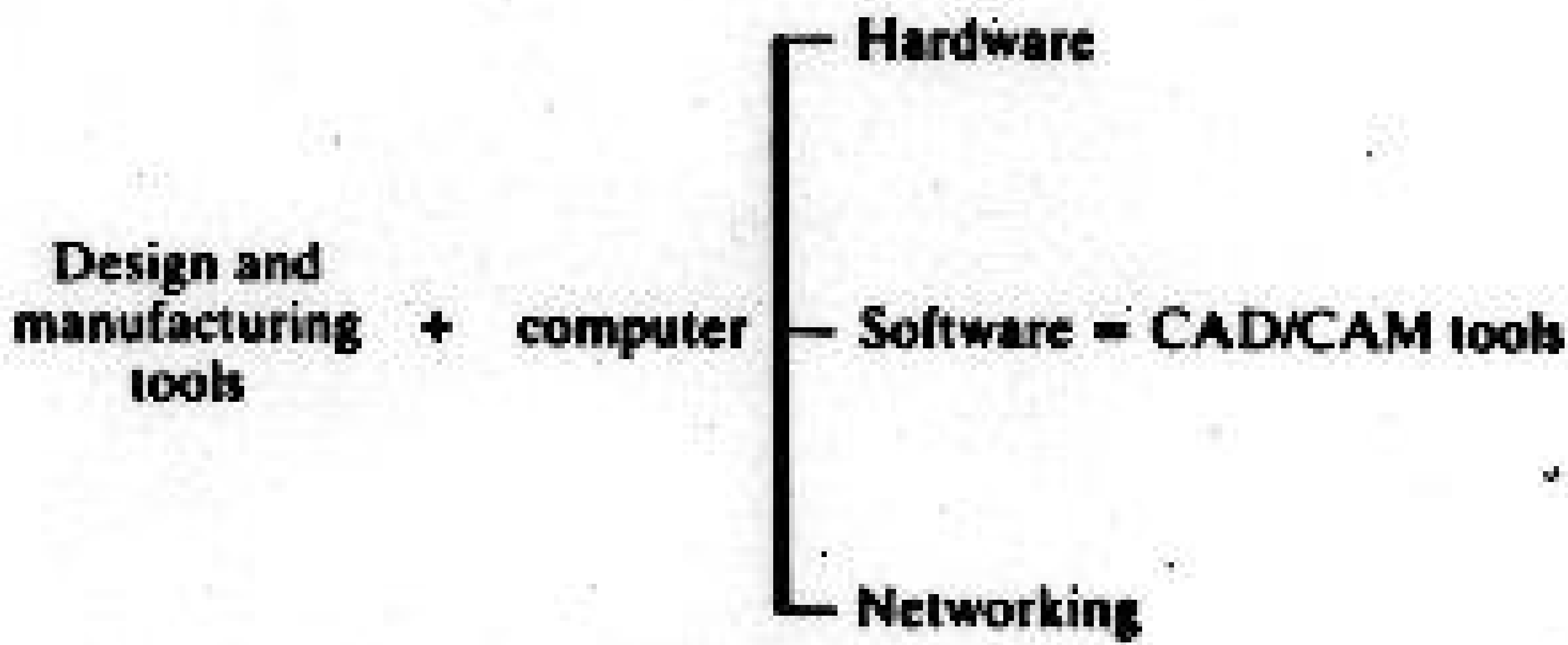
Definition of CAM tools based on implementation

Factors that determine the success of CAM implementation.

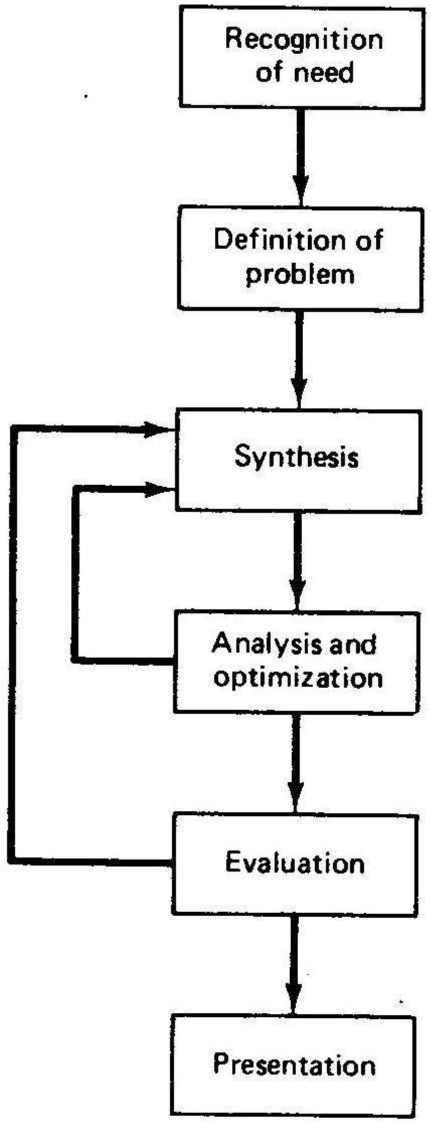
- The link between CAD and CAM must be a two-way route – CAD databases must reflect manufacturing requirements such as tolerances and features. Designers must think in terms of CAM requirements when finalizing their designs. CAD databases and their limitations must be conveyed to manufacturing engineers who plan to utilize them in process planning and other manufacturing functions.
- The hardware and software networking of the various CAM elements - Timely synchronization among robots, vision systems, manufacturing cells, material handling systems, and other shop-floor tasks is most important.



Definition of CAD/CAM tools based on constituents



Definition of CAD/CAM tools based on implementation



Conventional Design Process

Comparison of capabilities of designers and computers

- Computers are good at

1. Carry out long, complex and
   - laborious calculations
2. Store and efficiently search
   - large databases
3. Provide several alternative design solutions
4. Provide information on design methodologies, heuristic data and stored expertise
5. Simulation of design for
   - optimization
6. Aids in modeling, drafting and
   - documentation

- **Human designers are good at**

1. Identifying design needs
2. Drawing up specifications
3. Selecting design variations
4. Optimizing design solutions
5. Selecting the best design
6. Learning from experience

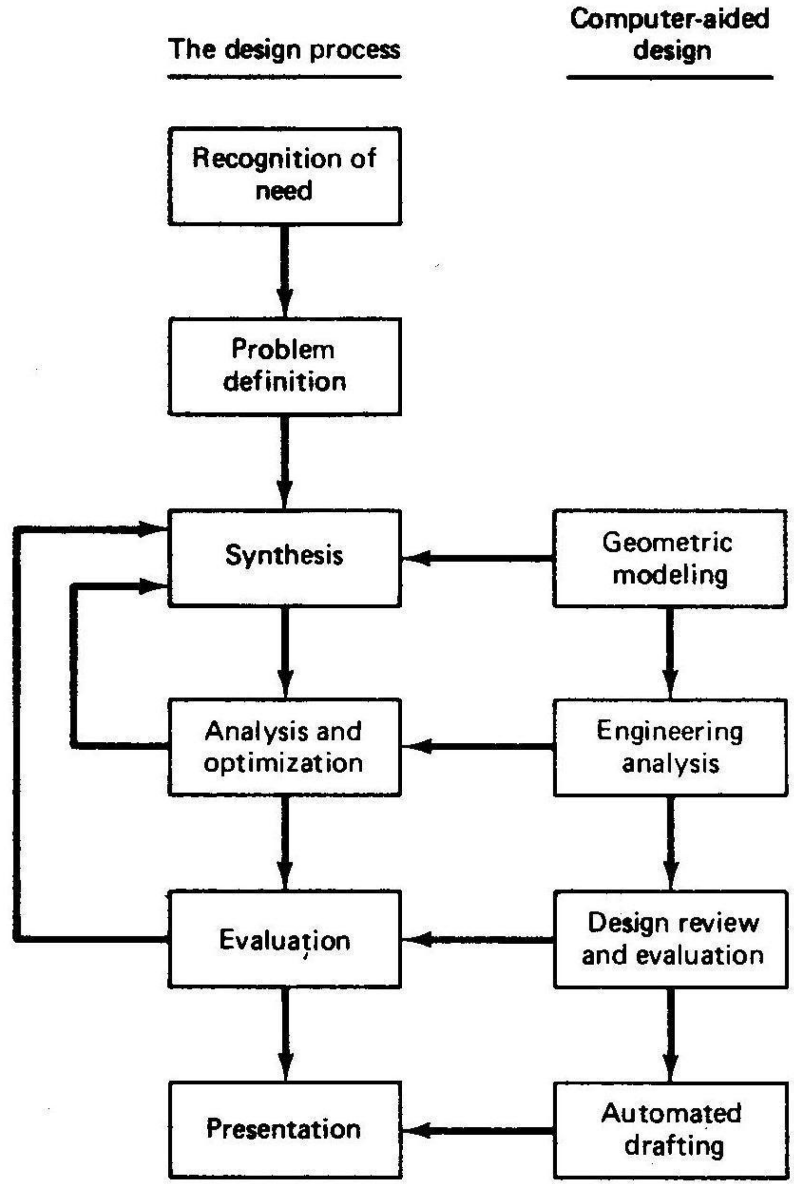


FIGURE 4.3 Application of computers to the design process.

ADVANTAGES OF CAD

1. **To increase the productivity of the designer**

- Create conceptual design of product
- Better visualization – rotate and view the objects from various sides and directions, display in several colours to appeal the customers, display all inner details of the assembly
- Detail drawing, assembly drawing, BOM can be automatically generated.
- Reduction in design cost
- Shorter project completion time
- Editing or refining the model to improve aesthetics, ergonomics and performance

2. **To improve quality of design**

- Use of analysis tools such as FEM – stress analysis, vibration, CFD- thermal, fluid analysis
- Mechanism analysis to check for interference or clearance between mating parts in static or dynamic situations
- Large no.of alternatives can be investigated
- Greater accuracy in design calculations and reduction in errors
- Study the product from various aspects such as material requirements, cost, value engineering, manufacturing processes, standardization, simplification, variety reduction, service life, lubrication, servicing and maintenance aspects etc.

ADVANTAGES OF CAD

3. **To improve communication**
- Better visualization, greater legibility
- Standardization of design, drafting, documentation procedures
- Direct feed back from manufacturing, assembly, inspection and other depts.
- Use of design data for analysis, drafting and documentation, process planning, tool and fixture design, manufacturing, inspection etc.

4. **To create a database of parts**
- Minimise product variations
- Parametric designs
- Making families of parts reducing tooling, fixturing and testing costs

Computer Integrated Manufacturing

- **CAD-CAM** → **CIM**
- **CIM** – A process of integration of CAD, CAM and business aspects of a factory. It attempts complete automation with all processes functioning under computer control.
- It uses database and communication technologies to integrate design, manufacturing and business functions.
- CIM stands for a holistic and methodical approach to activities of the enterprise in order to improve the industrial performance.
- Reduces human component of manufacturing
- **Lean manufacturing –** Reduce waste at all stages of manufacturing. (Toyota)
- **Objectives of CIM** –

1. Production improvement
2. Cost reduction
3. Fulfillment of delivery dates
4. Quality improvement
5. Global and local flexibility of manufacturing system

Lecture 2 & 3

Basic design process and application of computer at different stages in the design process

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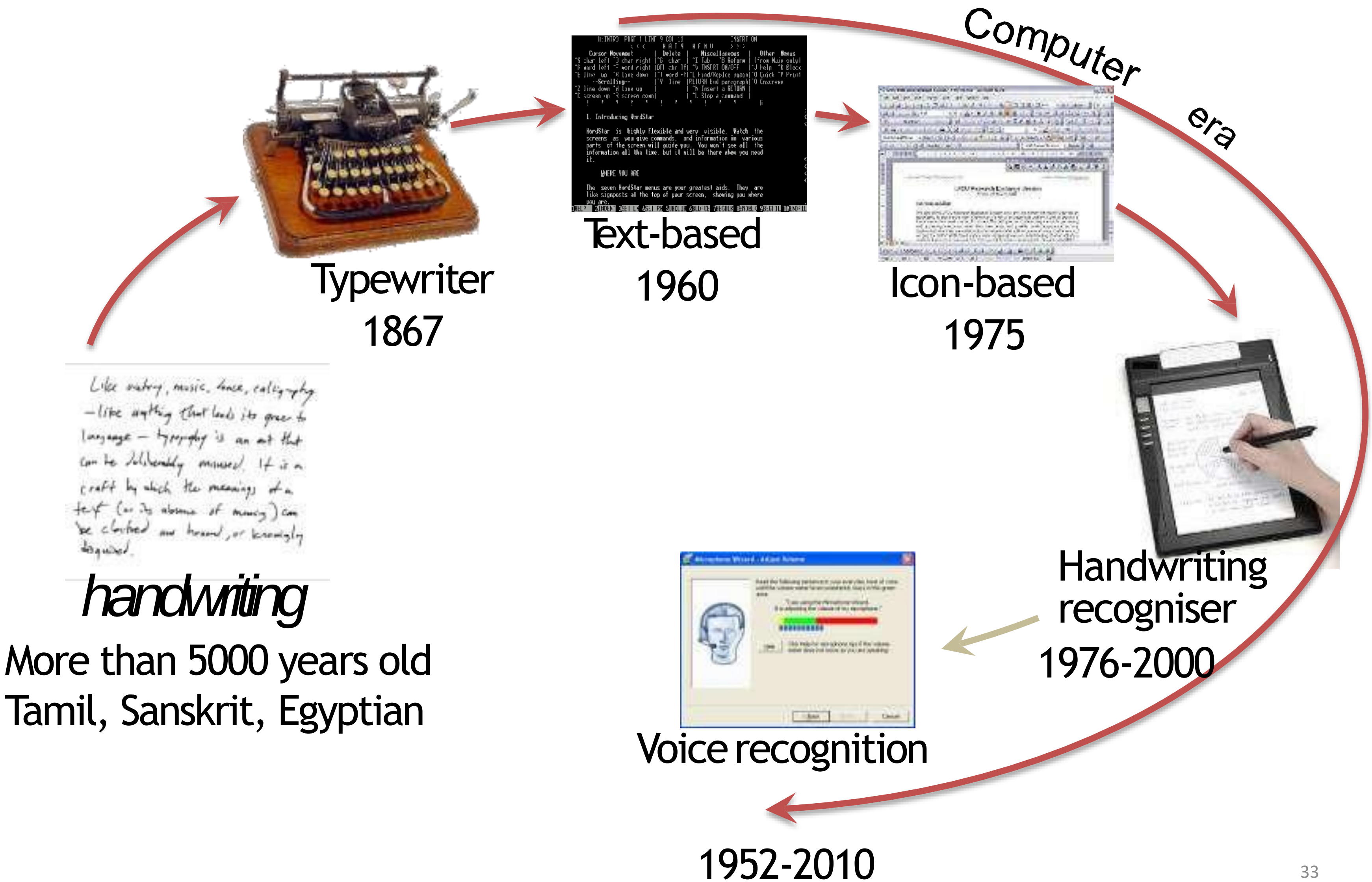
Text Generation

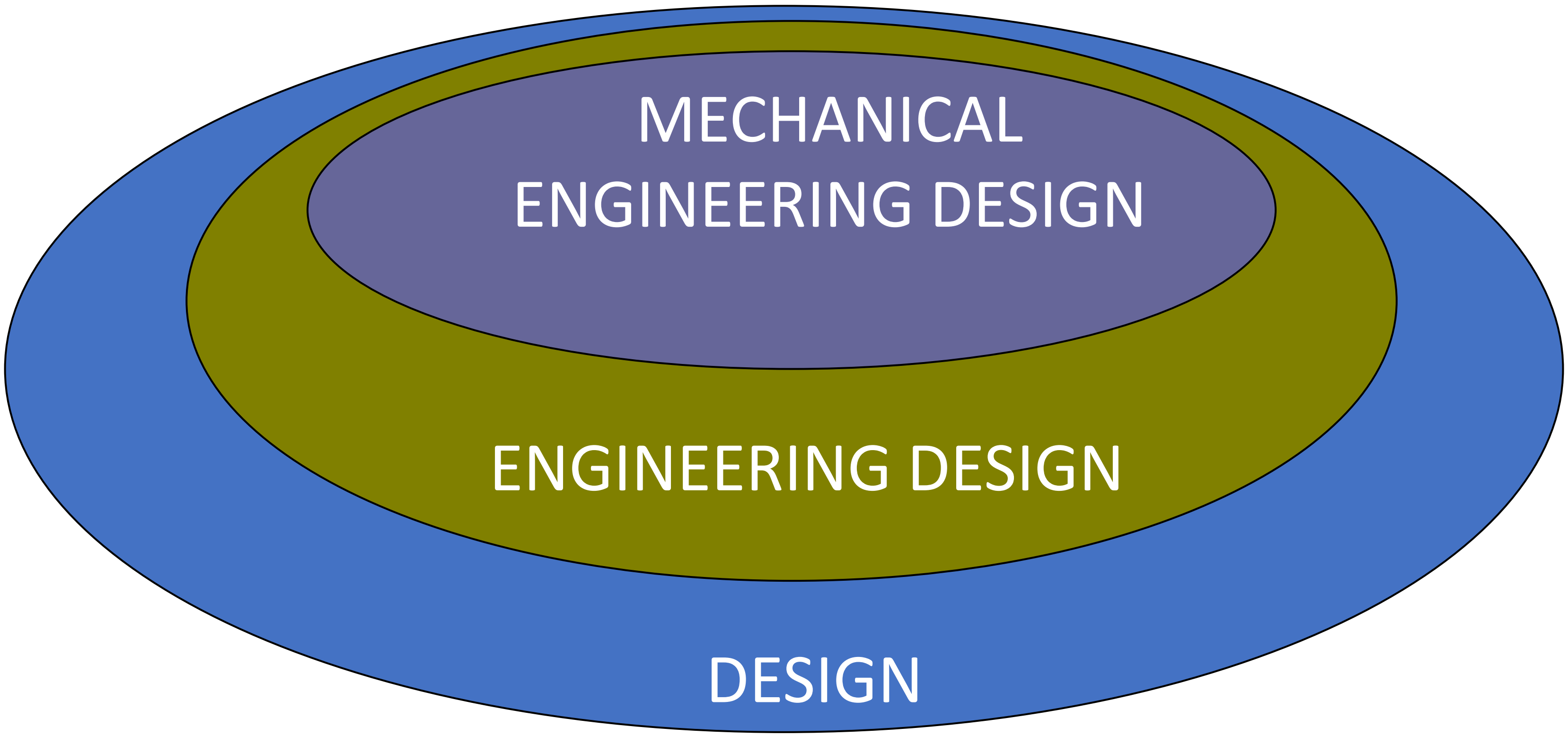


Computer-Aided Design (CAD)

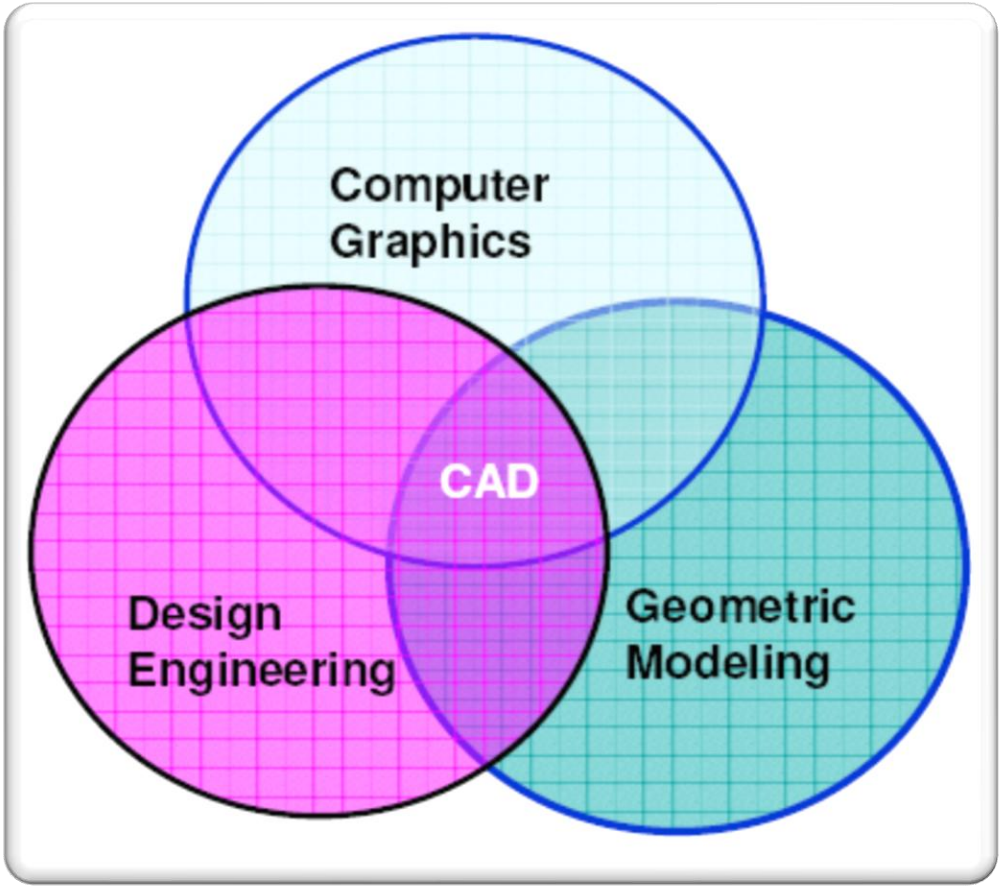
- Use of computer systems to assist in the creation, modification, analysis and optimization of a design

- Over the last 35 years, CAD has come to refer more specifically to Computer Aided Design and Drafting.

Computer Aided Design



- Computer aided Design is a sub-process of Design process



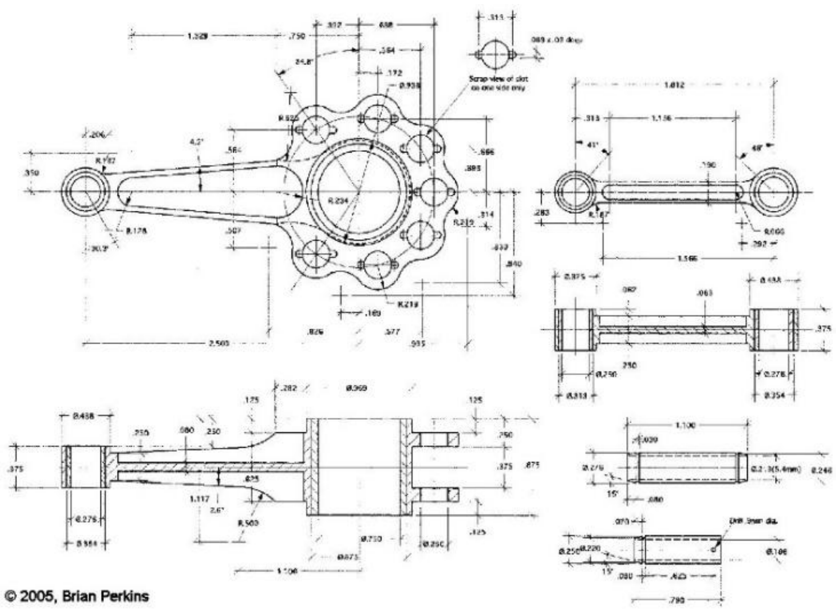
What is Design ?

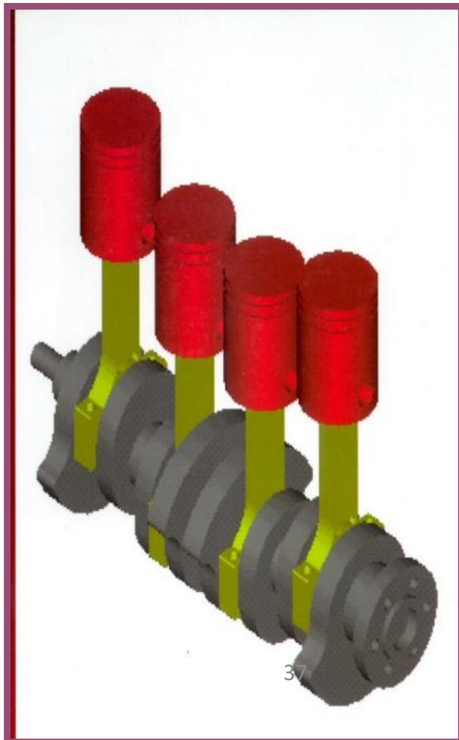
An act of working out the form of some thing by making sketch or outline or plan.

An act of converting functional requirements into products.

Examples of Designed Products

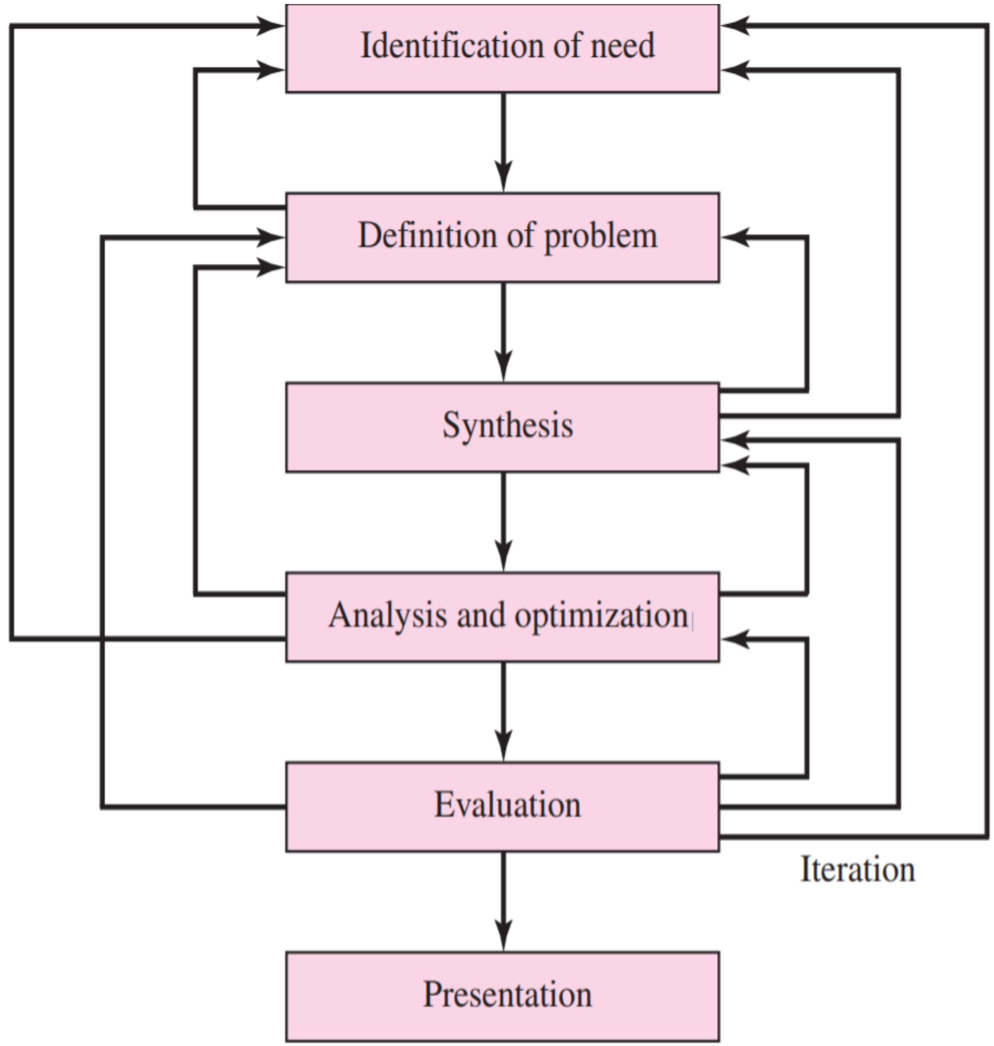
Greeting card, Web-page, Highway, Gear Box



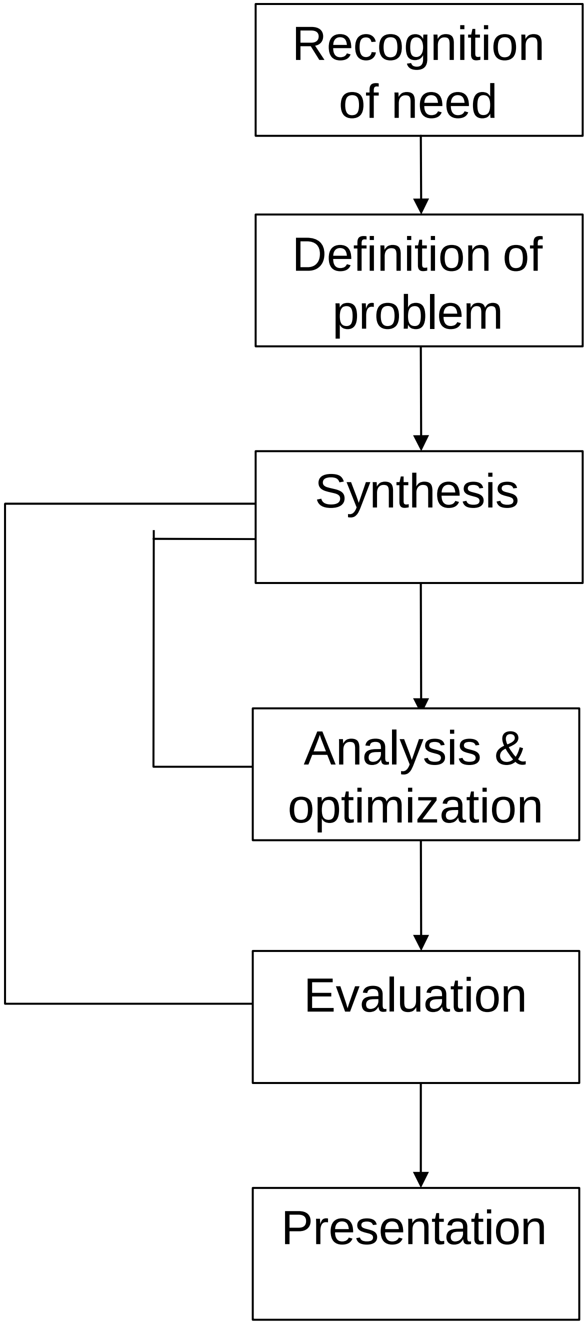


Design Process

Design process is an innovative and highly iterative process, given by **Joseph Edward Shigley (1909–1994),** for designing something.



The general design process defined by Shigley

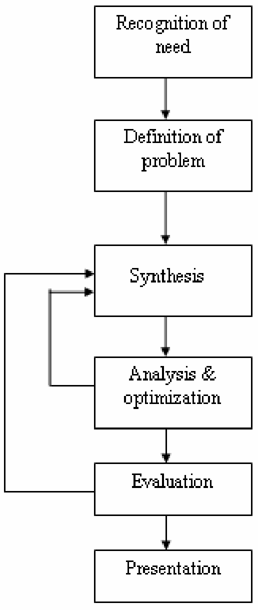


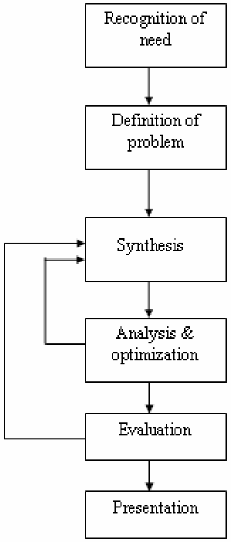
The Design Process:

- Iterative process consisting of
  1. Recognition of need
  2. Definition of the problem
  3. Synthesis
  4. Analysis and optimization
  5. Evaluation
  6. Presentation

1. Recognition of need

- The process of designing begins when there is a need.
- Wherever there are people there are problems needing solutions. In some cases the designer may have to invent a product. An example might be a game for blind persons.
- At other times the designer may change an existing design. (If the handle of a pot becomes too hot to touch, it must be redesigned.)
- Designers also improve existing products. They make the product work even better. Could the chair in the waiting room of a bus or train station be altered so that waiting seems shorter?





2. The Definition of the problem

- It involves thorough specification of items to be designed. i. e what is to be designed.
- Specification includes physical & functional characteristics, cost, quality, and operating performance.
- The problem definition cannot be vague. Some examples of need and problem definition are listed below:
- *Need:* The handle of a pot becomes too hot to hold when the pot is heated.
- *Prob. Definition:* Design a handle that remains cool when the pot is heated.
- *Need:* Waiting time in a bus or train station seems too long. There is nothing to do.
- *Prob. Definition* Provide a television for entertainment.

3. Synthesis

Creation and modification

–2D/3D drafting

–3D modeling for visualization

–Modeling

curves,

surfaces,

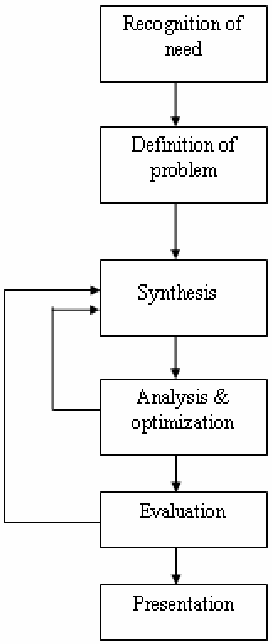
solids,

mechanism,

assemblies,

etc.

3. Synthesis



- In synthesis you must write down all the information you think you may need. Some thing to consider are the following:
- FUNCTION:A functional object must solve the problem described in the problem definition. The basic question to ask is : "What, exactly, is the use of the article?"
- APPEARANCE: How will the object look? The shape, color, and texture should make the object attractive.
- MATERIALS: What materials are available to you? You should think about the cost of these materials. Are they affordable? Do they have the right physical properties, such as strength, rigidity, color, and durability?
- CONSTRUCTION: Will it be hard to make? What methods you will need to cut, shape, form, join, and finish the material.
- SAFETY: The object you design must be safe to use. It should not cause accidents.

4. Analysis & Optimization

- Analyse the problem
- Optimise the solution.
- Developing alternative solutions
  - You should produce a number of solutions. It is very important that you write or draw every idea on paper as it occurs to you.
  - These first sketches do not have to be very detailed or accurate. They should be made quickly. The important thing is to record all your ideas. The more ideas you have, the more likely you are to end up with a good solution.
- Choosing a solution
  - You may find that you like several of the solutions. Eventually, you must choose one. Usually, careful comparison with the original design brief will help you to select the best.
  - You must also consider:
    - Your own skills, the materials available, time needed to build each solution.
    - Cost of each solution.
  - Deciding among the several possible solutions is not always easy. Then it helps to summarize the design requirements and solutions and put the summary in a chart.

5. Design Evaluation

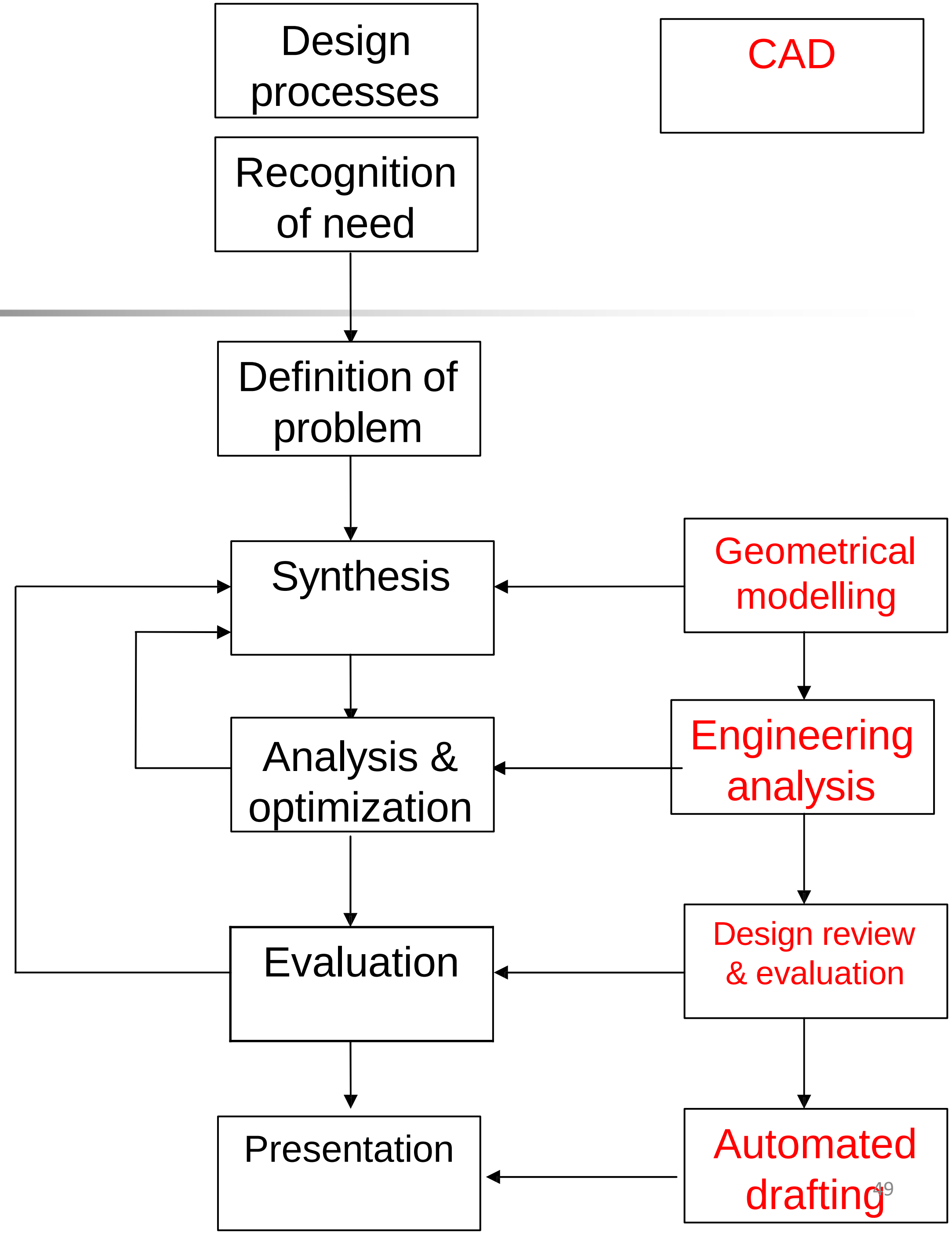
- Testing and evaluating answers three basic questions:
  - Does it work?
  - Does it meet the problem definition?
  - Will modifications improve the solution?
  - The question "does it work?" is basic to good design. It has to be answered.
  - This same question would be asked by an engineer designing a bridge, by the designer of a subway car, or by an architect planning a new school. If you were to make a mistake in the final design of the pencil holder what would happen? The result might simply be unattractive. At worst, the holder would not work well. Not so if a designer makes mistakes in a car's seat belt design. Someone's life may be in danger!
- MODELS AND PROTOTYPES
  - A model is a full-size or small-scale simulation of an object. Architects, engineers, and most designers use models. Models are one more step in communicating an idea. It is far easier to understand an idea when seen in three-dimensional form. A scale model is used when designing objects that are very large.
  - A prototype is the first working version of the designer's solution. It is generally full-size and often handmade. For a simple object such as a pencil holder, the designer probably would not make a model. He or she may go directly to a prototype.

6. Presentation

- Documentation of design by drawing
- Material specifications
- Assembly list i.e.,the creation of design database.

The application of computers for design

Application of computers to design process



Elements of Computer Aided Design

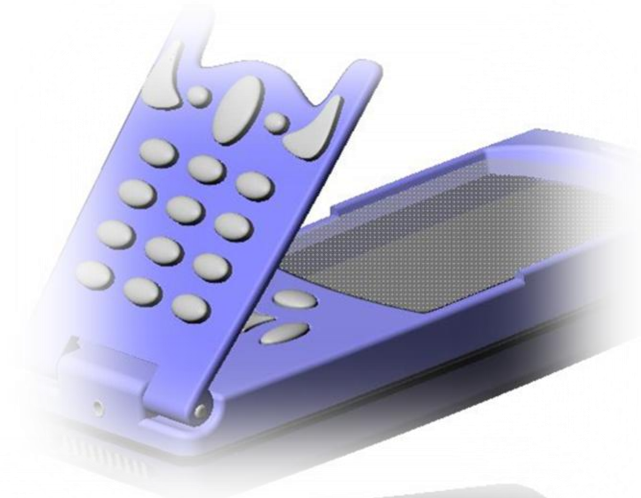
1. Geometrical modelling
2. Engineering Analysis
3. Design review and evaluation
4. Automated drafting

Geometric Modeling

- Geometric modeling refers to computer compatible mathematical representation of geometry. It deals with representation of curves, surfaces and solids.

- Geometric modeling is the basis for creating, representing, manipulation and storage of designs in today's CAD systems.

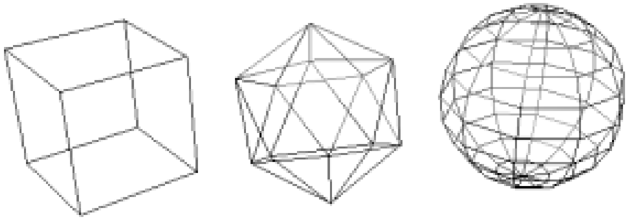
- Geometric model also forms the basis for integrating design with other life-cycle activities such as manufacturing.



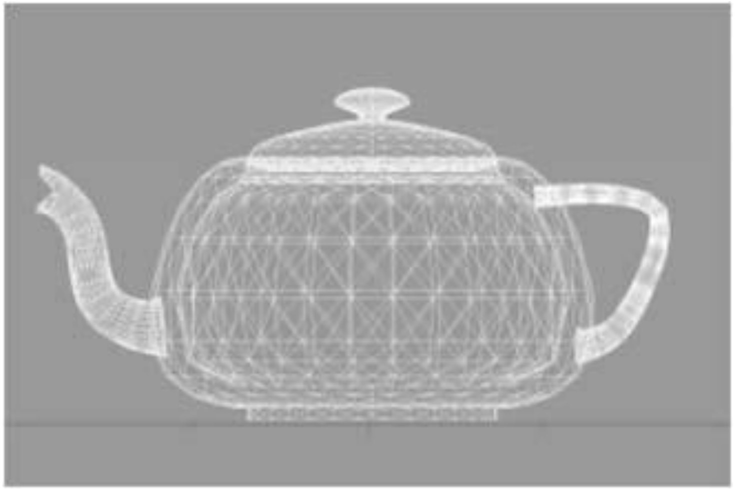
Geometrical Modelling

- It is concerned with computer compatible mathematical description of the geometry of object.
- Mathematical description allows the image of the object to be displayed and manipulated on a graphic terminal through signal from CPU of CAD system.
- Three types of command used to create the image on ICG system
  - I st type – generates basic geometry elements as points, lines, circles.
  - II nd type- Achieves scaling, rotation, translation, or other transformations.
  - III rd type- It makes the various elements to be joined into desired shape.

- During geometrical modelling, the computer converts the commands into a mathematical model, stores it into computer data files, and displays it as an image on CRT screen.
- The model can subsequently be called from the data file for review, analysis or alteration.
- Several methods are there to represent object in geometrical modelling. Basic form is wire frame, where object is displayed by inter connecting lines. These types are
  - 2D –used for flat objects
  - 2 ½ D – it permits 3D objects to be represented as long as it do not have side wall details.
  - 3 D – for modelling of complex geometry.
- Wire frame models

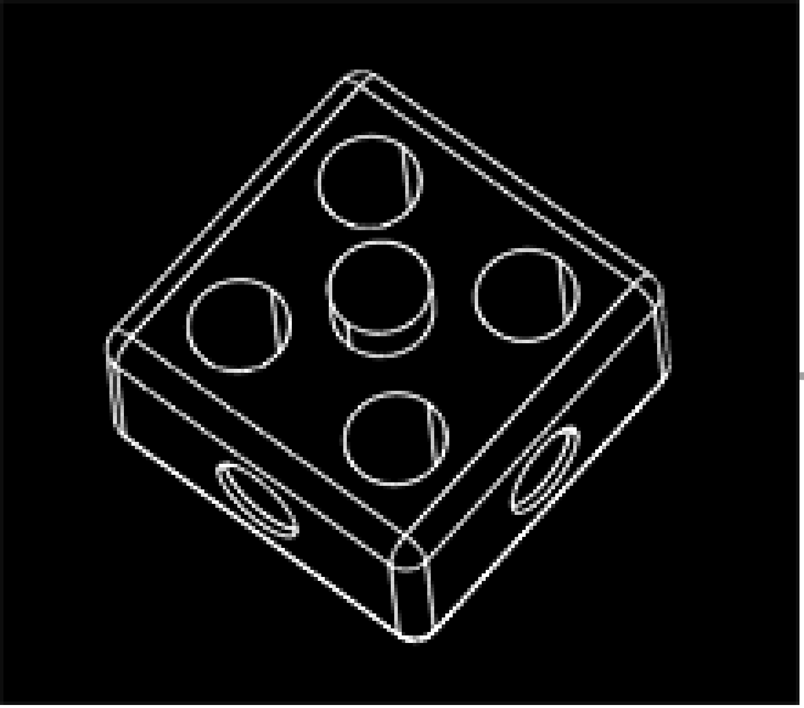


- Improvement in wire frame model
- Hidden line removal to provide less clustered image of object.
- By providing surface representation- this makes the object appear like solid to viewer, however the object is still stored in the computer as wire frame model.
- Most advance method of geometrical modelling is solid modelling in 3D. It uses solid geometry shapes called primitives to construct the object.
- The colour graphic feature keeps to classify components in an assembly or highlight dimensions.



Wire frame model

Surface model

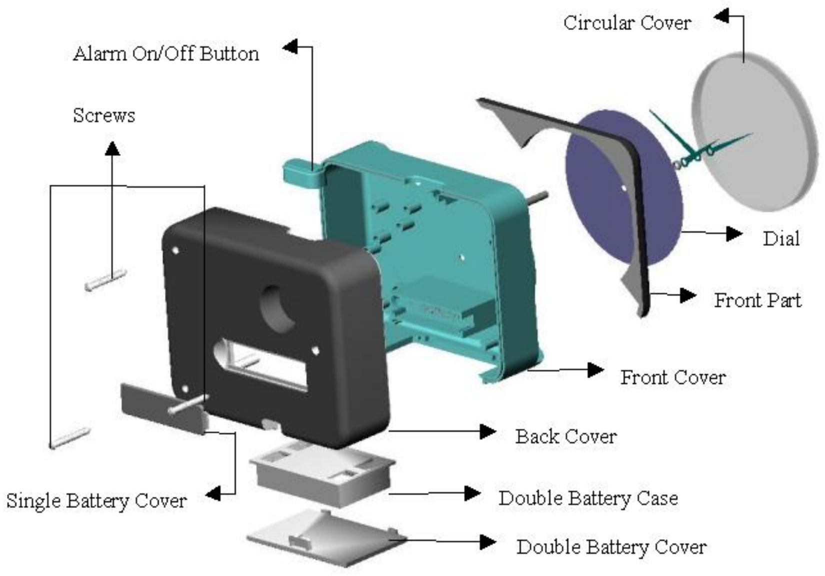


Wire frame model with hidden lines removed

- Surface model

Computer Aided Assembly

- Computer can be used to build assembly models of products by defining mating relationships between its components.
- Computers can be used to evaluate designs and redesign products for ease of assembly (DFA).
- Computers can be used to evaluate designs and redesign products for ease of dis-assembly.



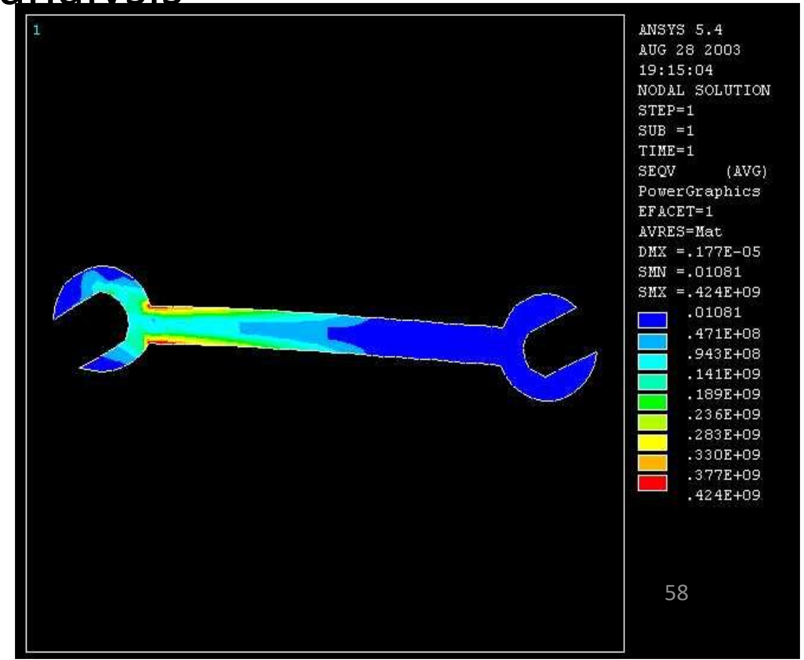
Computer Aided Analysis

- Computer aided analysis tools are used for routine and final design checks.
- Computers are used extensively for analysis such as stress analysis, heat-transfer analysis, fluid flow analysis, electromagnetic analysis etc.
- Simulation of actual use
- Optimizations
- The three stages of computer aided analysis

    pre-processing

    analysis

    post-processing



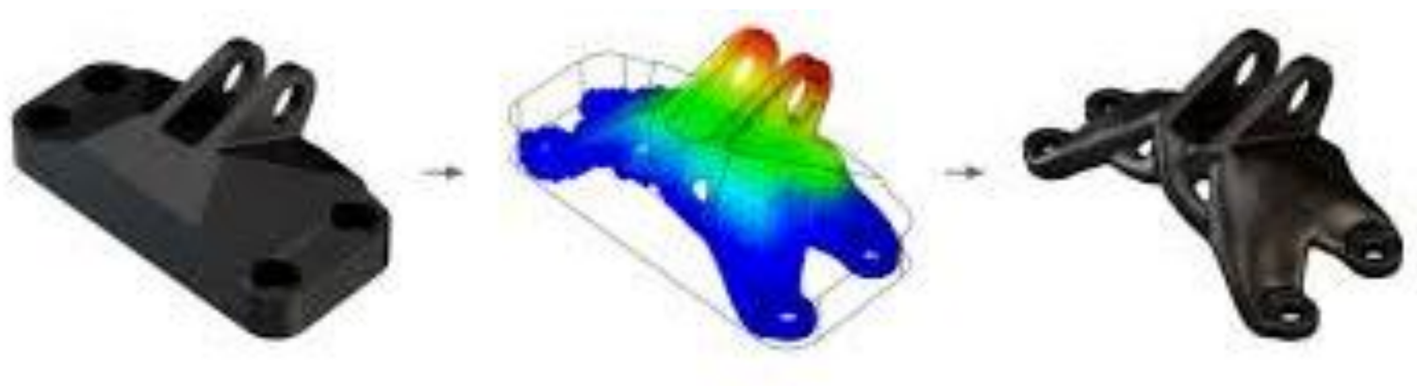
Engineering Analysis

- In engineering design project engineering analysis may involve stress strain analysis, calculation of differential equations to describe the dynamic behaviour of system being designed.
- One may use his own code or can use commercially available softwares.
- Commercially available softwares have features such as
  - Analysis of mass properties.
  - FE analysis
- Analysis of mass properties provides properties such as surface area, weight, volume, center of gravity, moment of inertia being analysed. For planar surfaces these properties may be perimeter, area, inertia properties.
- FE solution is derived in 4 phases
  - Formulation phase-dividing the region into elements and choosing the appropriate interpolation function.
  - Evaluation phase-computation of contribution of each element.
  - Assembly phase
  - Solution phase.
  - Optimization involves the selection of best possible solution.

Computer Aided Optimization

- Computer are used for arriving at optimum designs whenever there are many alternatives for feasible designs.
- Various types of optimizations which can be carried out include

  Parameter Optimization   Shape & Size Optimization
  Topology Optimization   Combinatorial Optimization



Design review and evaluation

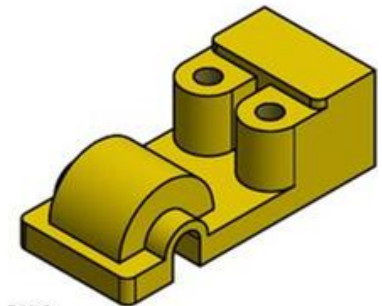
- Measuring the complete design against the specifications given in the problem.
- Using computer checking the accuracy can be done on graphic terminal using layering procedure.
- Overlaying the geometric shape of the machined part on image of rough casting to see that sufficient material is available on the casting to accomplish the final machine dimension.
- Interference checking: It involves the analysis of assembled structure.
- Kinematics: animation of mechanisms, enhances designers visualisation, helps to check interference.
- ADAMS (automated dynamic analysis of mechanical systems), developed at university of Michigan, can be used

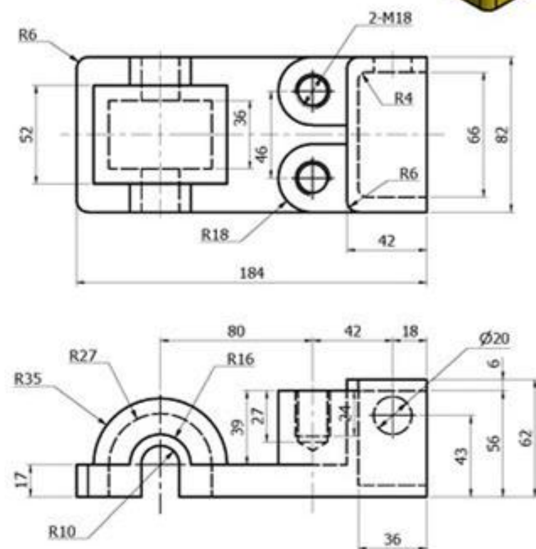
FEATURES OFFERED BY CAD SOFTWARE

- **ZOOM IN :** MAGNIFY THE IMAGE FOR CLOSE SCRUTINY MAKING THE REVIEWING PROCESS FAR MORE AUTHENTIC.
- **LAYERING**: BY THE PROCESS OF LAYERING YOU CAN OVERLAY THE MACHINED PART ON THE CASTED PART.
- **CHECKING INTERFERENCE**: THE INTERFERENCE CHECKING FEATURE OF THE SOFTWARE ENSURES THAT SUCH PROBLEMS WON’T OCCUR.
- **ANIMATION CAPABILITY:** IT ENHANCES DESIGNER’S VISUALIZATION CAPACITY AND TO CHECK FOR THE INTERFERENCE OF THE OBJECT. WITH ANIMATION FEATURE CHECKING THE OBJECTS LIKE HINGES, LINKS AND THE COMPLETE ASSEMBLED

Automated CAD Drafting

- ❑Detail parts drawings
- ❑Bill of materials
    - specifications of various materials as used for the manufacturing the components of the object.





Automated drafting

- It is creation of hard copy engineering drawing from CAD data file.
- Some basic features are
  - Automated dimensioning.
  - Generation of crossed hatched area
  - Scaling of the drawing.
  - Capability to develop sectional and pictorial views of particular part details.
  - Ability to rotate the part, or to perform other transformation of image as perspective projection, isometric views.
  - Most CAD system can generate at least 6 views.
  - CAD database can be used to create part classification.
- Existing drawing can be retrieved and modified instead of creating new one.

Computer Aided Design

- Introduction
  - Technology concerned with use of digital computers to perform certain functions in design i.e. creation, modification, synthesis, analysis, optimization
- Principal advantage- large amount of data can be stored.
- Computer system: Hardware & Software
  - Hardware:
    - Computer, graphic display terminal, keyboards, peripheral equipments
  - Software-
    - Computer programmes to implement computer graphics on system.
    - Application programmes to facilitates engineering functions, e.g. stress starin analysis of componenets, dynamic response of mechanisms, heat transfer calculations, numerical control part programming.

CAD defined

- Design activity using computers to develop, analyze or modify engineering design
- Based on ICG (interactive computer graphics)
- ICG – is user oriented system in which computer is employed to create, transform, and display data in form of pictures or symbols.
- User: designer communicates data and commands computer through input devices
- Computer: communicates with user via a CRT (cathode ray tube).
- In most of system image is constructed out of basic geometric elements as points, lines, circles etc., they are modifies & transformed.

- Other major component in CAD is human designer
- Designer has:
  - Conceptualisation + Independent thinking
- Computer has:
  - speed of calculations + visual display+ storage of large amount of data
- Some common editing features in software are:
  - Move, duplicate, rotate, mirror, delete, trim, scale

Reasons for implementing CAD

- Increase productivity of designer
  - Visualise, time reduced
- To improve the quality of design
  - Through analysis, large alternatives, less errors
- To improve communications
  - Better drawing, standardisation in drawing, less errors.
- To create a data base for manufacturing
  - Product design geometries, dimensions, material specifications, bills of materials.
- Integrate CAD/CAM, representation of sculptured surfaces, bezier, B-spline, calculation of mass property, FEM, mechanism, robotics simulation
- Solid modelling theory
- Major solid modelling systems
  - GMSOLID- General Motors
  - Romulus: Shape data
  - Soliddesign-Computer vision.
  - PROE- PTC

Benefits of CAD

- CAD has revolutionized automobile & aircraft industries.
- Productivity improvement in design
  - Time reduced for developing conceptual design, analysis, drafting.
  - Reduced manpower for a given project.
  - Improvement in design productivity depends on
    - Complexity of drawing.
    - Degree of repetitiveness of features in designed parts.
    - Degree of symmetry in the parts.
      - Extensive use of library, user defined shapes.
- Shorter lead time
  - Final drawing and documentation can be done in short time.
  - Time between customer order and delivery reduced.

- Flexibility in design
  - Modification in design is easy to satisfy customer requirements.
- Design analysis.
  - Software help to optimise design.
  - Software (FEA, Kinematic analysis) reduce time, improve design accuracy, reduce material used.
  - Mass property calculation is instantaneous.
- Less design errors
  - Interactive CAD has ability to reduce error in design, drafting, documentation.

- Standardisation of design
  - Single data base and operating system provides common base for design, analysis and drafting process.
  - Previous modules may be reused to develop range of products.
- Drawing are more understandable.
  - With 3D view & solid model it is easy to comprehend the features.
  - One does not require the reconstuct mentally solid shape from 2D model.
  - Packages allow 3D view generated from 2D model.

- Improved procedure for engineering changes.
  - Control & implementation of engineering changes easier.
  - Revised information can be retained, new drawing with changes can be created without destroying the old one.
- Benefit of CAD in manufacturing.
  - CAD data base can be used in
  - Tool & fixture design
  - Computer aided process planning.
  - Assembly list & bill of materials.
  - Computer aided inspection.
  - Coding and classification of components.
  - Production planning and control.
  - NC part programming.
  - Assembly sequence planning.

CAD System Software's

- Software
- Software has multi layered GUI (Graphical user interface).
- Client/server or standalone application.
- Network version and standalone model.
- Installing-self extracting files.
- It utilises data structure to save geometry and topology.
- Data structure is well defined storage scheme that stores model data.
- .prt, .assem, .dwg extensions

CAD Applications

- Applications targeting towards a specific market
- Mechanical, electrical, architectural CAD.
- Have many common modules
  - Geometric module/engine: it provides user with function to perform geometric modelling, editing and manipulation of existing geometry, drafting and documentation. The aim of the geometric model is to utilise it for design and manufacturing purpose. Application module achieves this goal.
  - Application module: mechanical application module includes mass property calculations, assembly analysis, tolerance analysis and synthesis, sheet metal design, finite element modelling and analysis, animation and simulation techniques.

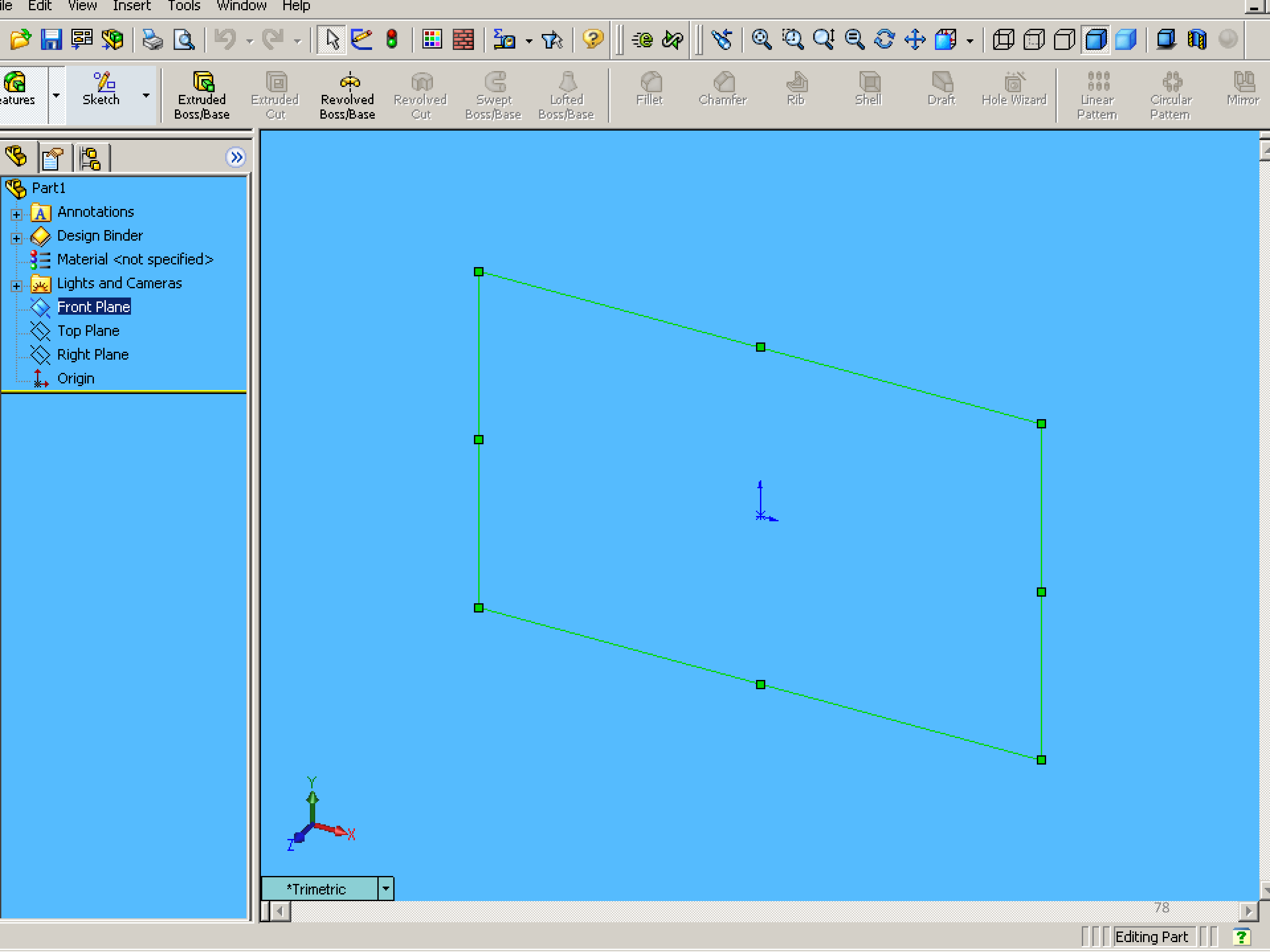
- The programming module: allows users to customize systems by programming them to fit certain design and manufacturing task.
  - Programming a CAD/CAM system requires advanced knowledge of system architecture, its data base format, and high level programming language such as C, C++, Java.
- The communication module: to achieve integration between CAD/CAM systems.
- The collaborative module: through world wide web and internet this module supports collaborative design

Coordinate system

- Use hand to identify handedness
  - Point thumb, index finger, and middle finger in orthogonal directions
    - Thumb = x-axis
    - Index = y-axis
    - Middle = z-axis
  - Left and right hands correspond to left and right hand coordinate systems.
- Coordinate systems and sketch planes are most important part of CAD systems.
- They are used to input, store, and display model geometry and graphics.
- The three coordinate system that achieve these tasks are model coordinate system (MCS), working coordinate system (WCS) and screen coordinate system (SCS).

MCS

- It is the reference space of the model with respect to which all the model’s geometric data are stored.
- In Cad systems MCS is shown by displaying the X, Y, and Z axes.
- The orthogonal planes formed by the axes of MCS are datum plane, sketch planes, or construction planes.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Rib
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Draft
Hole Wizard
Linear Pattern
Circular Pattern
Mirror
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Lights and Cameras
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Top Plane
Right Plane
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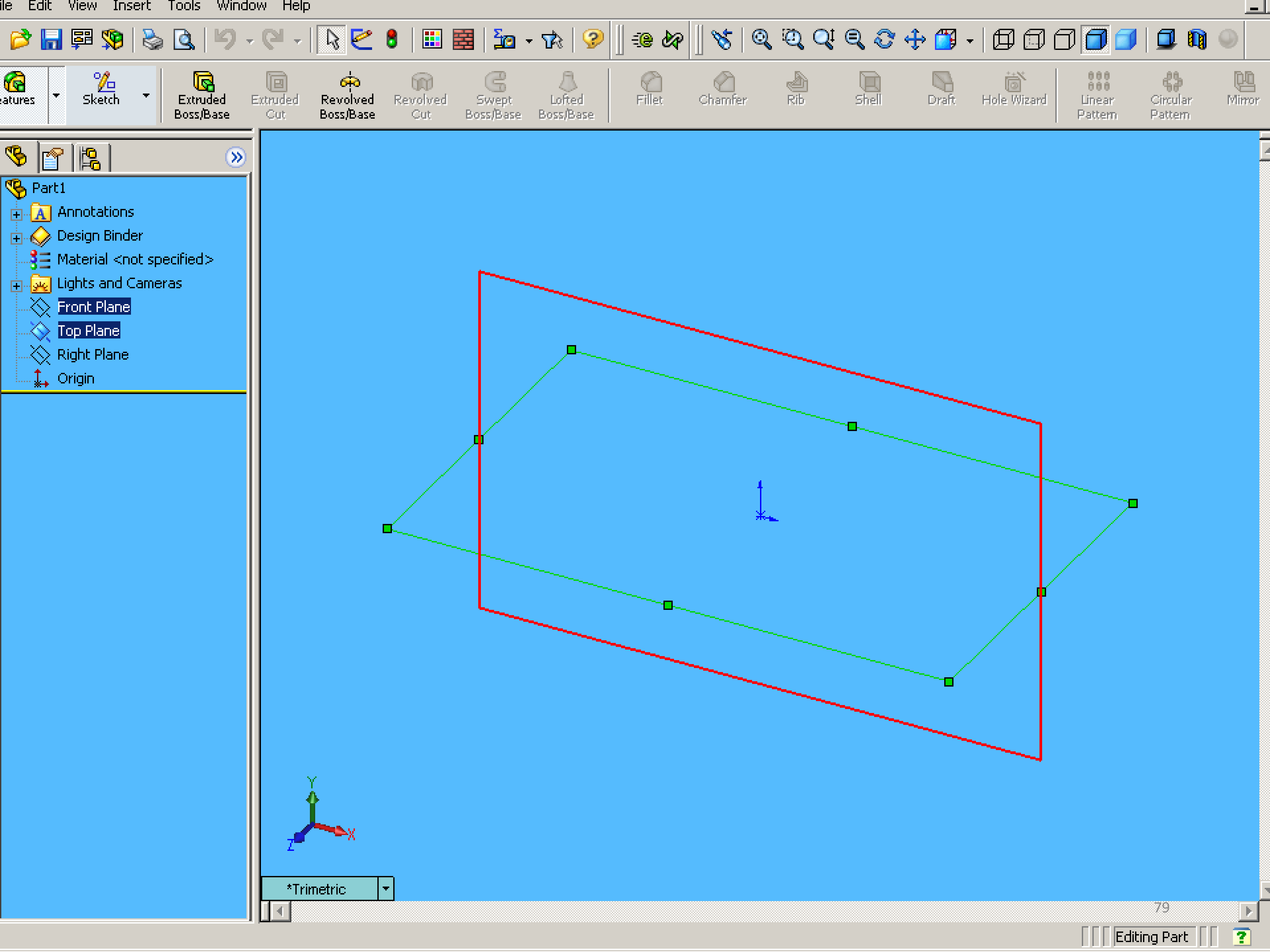
Editing Part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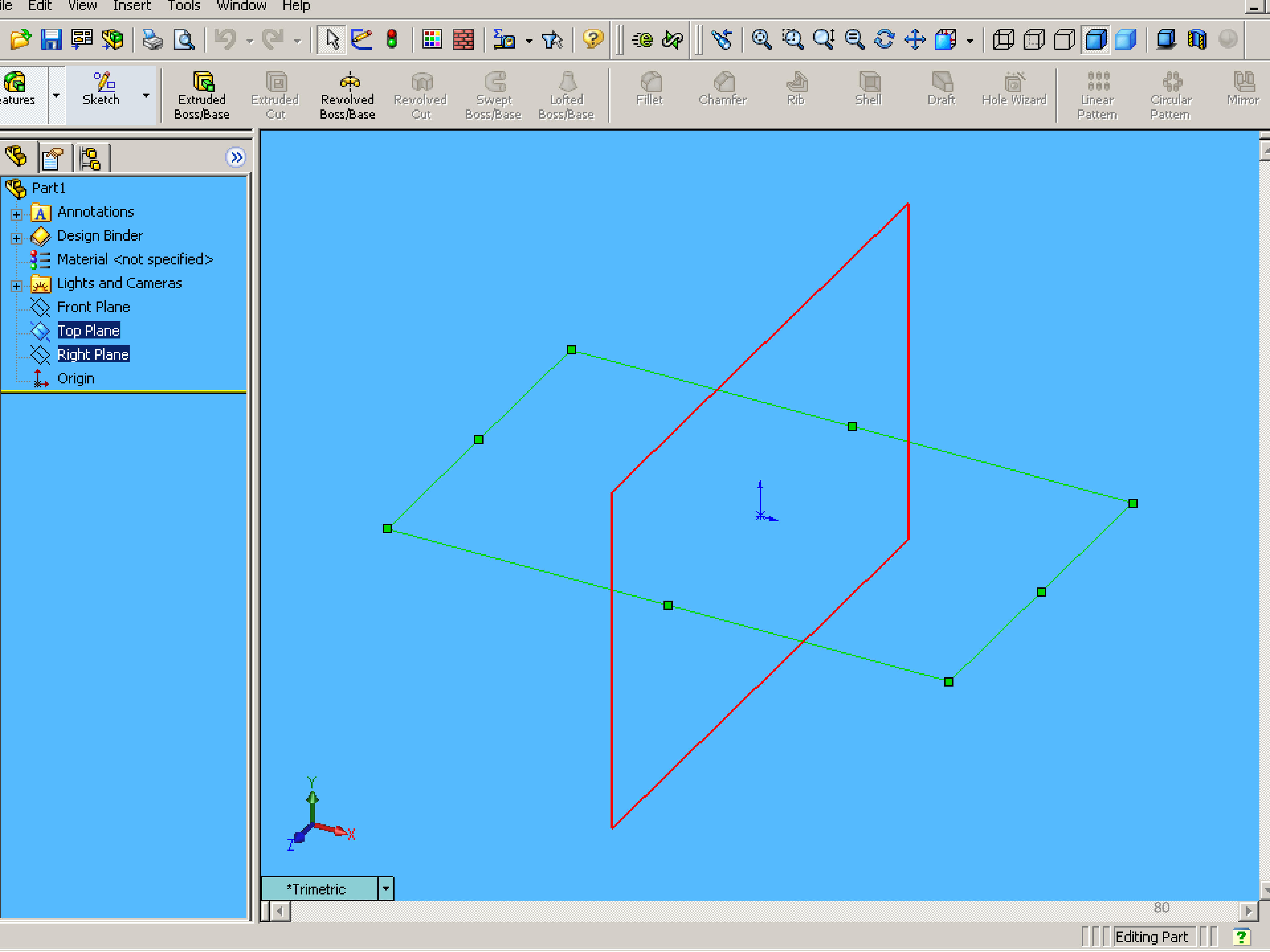
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Material <not specified>
Lights and Cameras
Front Plane
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Right Plane
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Y
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*Trimetric
Editing Part

WCS

- A WCS can be thought of as a portable coordinate system.
- It is often used when the desired plane of sketching is not easily defined as one of the MCS planes.
- The user can define a WCS (and thus a sketch plane) for such a condition and relate it to MCs using the transformation matrix that allows geometric data to be stored with respect to MCS.
- In solid works or ProE there is no physical display of WCs, however when you are creating/selecting sketch planes you are essentially creating WCS.

SCS

- An SCs is a 2D device dependent coordinate system whose origin is located at the lower left corner of the screen.
- It is mostly used in view related clicks such as definitions of view origin and selecting views for graphic operations.

Lecture 4

Configuration of graphics system; Functions of a Graphic system.

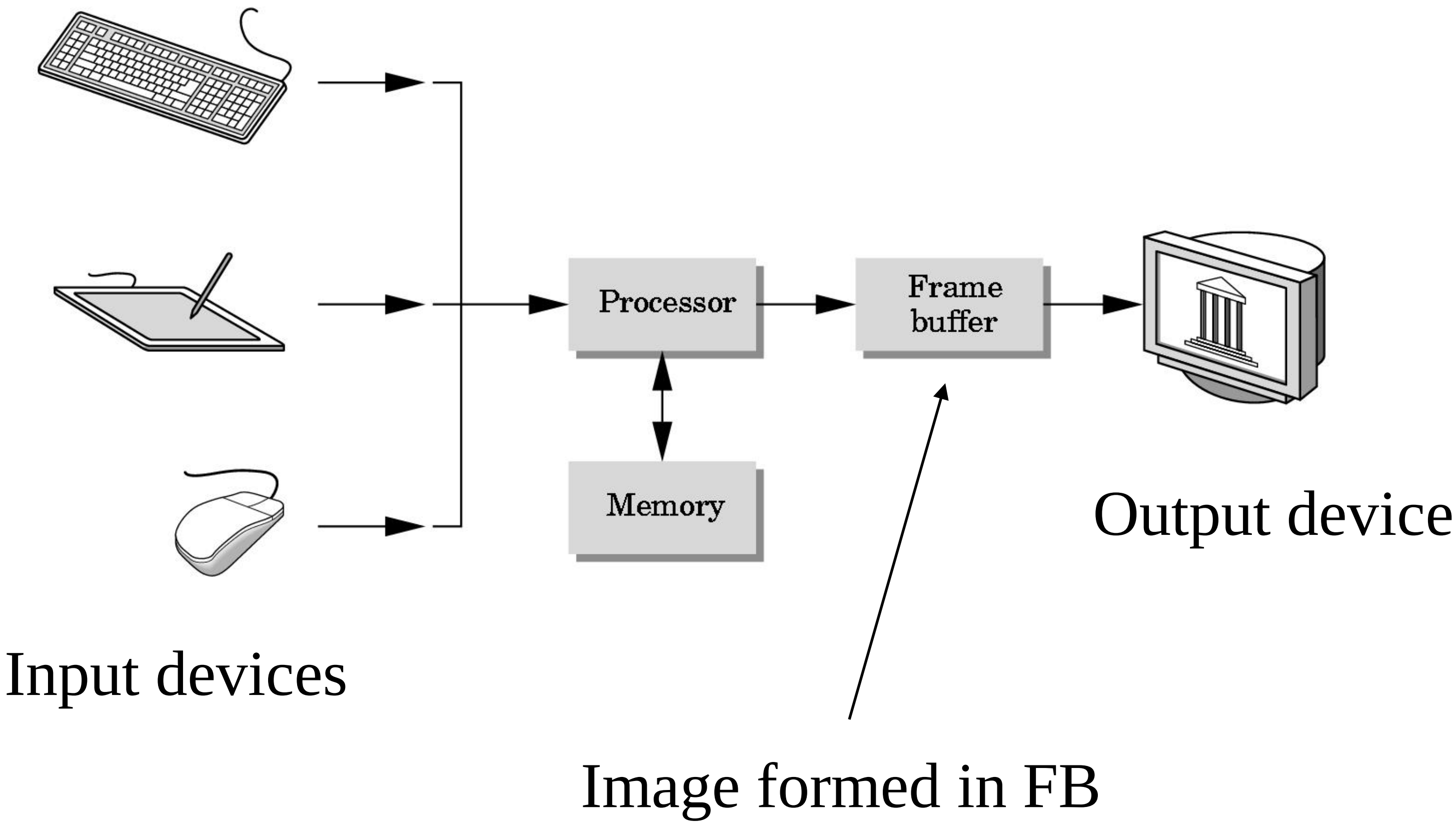
Dr. Sunil Kumar
Associate Professor
Mechanical Engineering Department
Sant Longowal Institute of Engineering and Technology, Longowal

Computer Graphics

Computer graphics deals with all aspects of creating images with a computer

- Hardware
- Software
- Applications

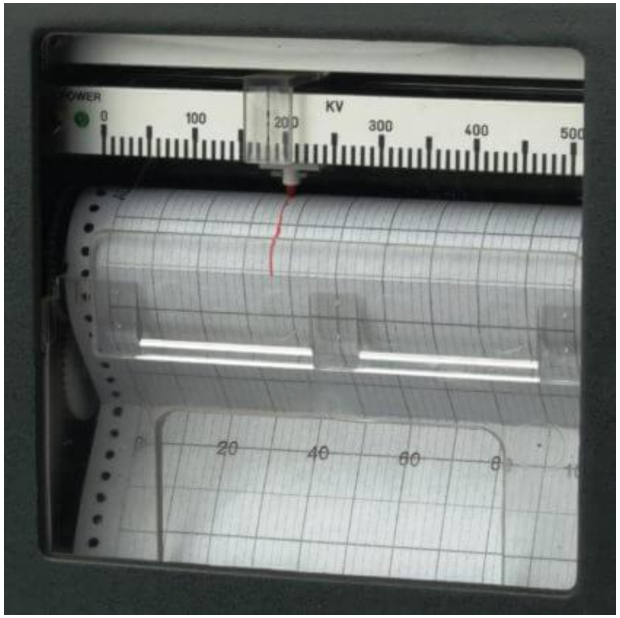
Basic Graphics System



Computer Graphics: 1950-1960

- Computer graphics goes back to the earliest days of computing
  - Strip charts
  - Pen plotters

Pen plotters



Strip charts

- Simple displays using A/D converters to go from computer to calligraphic CRT

Cost of refresh for CRT too high

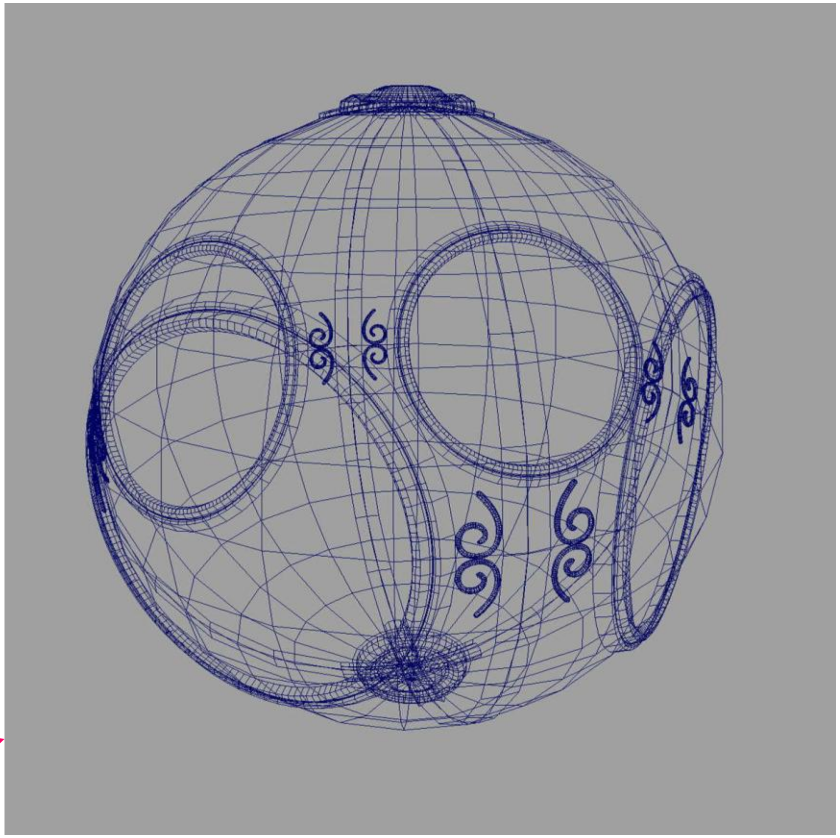
Computers slow,

expensive, unreliable

Computer Graphics: 1960-1970

- *Wireframe* graphics
  - Draw only lines
- Sketchpad
- Display Processors
- Storage tube

wireframe representation
of sun object

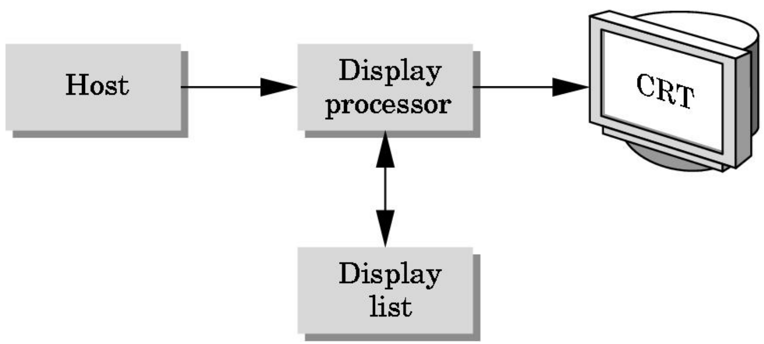


Sketchpad

- Man-machine interaction
- Loop
  - Display something
  - User moves light pen
  - Computer generates new display
- Common algorithms for computer graphics

Display Processor

- Rather than have the host computer try to refresh display use a special purpose computer called a *display processor* (DPU)



- Graphics stored in display list (display file) on display processor
- Host *compiles* display list and sends to DPU

Direct View Storage Tube

Created by Tektronix

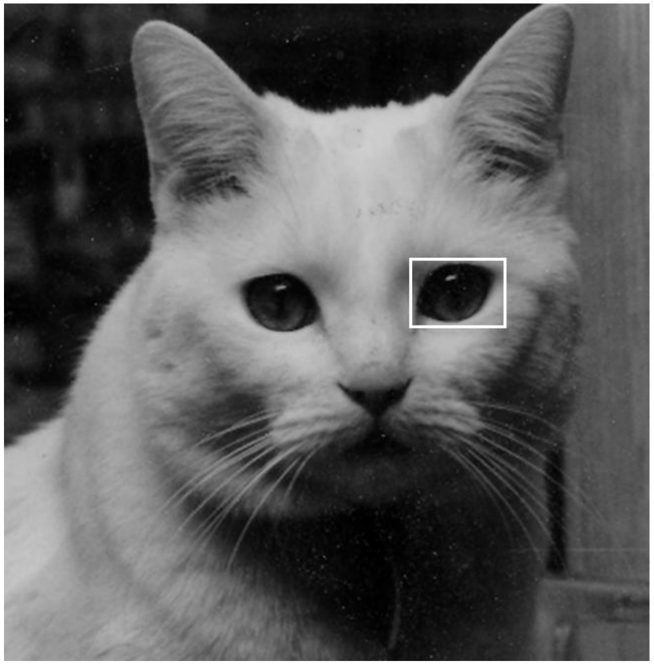
- Did not require constant refresh
- Standard interface to computers
  - Allowed for standard software
  - Plot3D in Fortran
- Relatively inexpensive
  - Opened door to use of computer graphics for CAD community

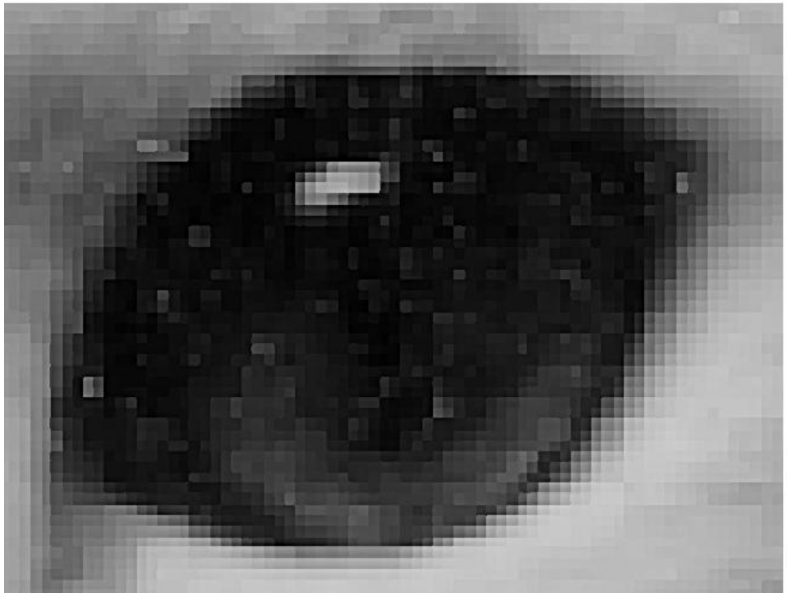
Computer Graphics: 1970-1980

- Raster Graphics
- Beginning of graphics standards
  - GKS: European effort
    - Becomes ISO 2D standard
  - Core: North American effort
    - 3D but fails to become ISO standard
- Workstations and PCs

Raster Graphics

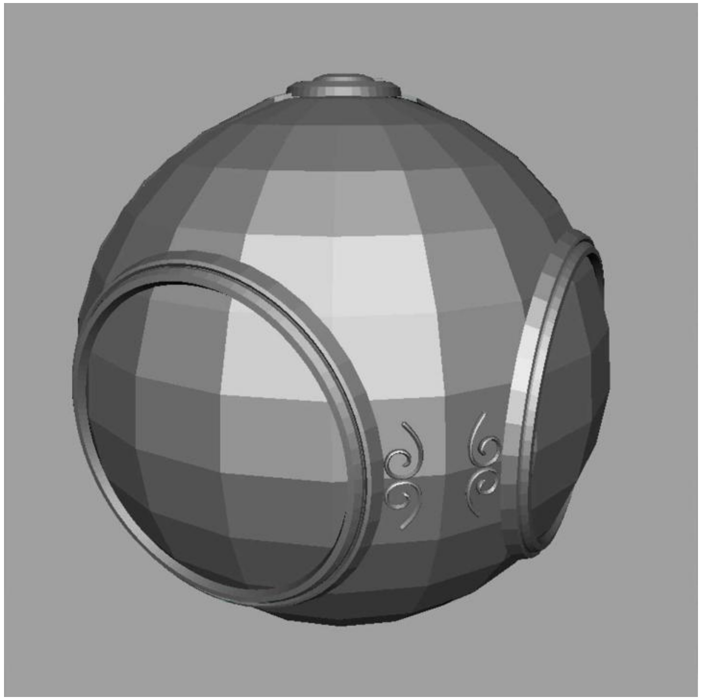
- Image produced as an array (the *raster*) of picture elements (*pixels*) in the *frame buffer*





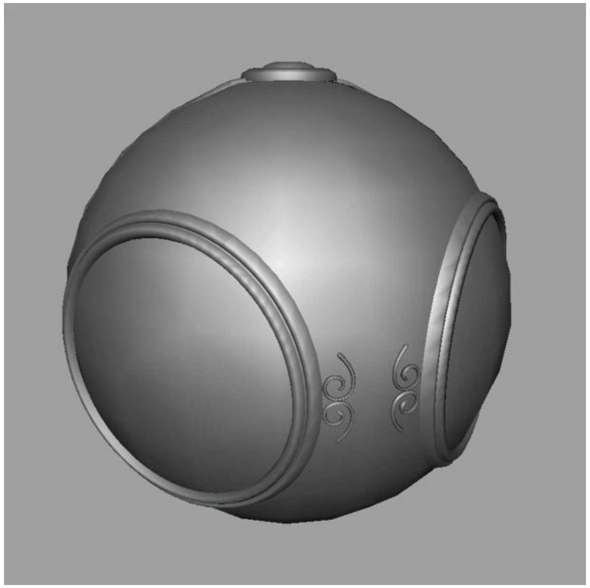
Raster Graphics

- Allows us to go from lines and wire frame images to filled polygons



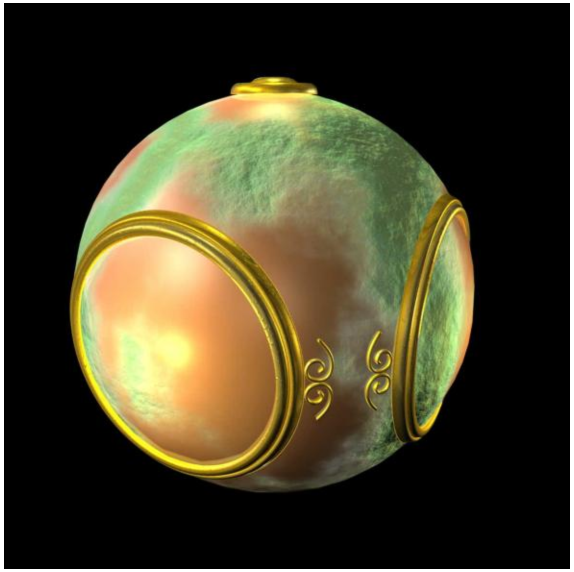
Computer Graphics: 1980-1990

Realism comes to computer graphics



smooth shading

environment mapping



bump mapping

Computer Graphics: 1980-1990

- Special purpose hardware
  - Silicon Graphics geometry engine
  - VLSI implementation of graphics pipeline
- Industry-based standards
  - PHIGS
  - RenderMan
- Networked graphics: X Window System
- Human-Computer Interface (HCI)

Computer Graphics: 1990-2000

- Open Graphics Library and application programming interface
- Completely computer-generated feature-length movies (Toy Story) were successful
- New hardware capabilities
  - Texture mapping
  - Blending
  - Accumulation, stencil buffers

Computer Graphics: 2000-2010

- Photorealism
- Graphics cards (GPU) for PCs dominate market
  - Nvidia, ATI
- Game boxes and game players determine direction of market (Wii, Kinect, etc.)
- Computer graphics routine in movie industry
- Programmable pipelines

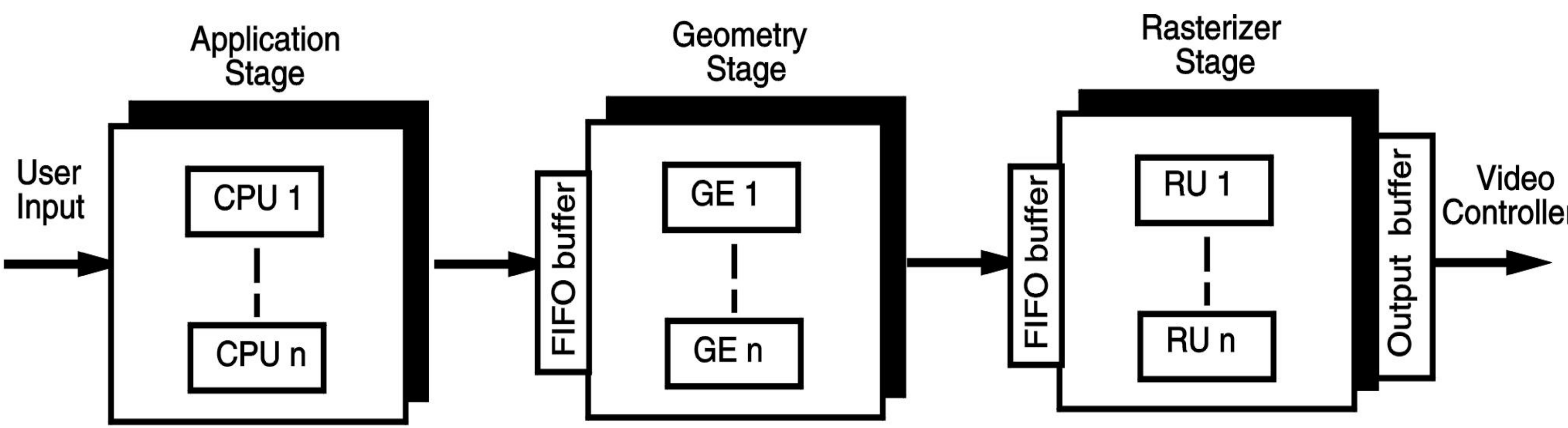
Computer Graphics: 2010-

- Mobile Computing
  - iPhone, Android
- Cloud Computing
  - Amazon Web Services (AWS)
- Virtual Reality
  - Oculus Rift
- Artificial Intelligence
  - Big Data/Deep Learning
  - Google Car

Stages in Computer Graphics

There are three stages

- Application Stage
- Geometry Stage
- Rasterization Stage



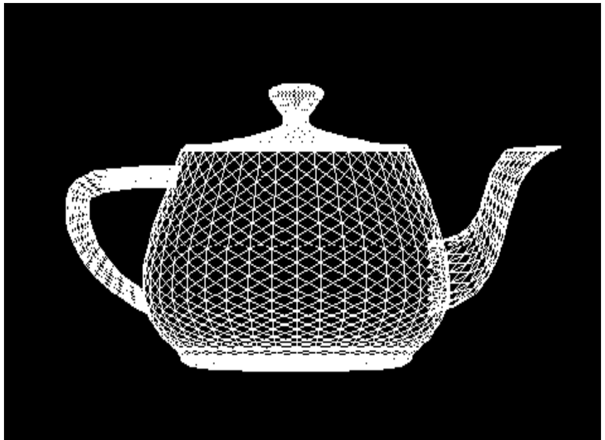
Application stage

Entirely done in software by the CPU

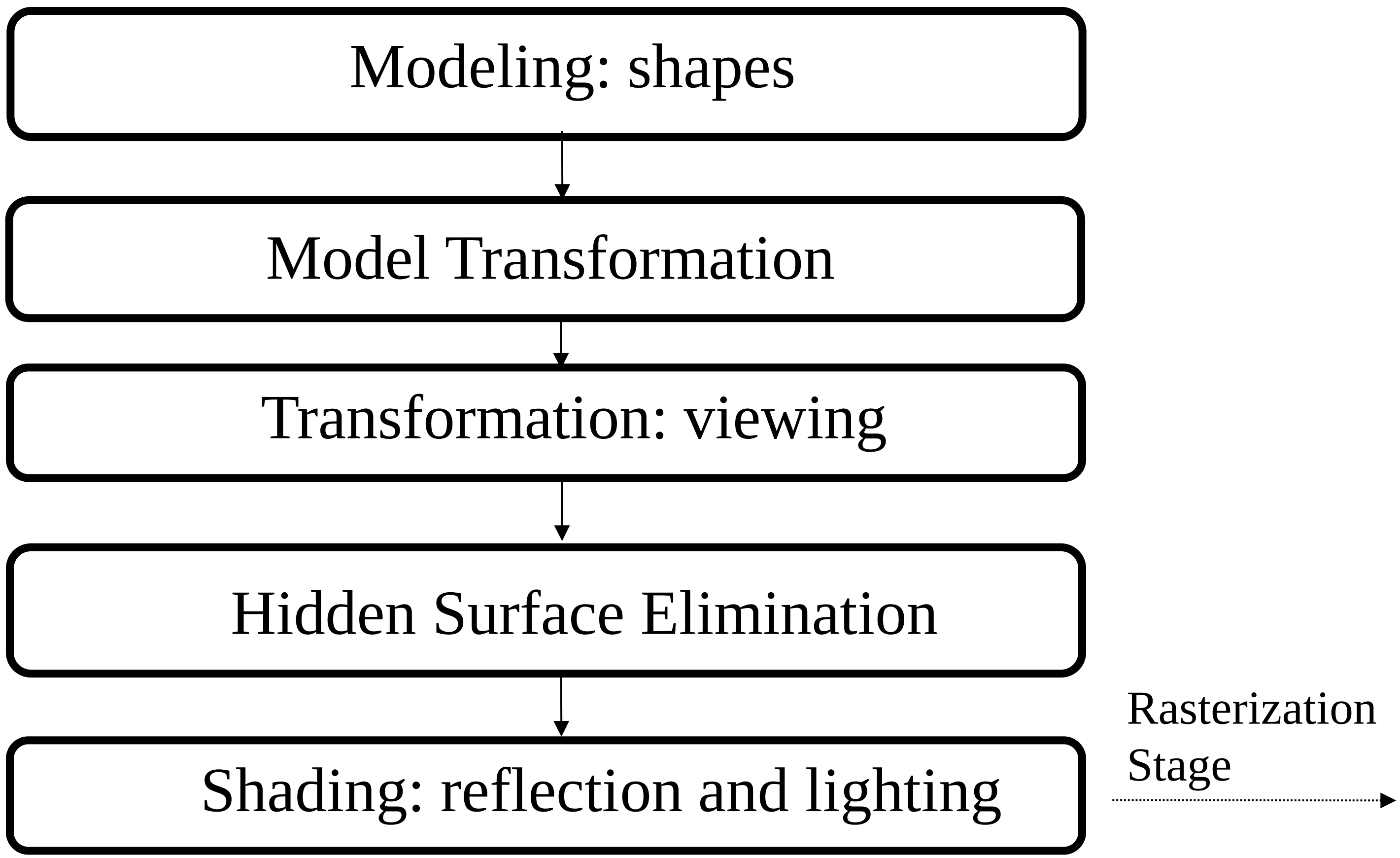
Read Data

- The world geometry database,
- User's input by mice, trackballs, trackers, or sensing gloves

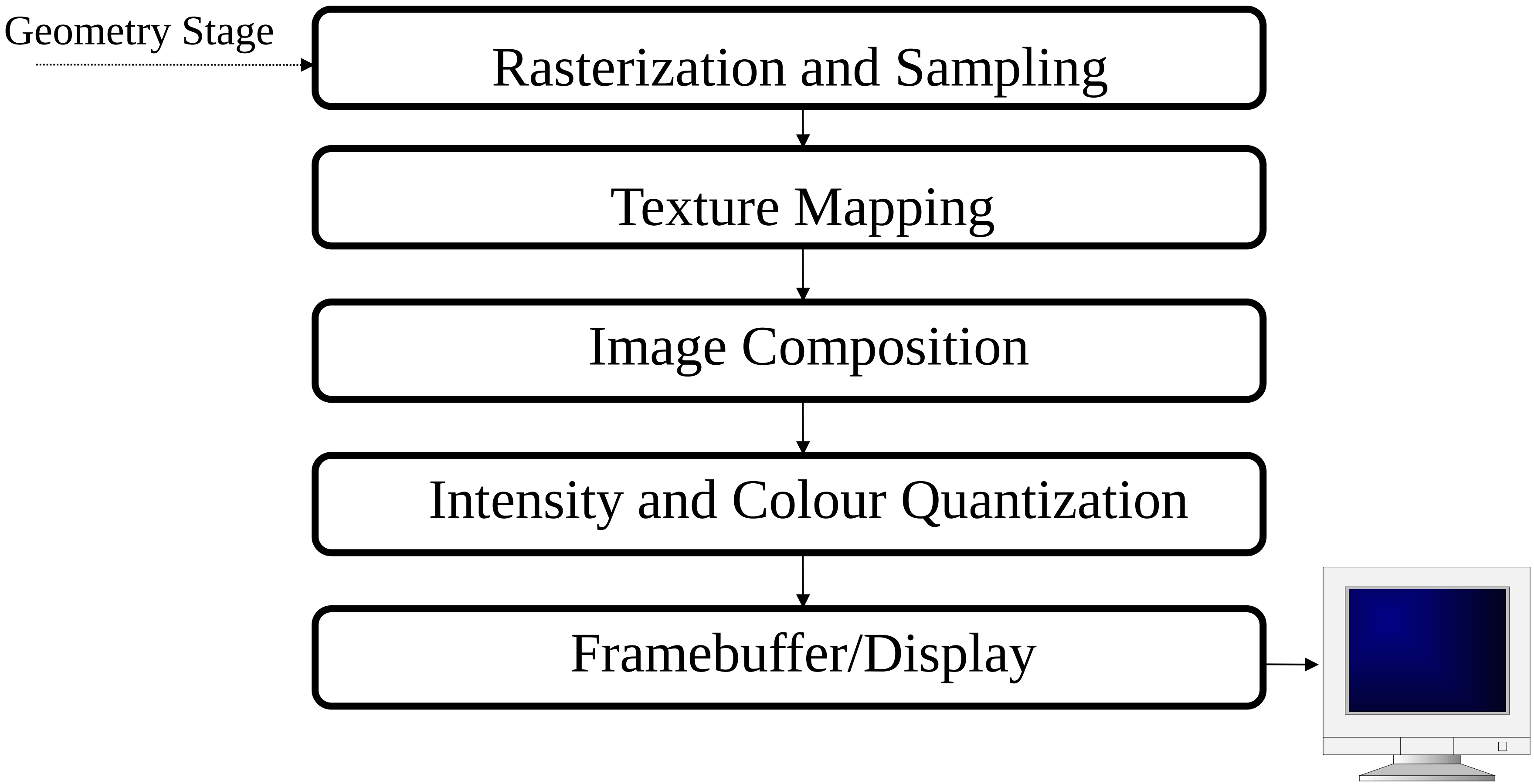
In response to the user's input, the application stage change the view or scene



Geometry Stage

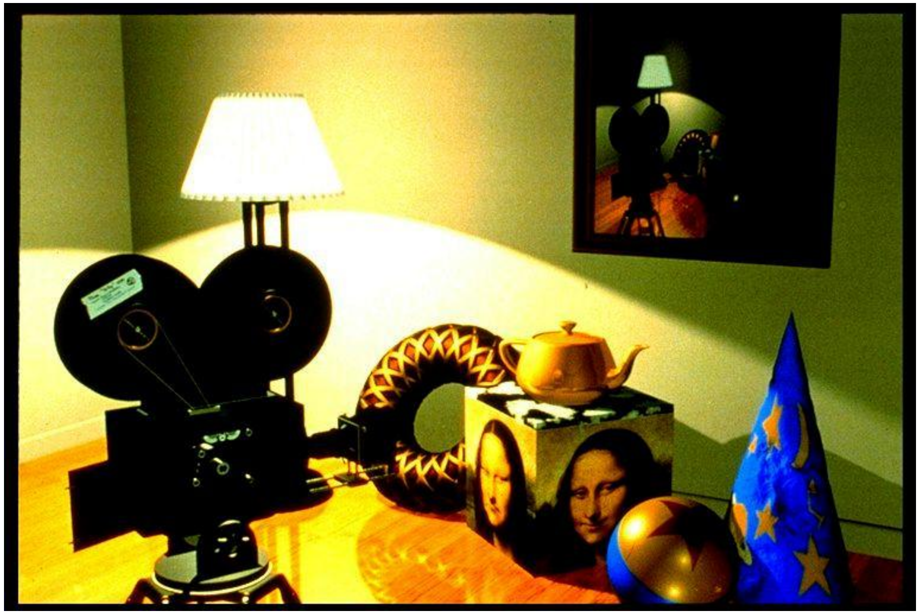


Rasterization Stage

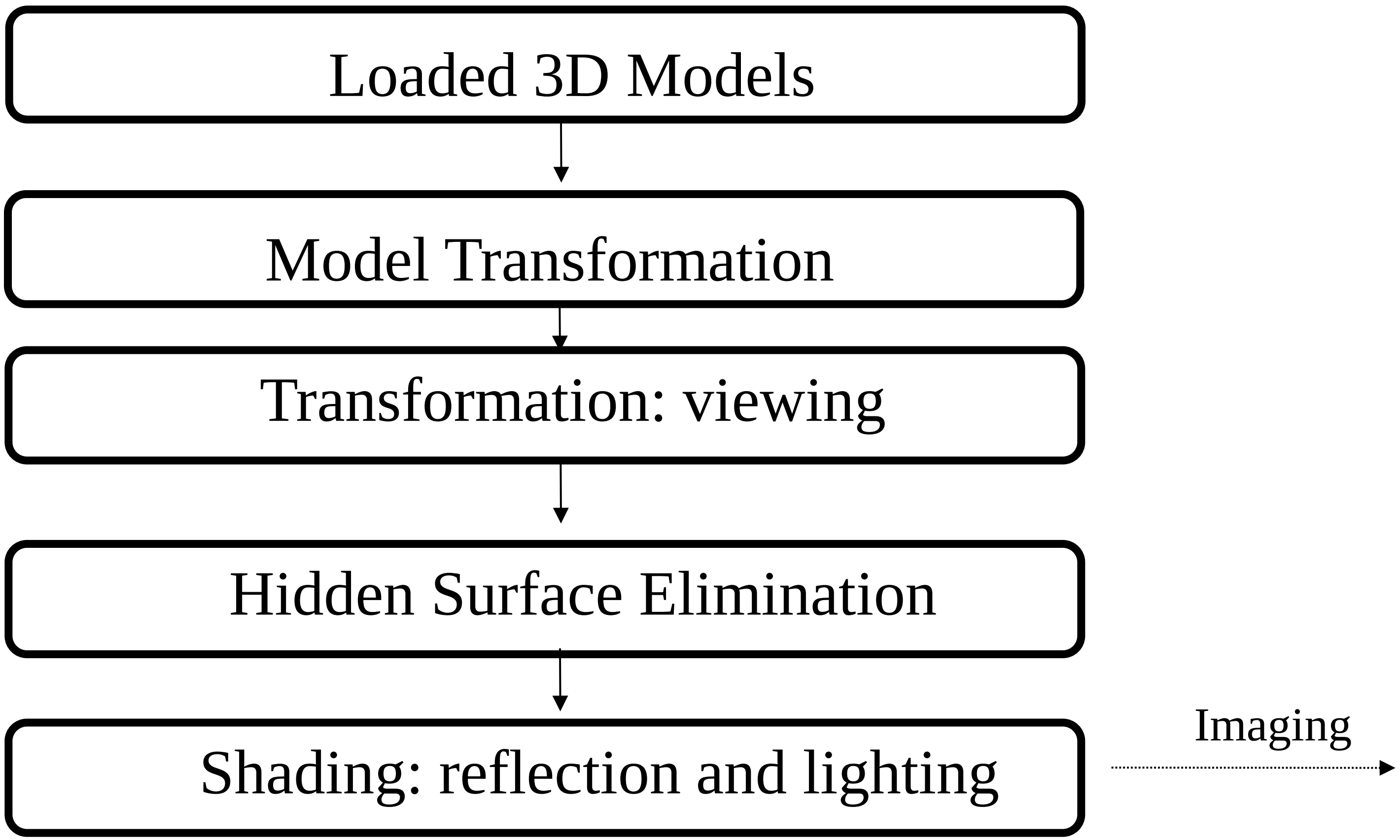


An example …

The scene we are trying to represent:



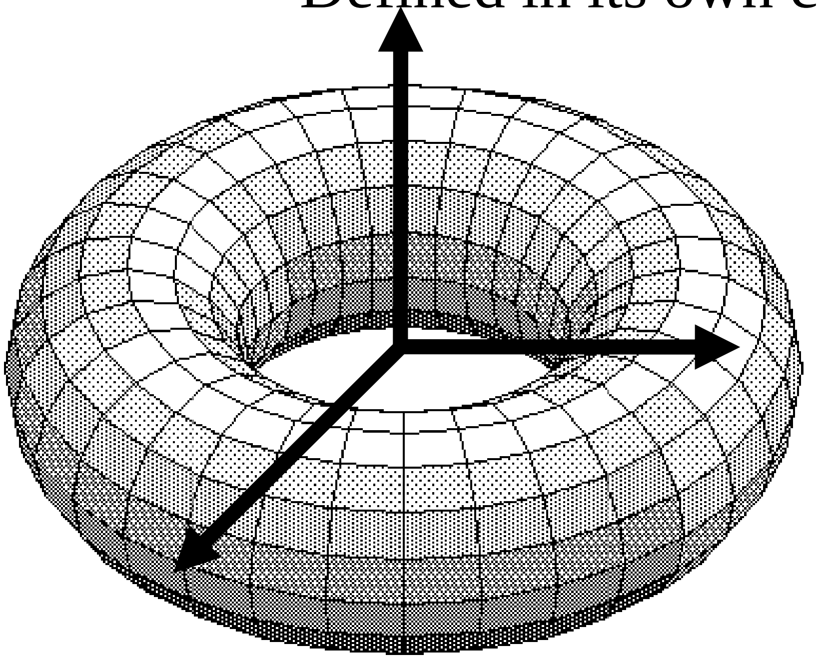
Geometry stage

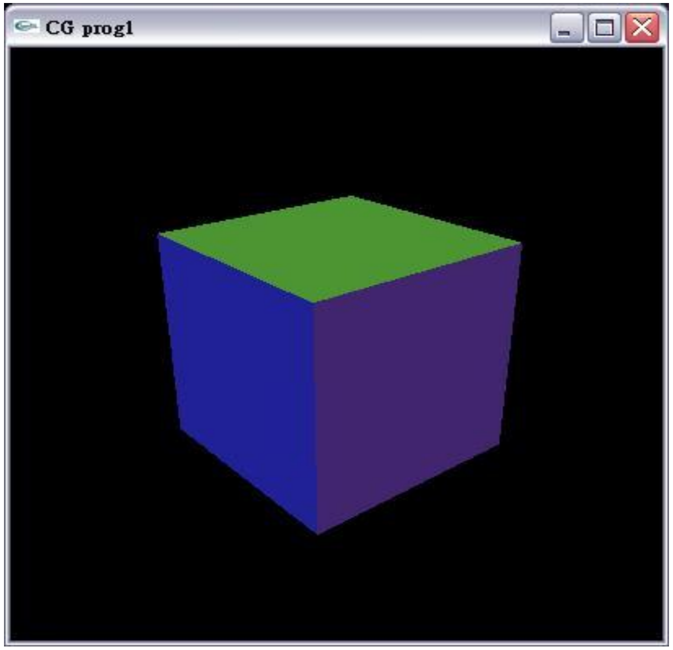


Preparing Shape Models

Designed by polygons, parametric curves/surfaces, implicit surfaces and etc.

Defined in its own coordinate system



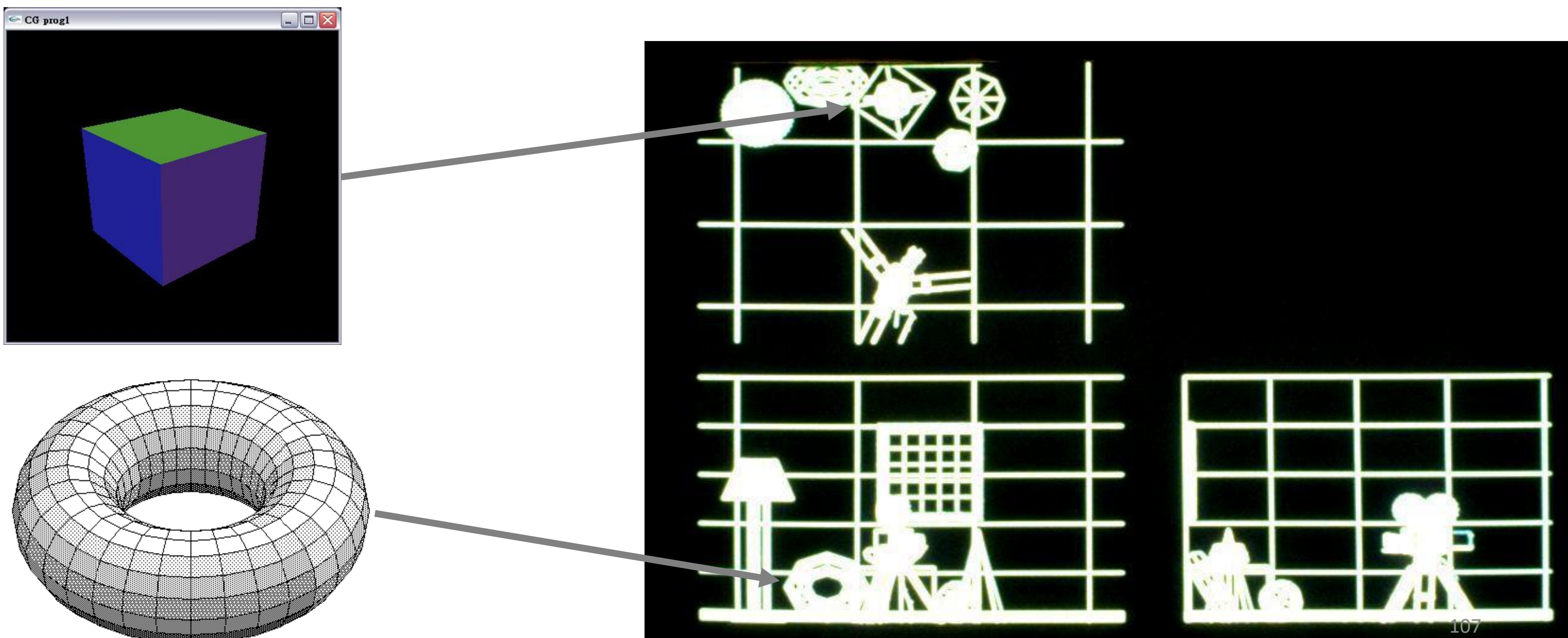


Model Transformation

Objects put into the scene by applying translation, scaling and rotation

Linear transformation called homogeneous transformation is used

The location of all the vertices are updated by this transformation

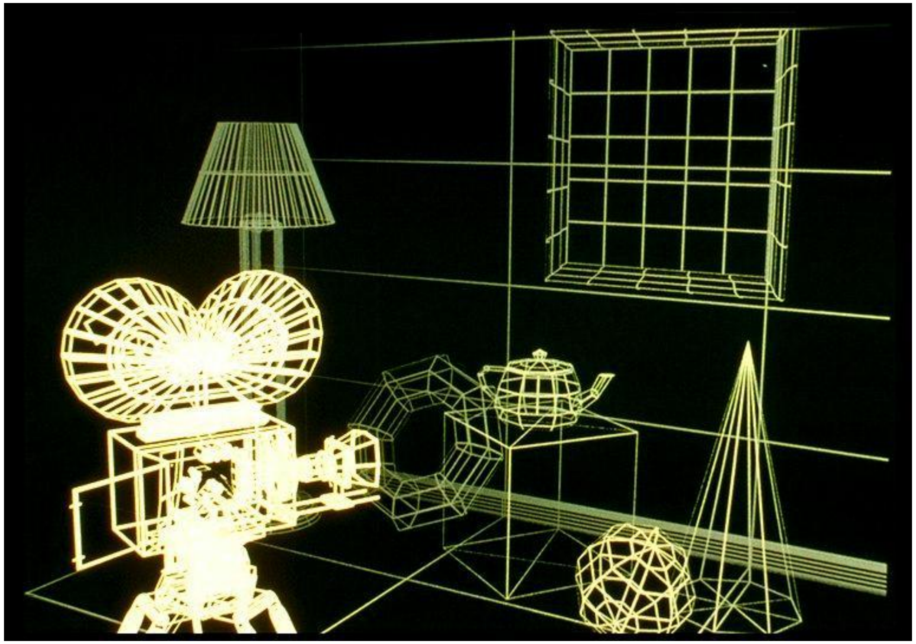


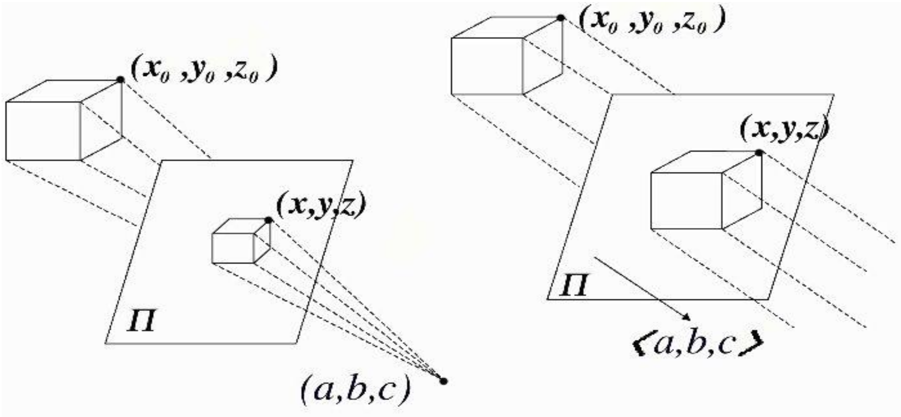
Perspective Projection

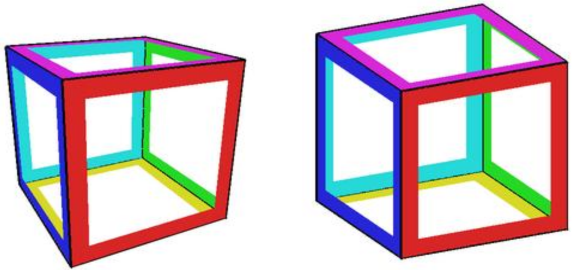
We want to create a picture of the scene viewed from the camera

We apply a perspective transformation to convert the 3D coordinates to 2D coordinates of the screen

Objects far away appear smaller, closer objects appear bigger

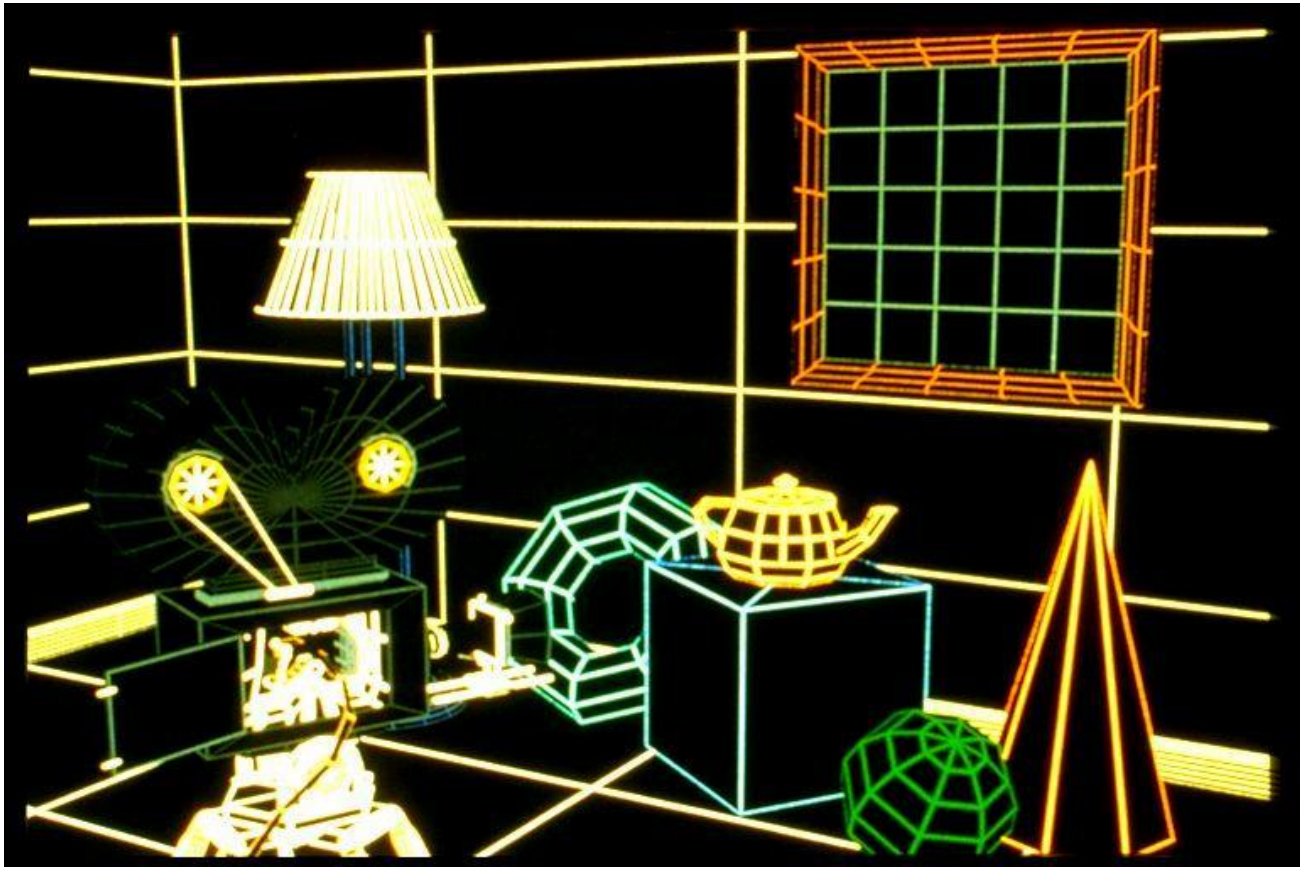






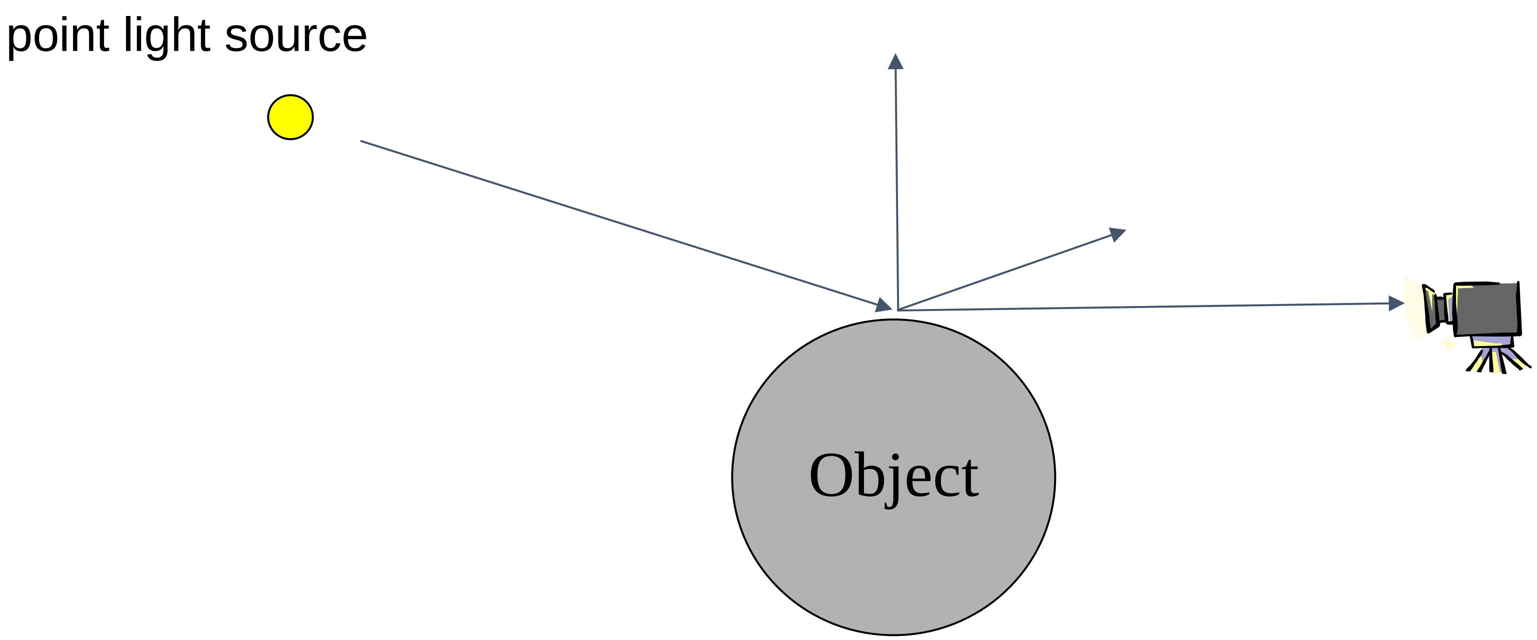
Hidden Surface Removal

Objects occluded by other objects must not be drawn



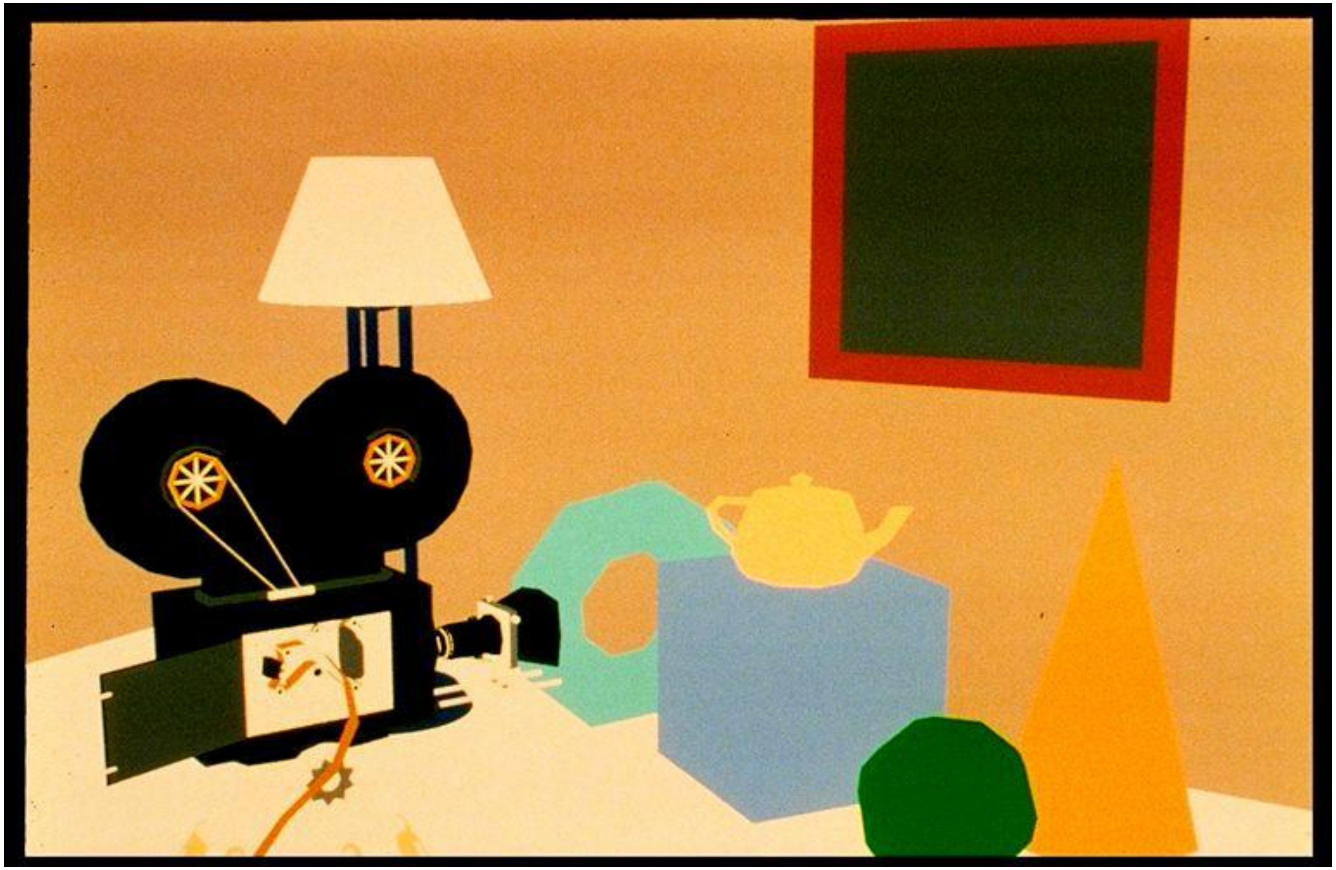
Shading

Now we need to decide the colour of each pixels taking into account the object's colour, lighting condition and the camera position



Shading : Constant Shading - Ambient

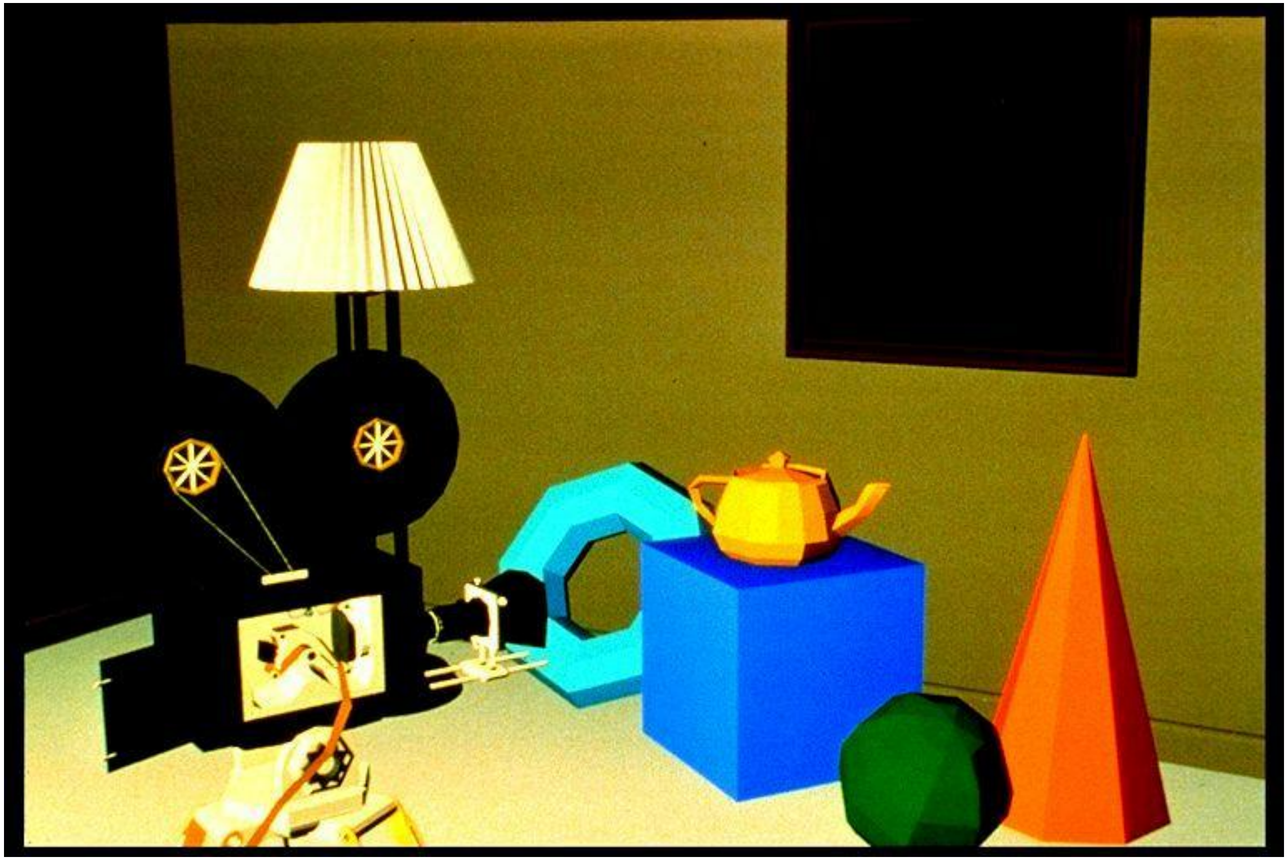
Objects colours by its own colour



Shading – Flat Shading

Objects coloured based on its own colour and the lighting condition

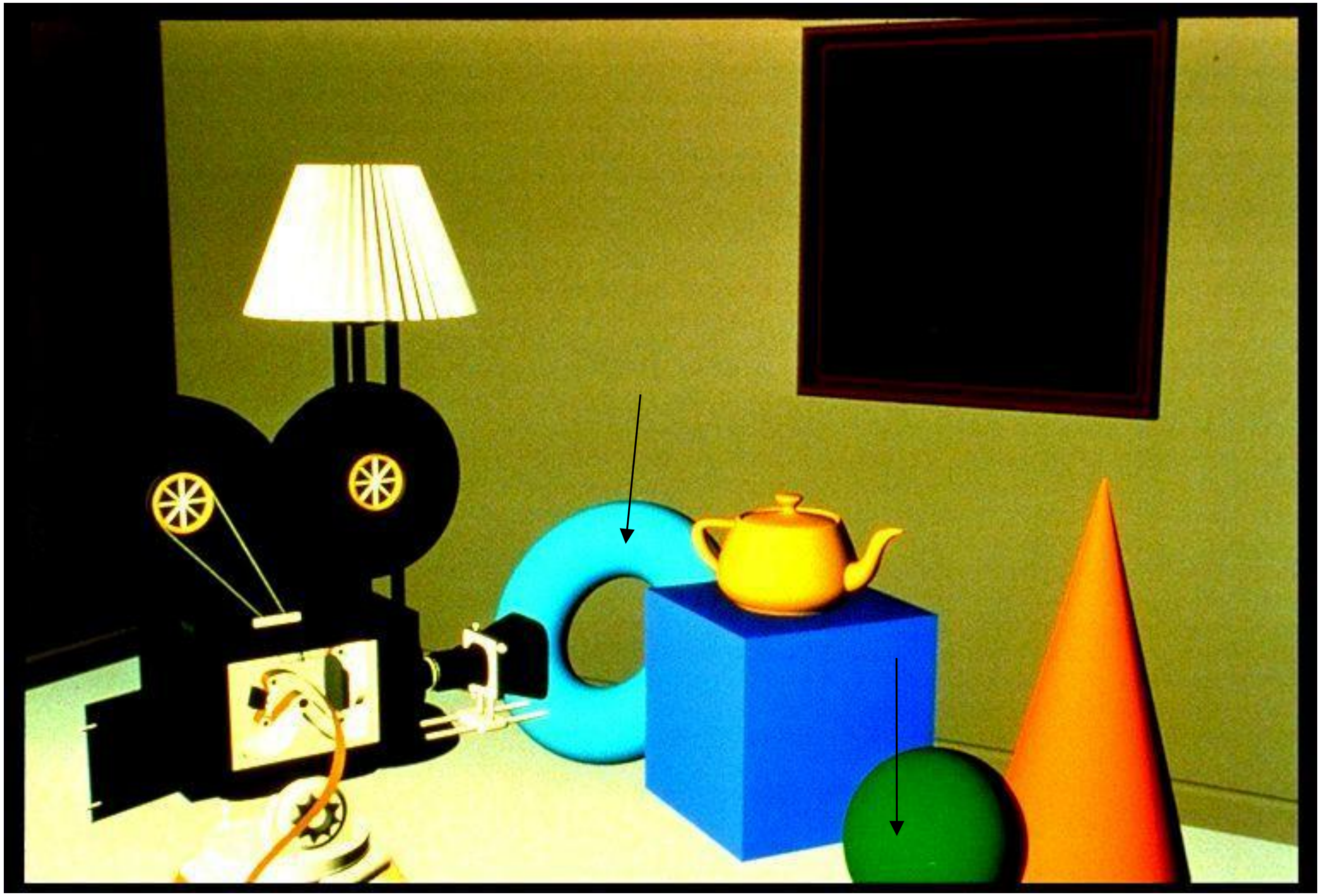
One colour for one face



Gouraud shading, no specular highlights

Lighting calculation per vertex

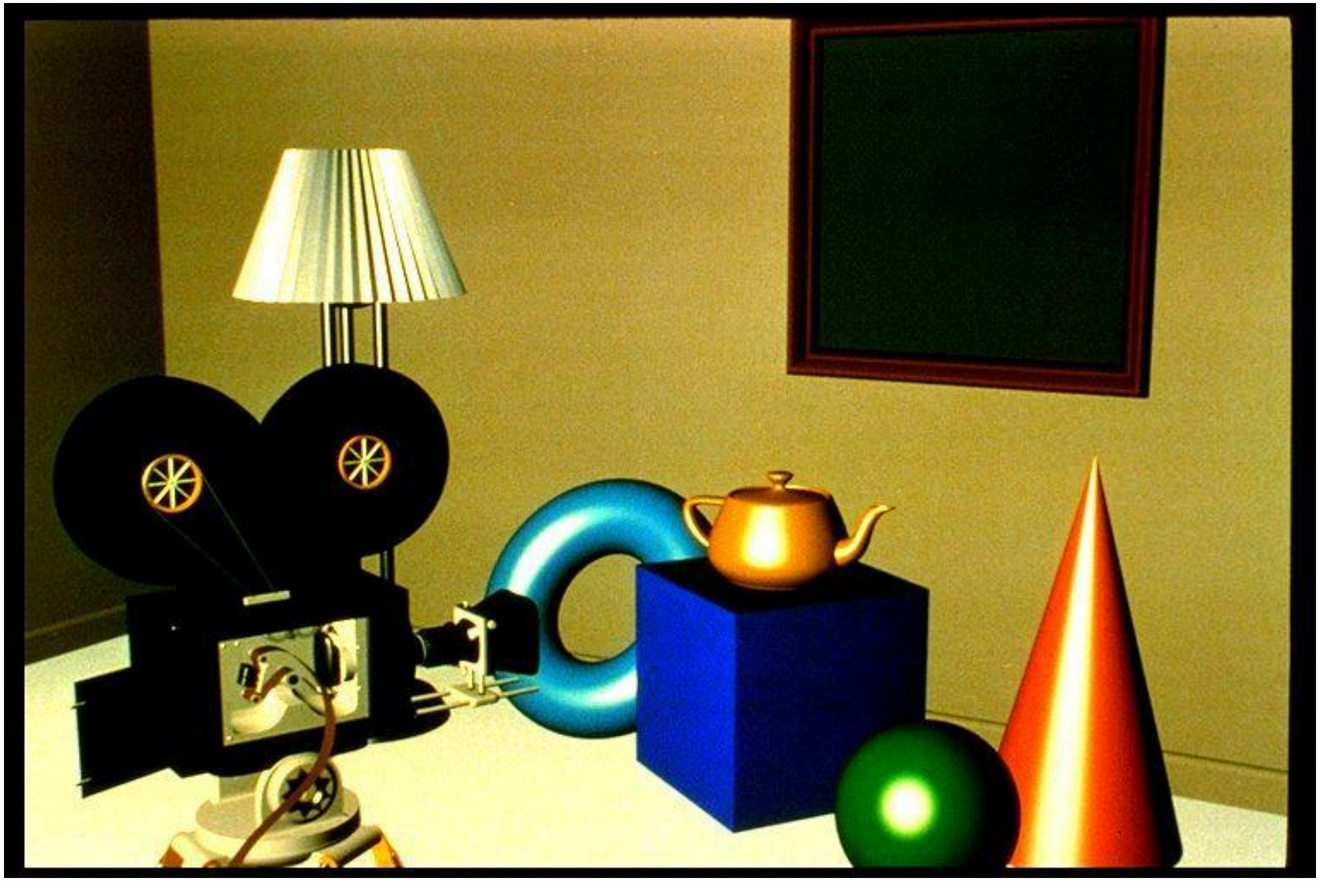
Shapes by Polynomial Surfaces



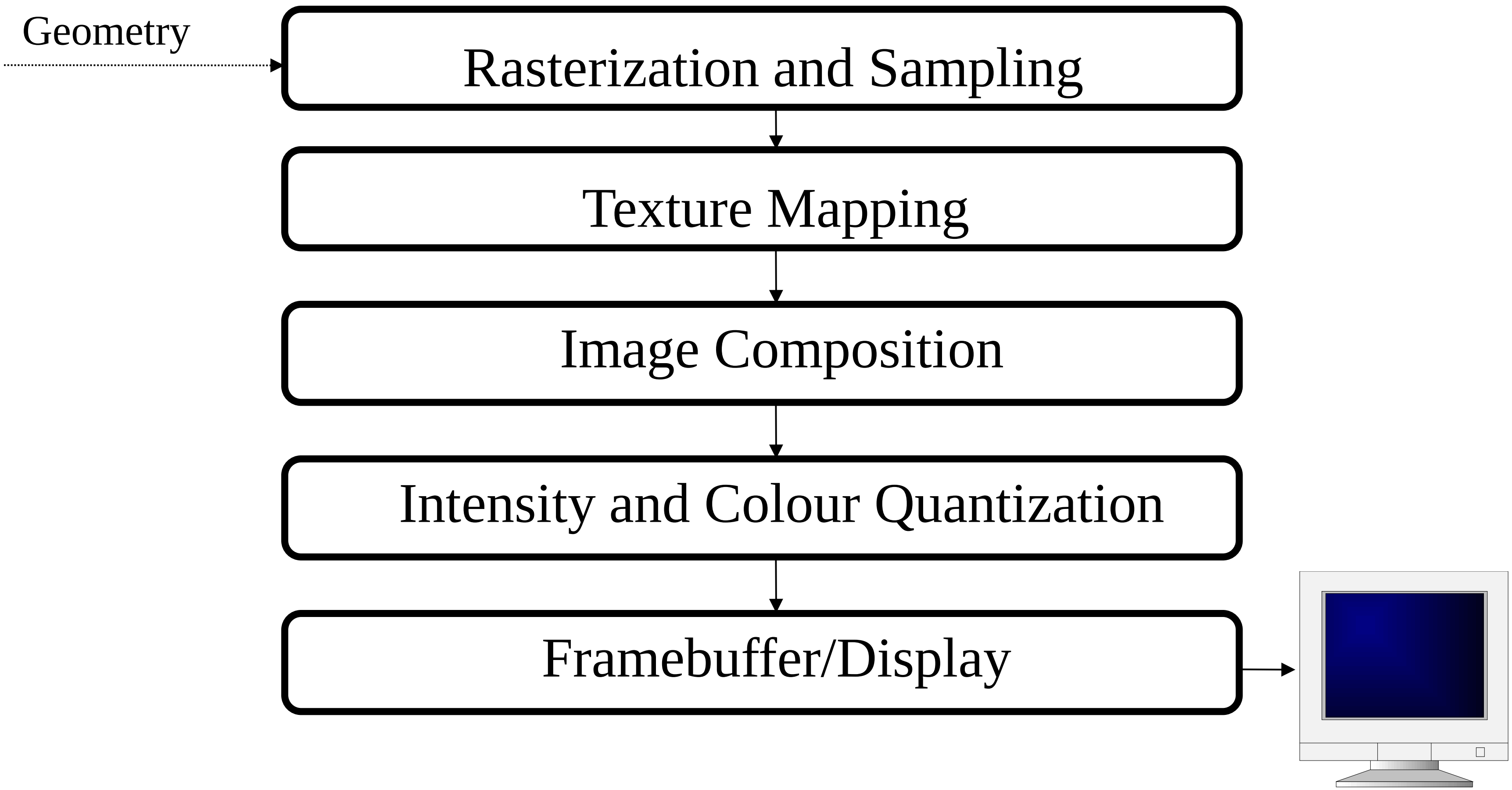
Specular highlights added

Light perfectly reflected in a mirror-like way

Phong shading



Next, the Imaging Pipeline

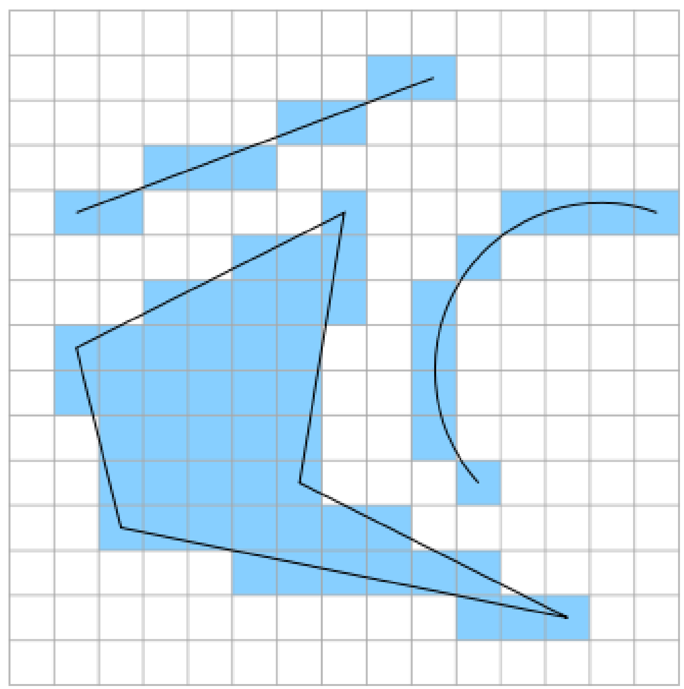


Rasterization

Converts the vertex information output by the geometry pipeline into pixel information needed by the video display

Aliasing: distortion artifacts produced when representing a high-resolution signal at a lower resolution.

Anti-aliasing : technique to remove aliasing

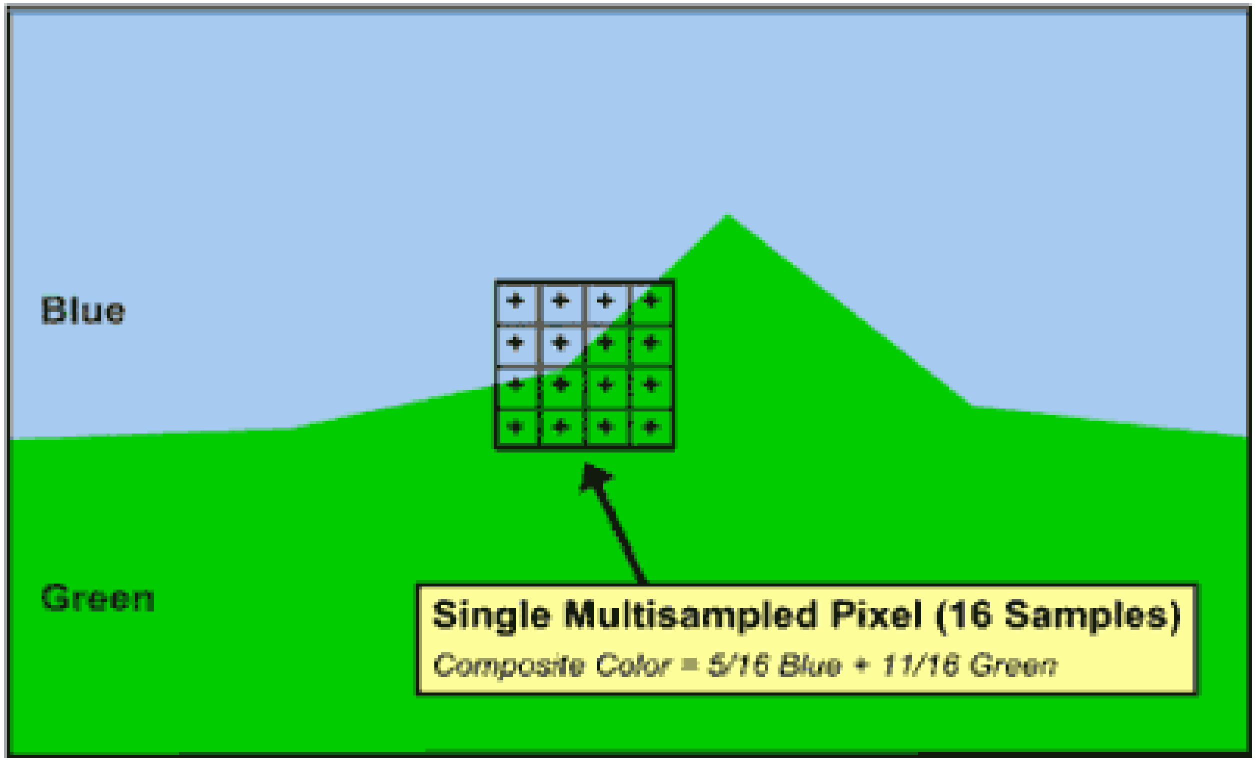


Anti-aliasing

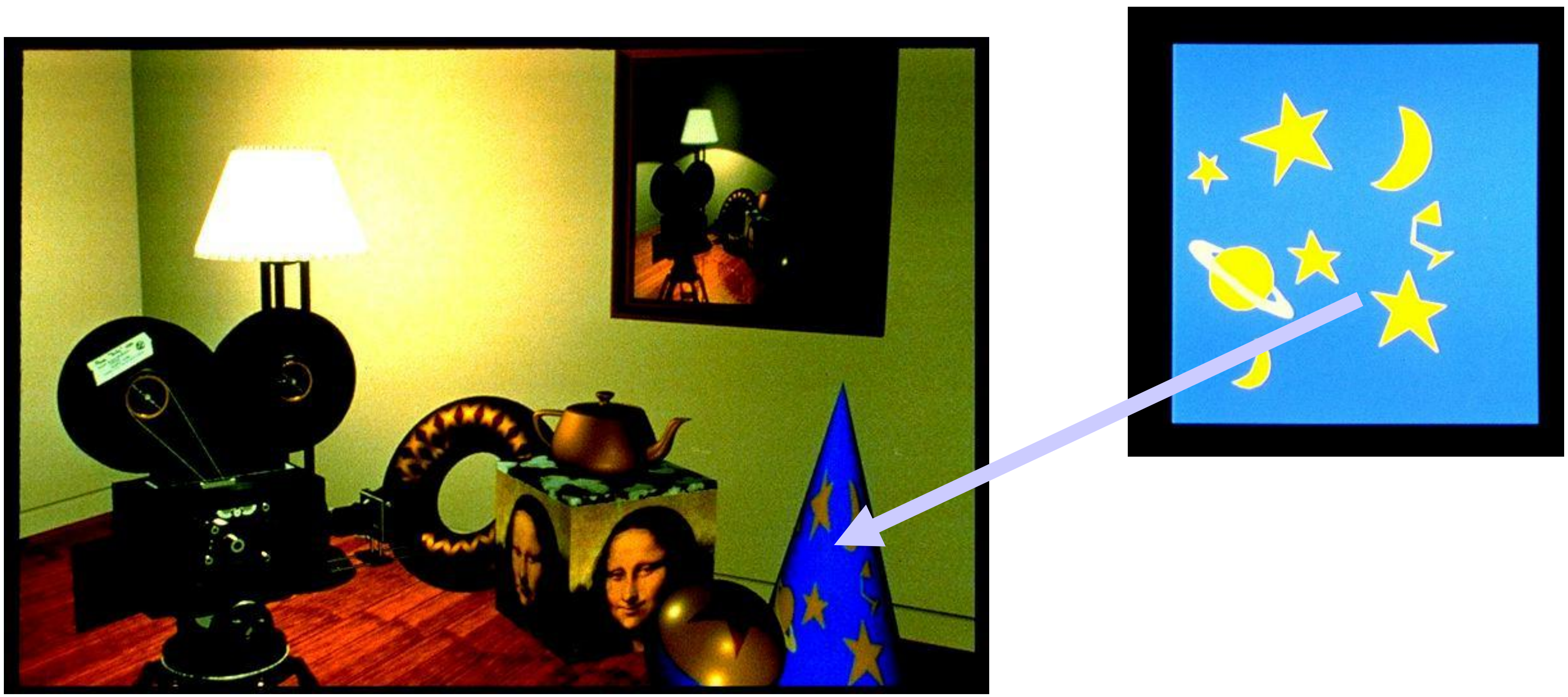
Aliased polygons (jagged edges)

Anti-aliased polygons

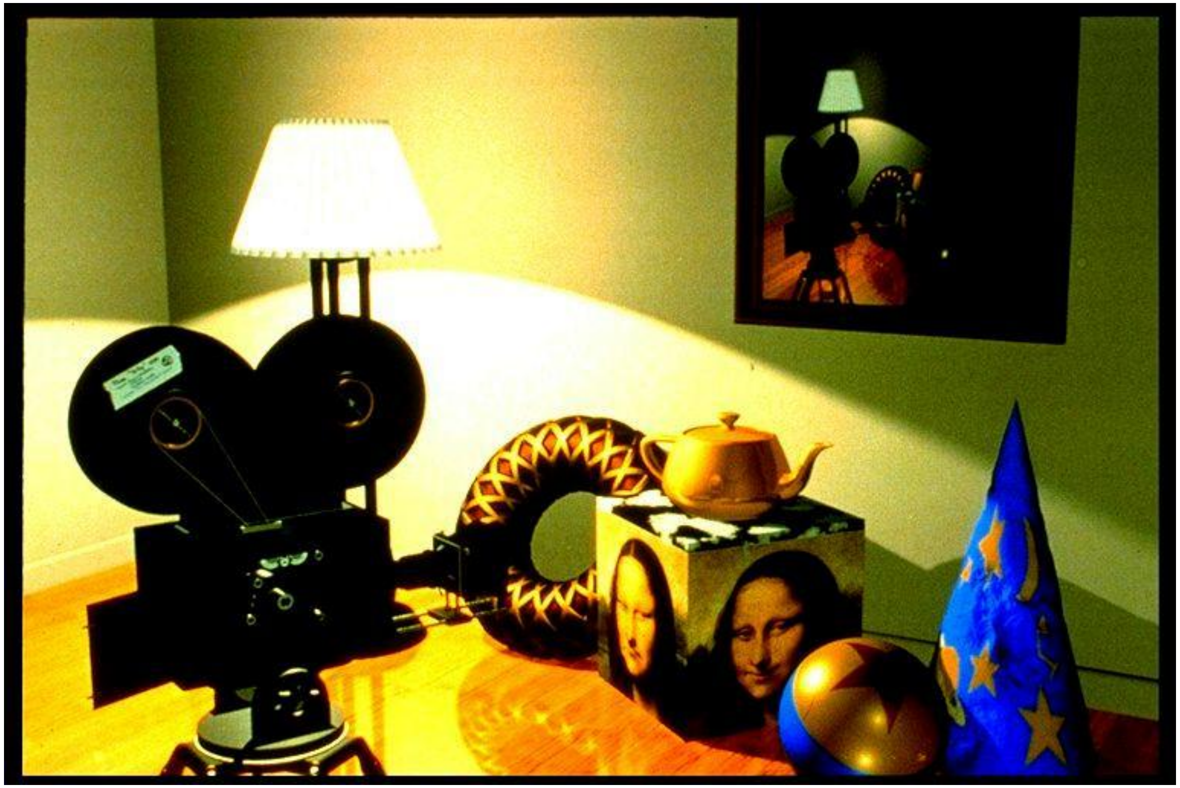
✓**How is *anti-aliasing* done? Each pixel is subdivided (sub-sampled) in n regions, and each sub-pixel has a color;**
✓**Compute the average color value**



Texture mapping

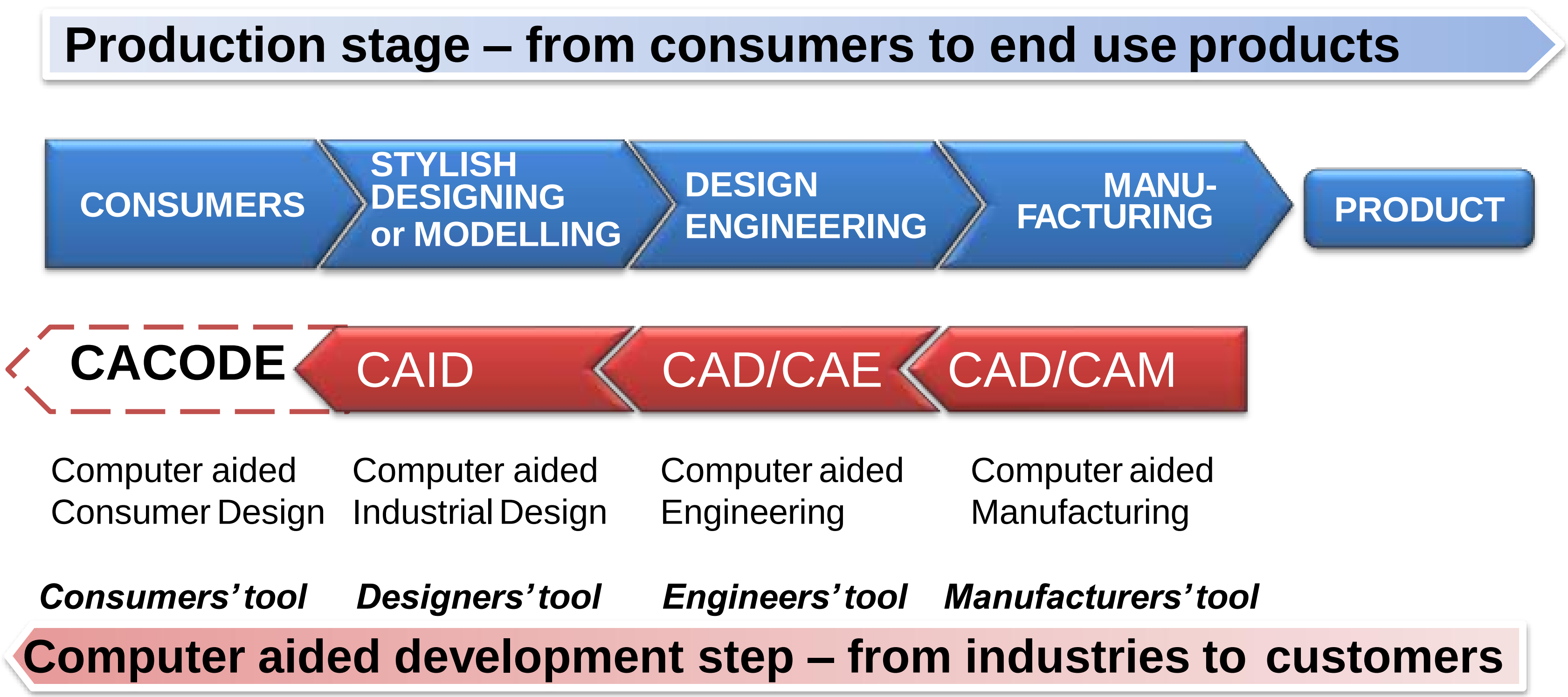


Other covered topics:
Reflections, shadows & Bump mapping



Finally scene is created

Future CAD **Prediction**



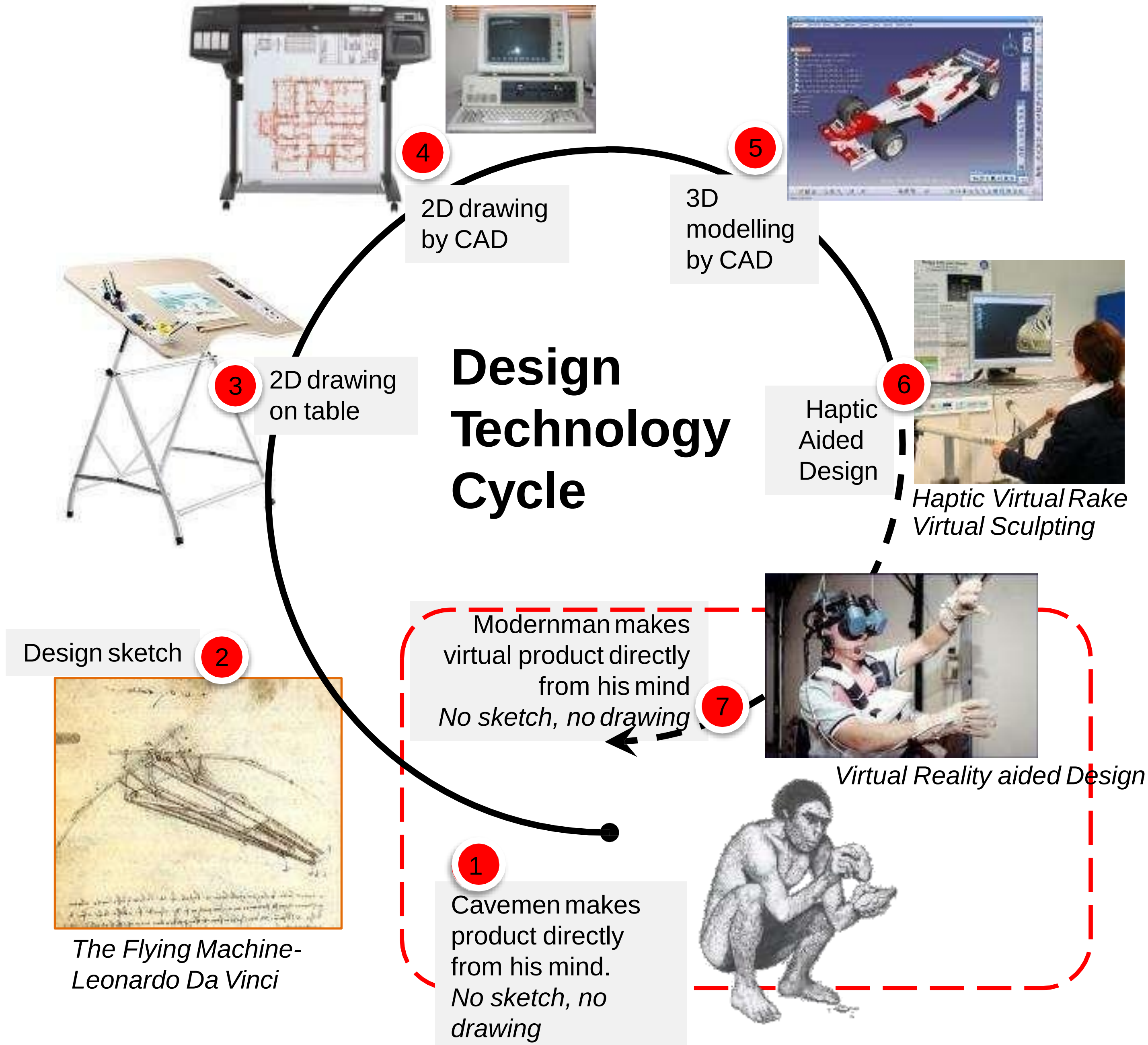
Software's for Design

CATiA and Solid Works are Powered by Dassault System

Here are Software you might need to be aware of, as well.

- SolidEdge
- SurfCAM
- Space Claim
- Solid thinking Evolve
- ThinkerCAD
- T FLEX CAD
- TurboCAD
- ZW3D
- ViaCAD 3D
- SketchUp
- Rhino
- OpenSCAD
- MasterCAM X8
- Moi3D
- Modo
- LightWave
- Key Creator
- Kompas 3D
- IronCAD
- Fusion 360
- Femap
- FreeCAD
- DraftSight
- SolidFace
- Keyshot

Software's for Programming are :


Design Technology Cycle
1
Cavemen makes product directly from his mind.
No sketch, no drawing
2
Design sketch
The Flying Machine- Leonardo Da Vinci
3
2D drawing on table
4
2D drawing by CAD
5
3D modelling by CAD
6
Haptic Aided Design
Haptic Virtual Rake
Virtual Sculpting
7
Modernman makes virtual product directly from his mind
No sketch, no drawing
Virtual Reality aided Design

Lecture 5 & 6

Hardware

Dr. Sunil Kumar
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Types of systems

- Mainframe based systems
- Minicomputer based systems

Mainframes

- Systems used in 1960s
- one or more drafting / design stations
- Linked with various input and output devices

Minicomputers

- Developed in 1970s
- LSI and VLSI
- Smaller in size

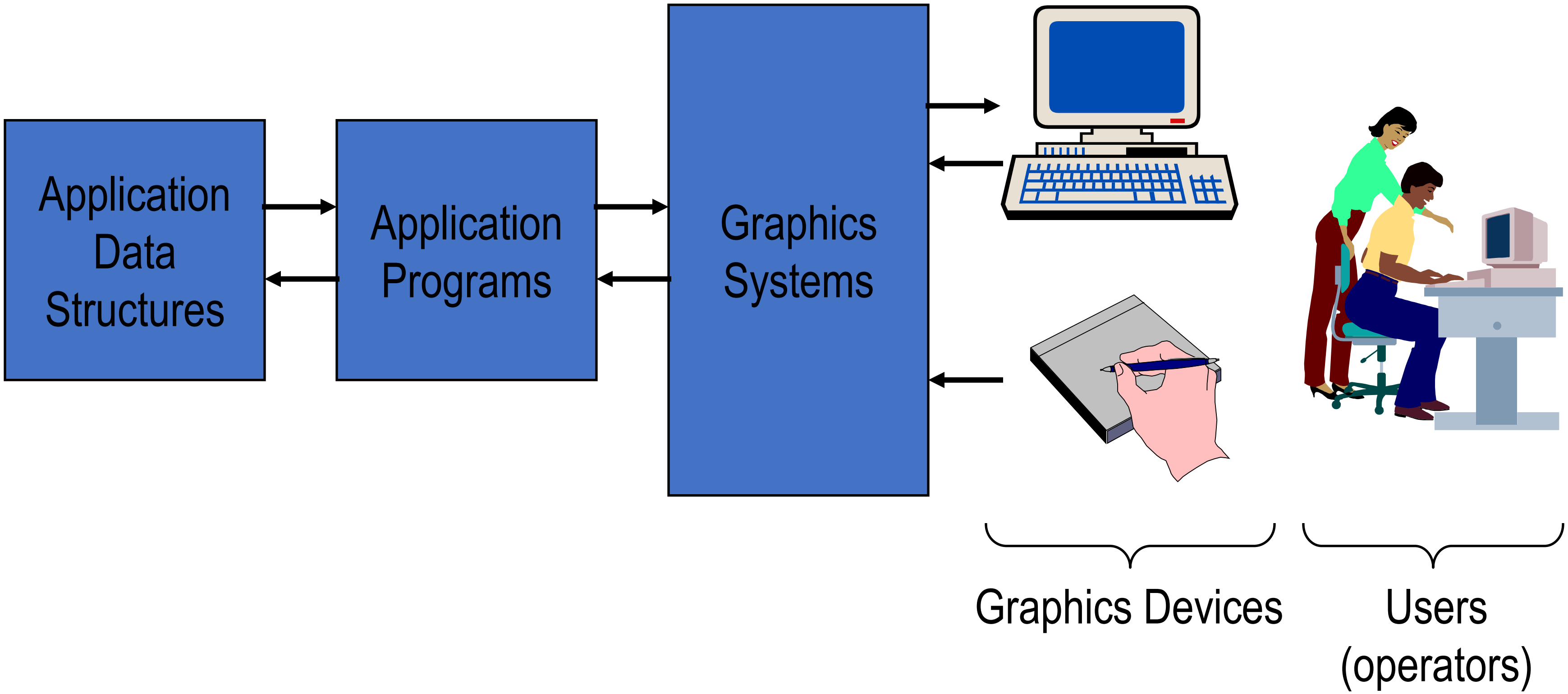
Microcomputers

- One computer per graphic terminal
- One system is generally made a server

Workstations

- Well established system technology
- Portability and availability
- Own computing power for each graphic terminal
- Distributed computing instead of shared computing
- Next generation CAD/CAM systems

The Programmer's Model of Interactive Graphics

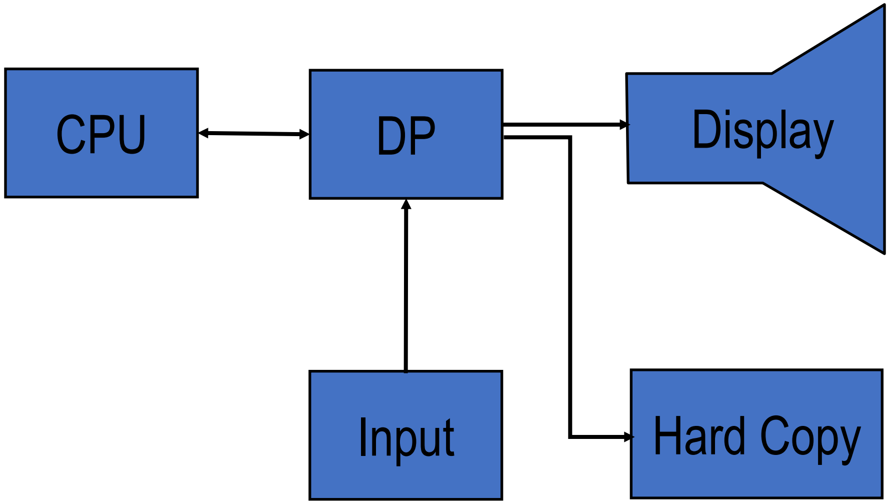


- Application Data Structures / Models
- Application Programs
- Graphics Systems
- Graphics Devices

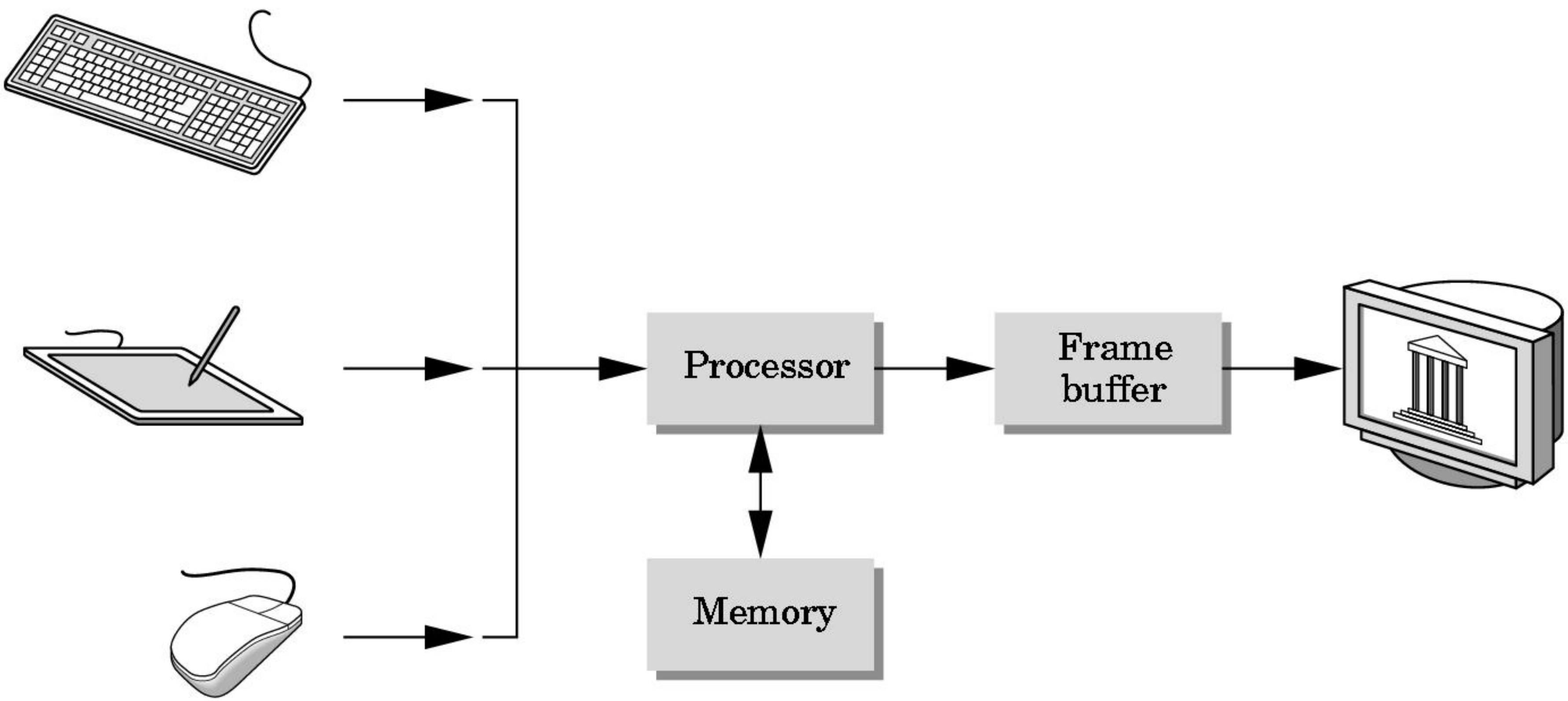
Graphics Devices

- Output Devices
  - Display Devices
  - Hard Copy Devices

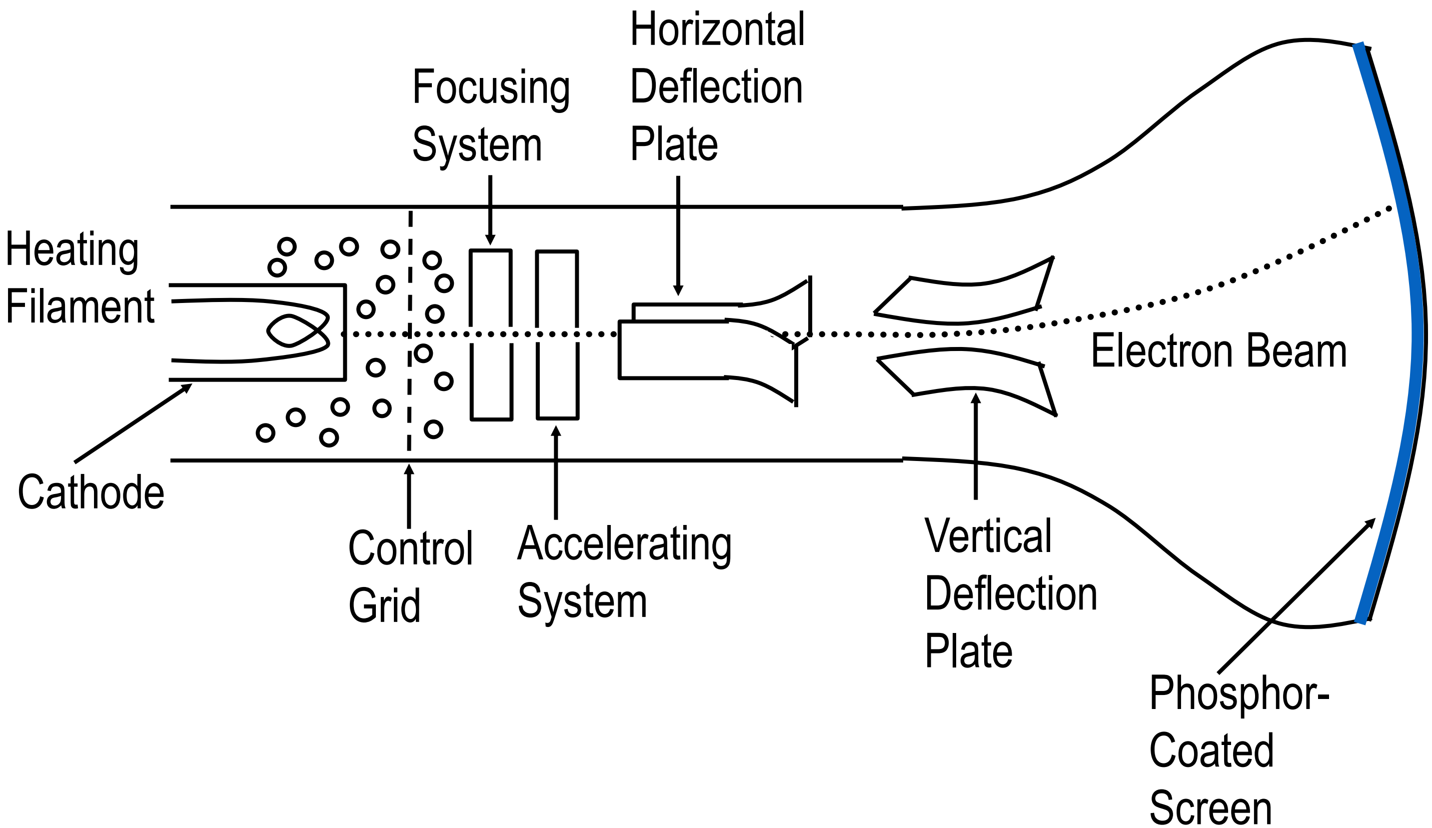
- Input Devices
  - Locator
  - String (Keyboard)
  - Choice (Button)
  - Pick



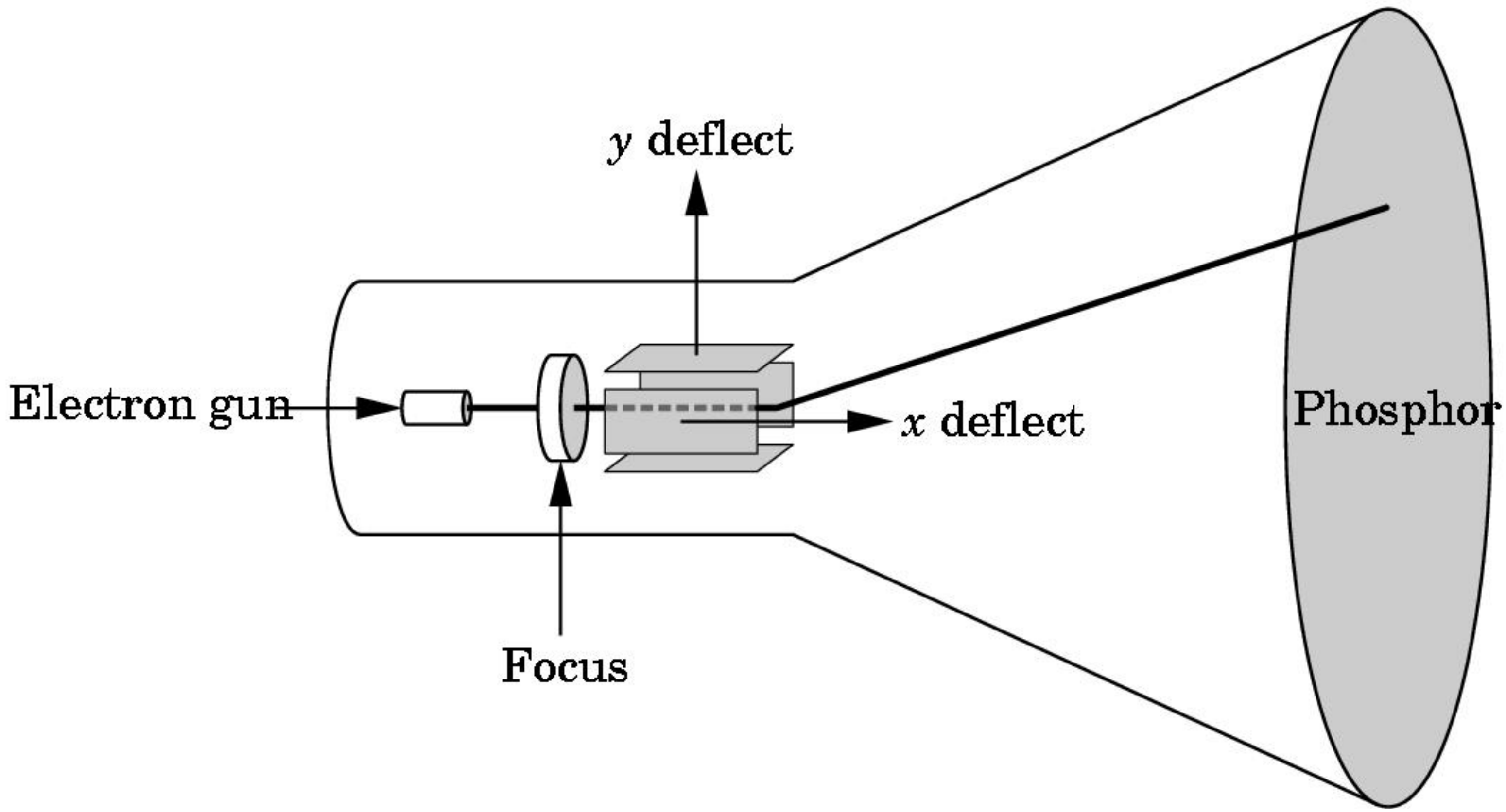
Five major elements - processor, memory, frame buffer, output devices, input devices



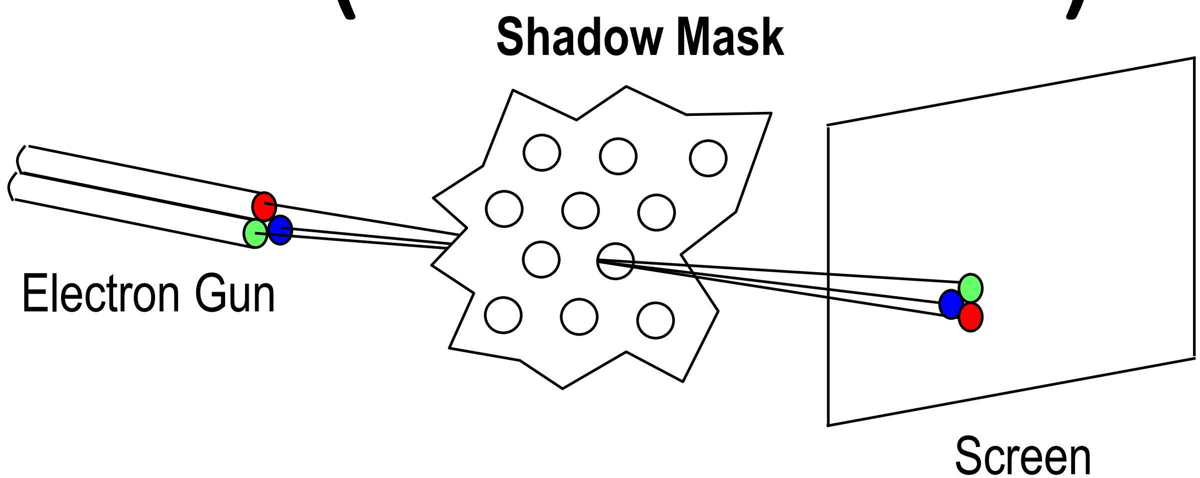
CRT Basics

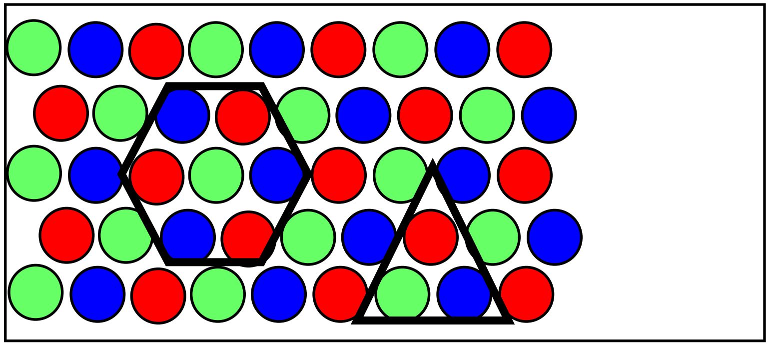

Horizontal Deflection Plate
Focusing System
Heating Filament
Cathode
Control Grid
Accelerating System
Electron Beam
Vertical Deflection Plate
Phosphor-Coated Screen

The cathode-ray tube CRT



Color CRT (Shadow Mask)

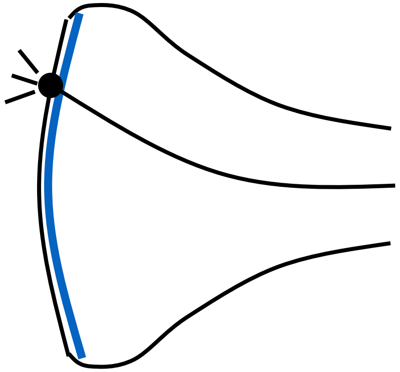




Phosphor dot pattern

Different phosphor for each color !!!

- When hit by an electron beam, phosphor emits light according to the quantum theory



persistence: **How long a phosphor continues to emit light after the electron beam is removed**

Persistence $\uparrow$ **Refresh rate** $\downarrow$

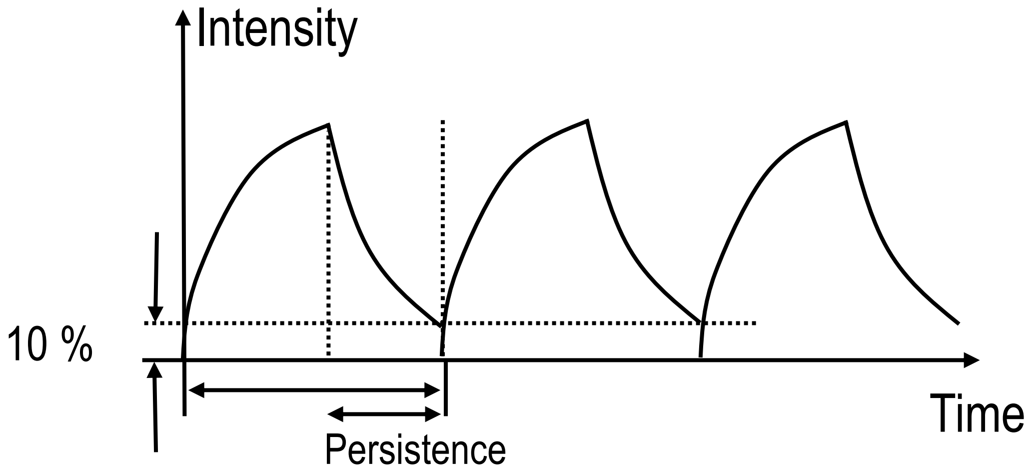
Is higher persistence always better ?

No !!!

Why ?

The persistence **of a phosphor is defined as** the time **it takes for emitted light to decay to** 1/10 **of its original intensity**

Refreshing



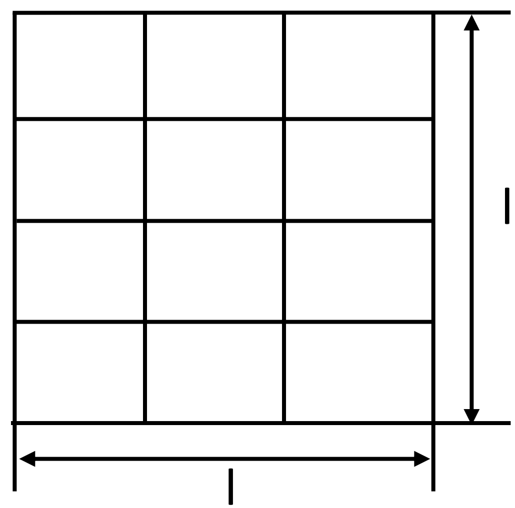
Refresh rate

- # of times/sec a picture is redrawn
- 60 Hz for raster scan displays

Aspect Ratio

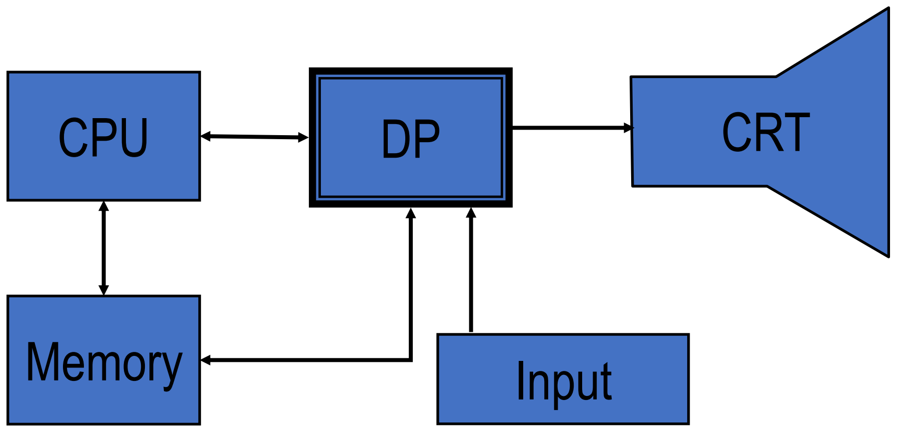
The aspect ratio **of a display device is the ratio of the number of *vertical* points to that of *horizontal* points necessary to produce equal length of lines in both direction on screen**

4/3 = 1.33...



Note: **Sometimes, aspect ratio is stated in terms of the ratio of *horizontal* to *vertical* points 3/4 = 0.75**

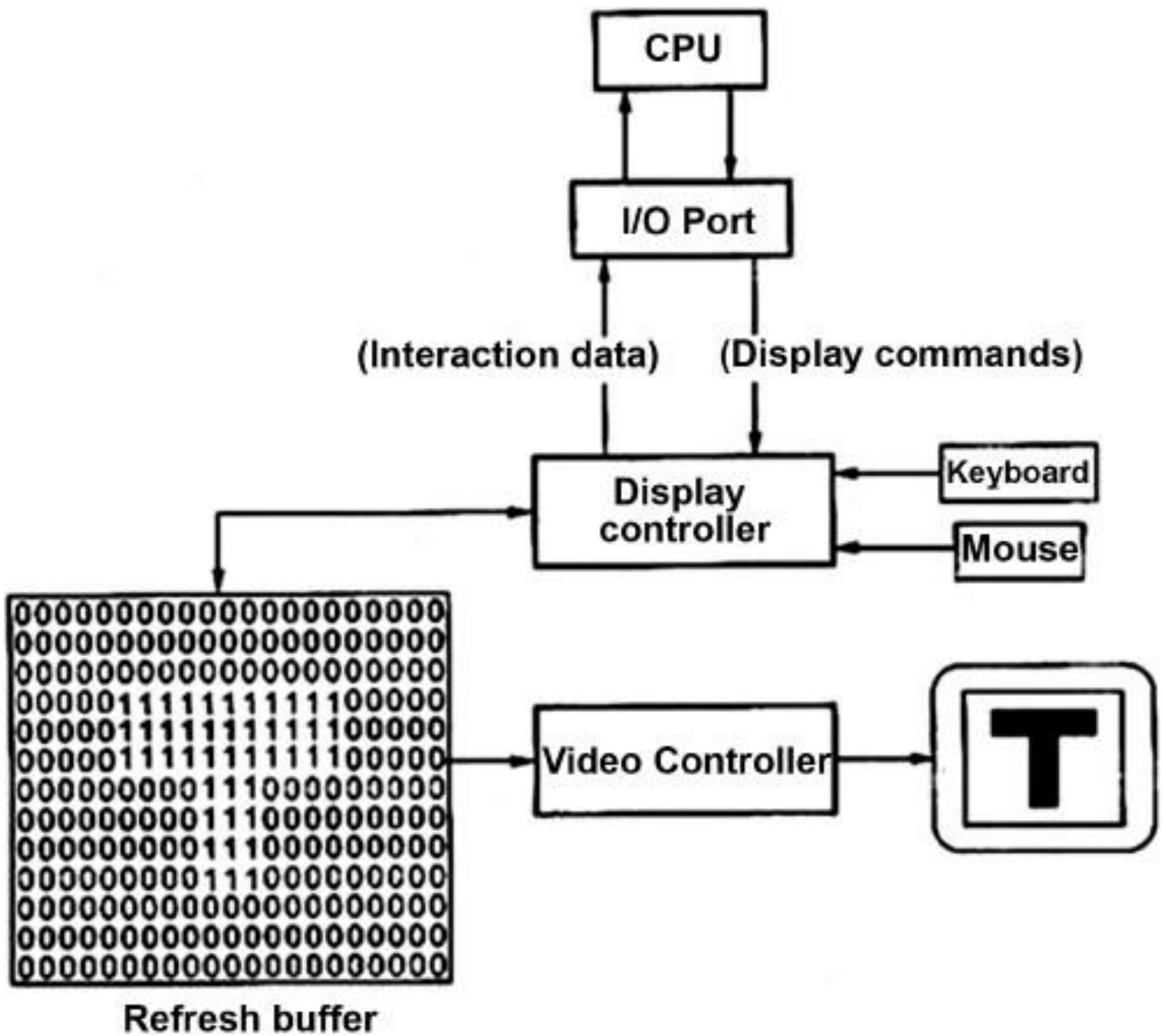
DP (Display Processor)



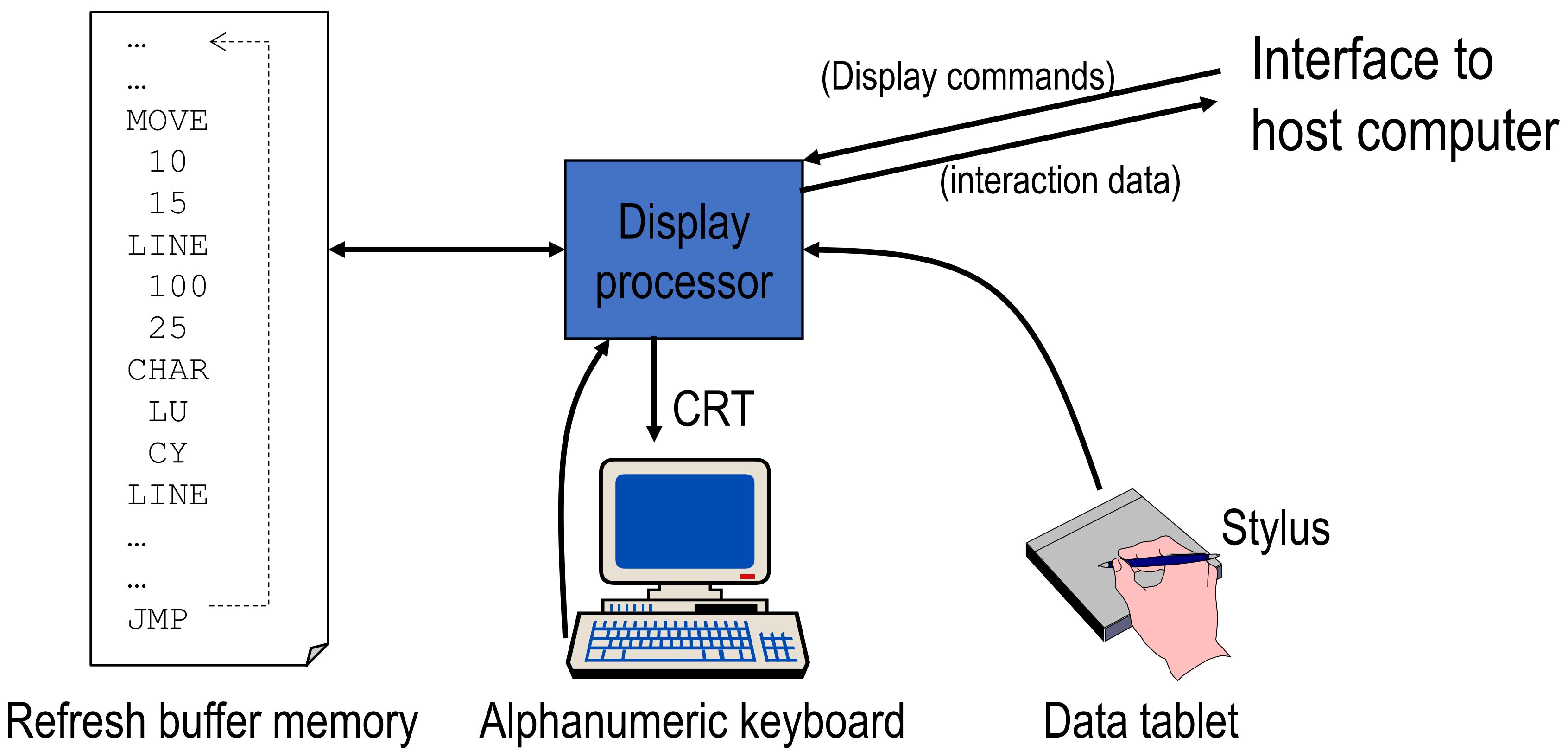
Why DP ?

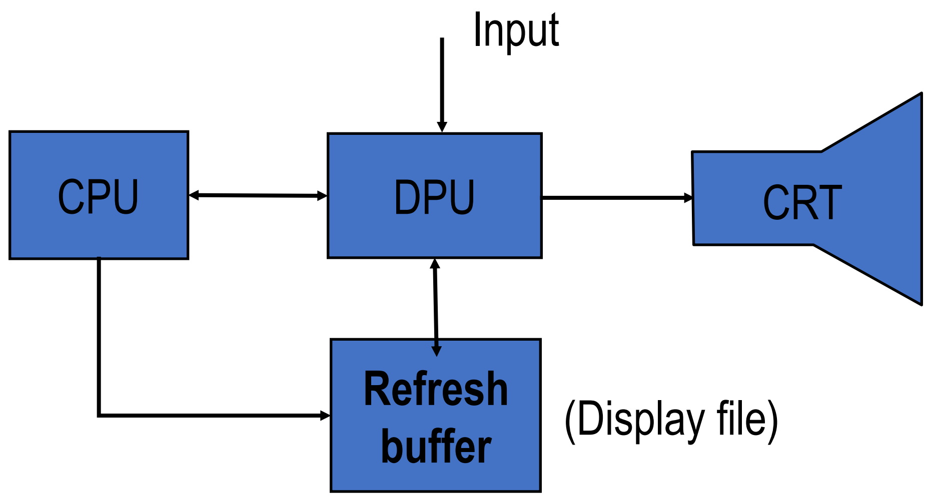
- Scan conversion
- Refreshing
- Raster operations
- Character generation
- Interfacing with interactive input devices

Rastar Scan Display



Refresh CRT (Vector CRT)





What is the display file ?

DPU program !!!

What if a picture is complicated ?

Longer DPU program !!!

The size of the refresh buffer limits the complexity of a picture

A complex picture **may cause** flickering **!!!**

Dynamic picture update

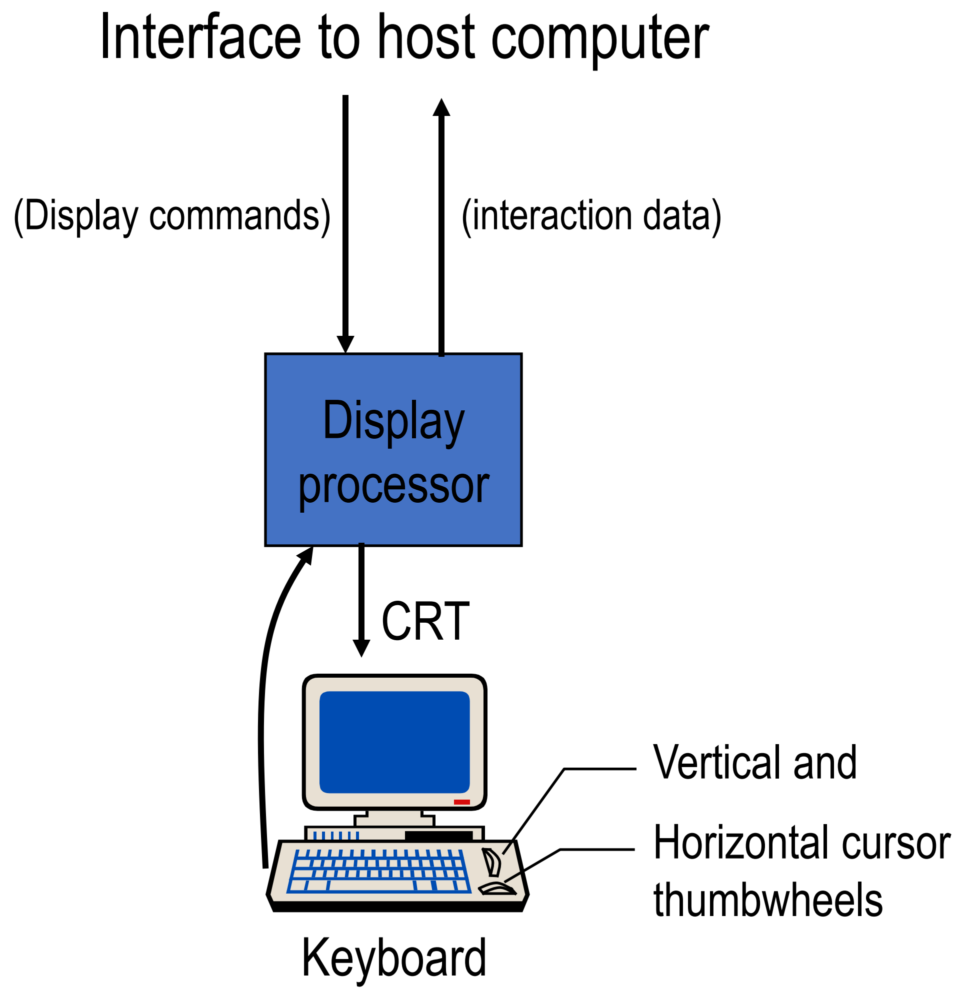
Selective erasing

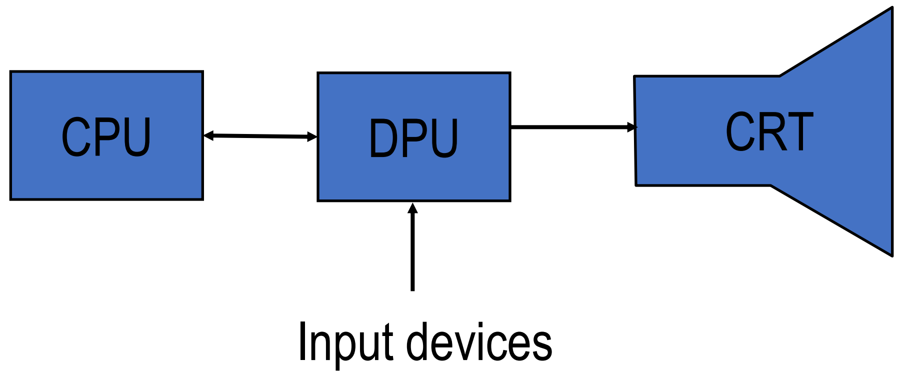
30 frame / sec

depending on the complexity of a picture

Refresh rate

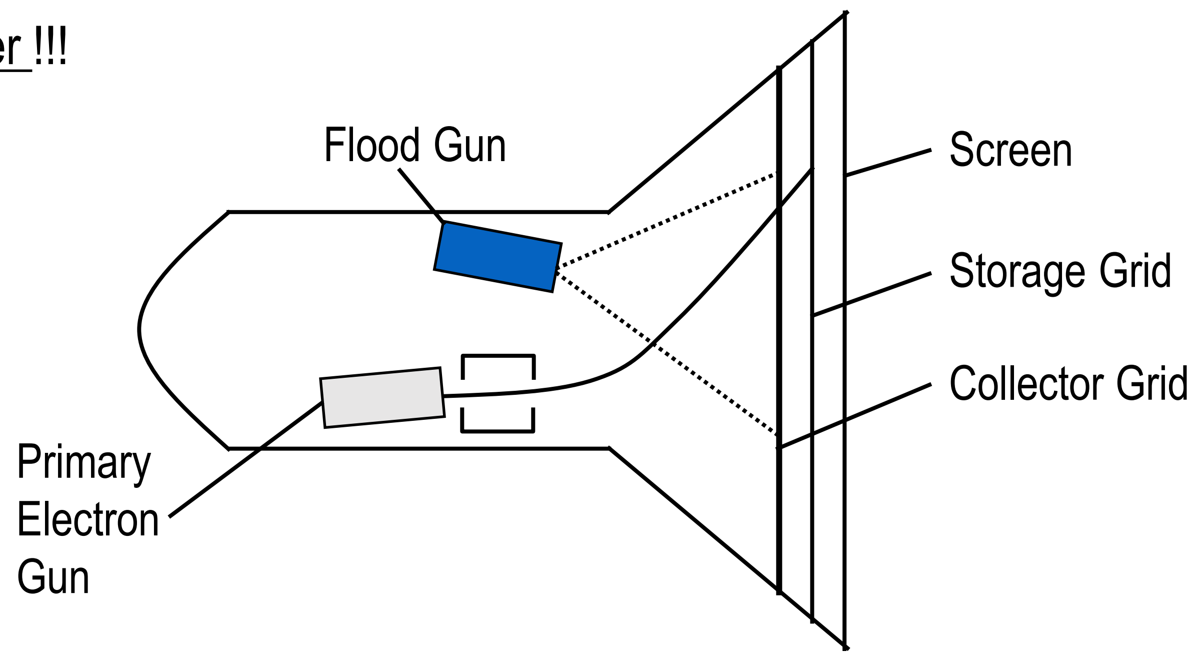
DVST (Direct View Storage Tube)



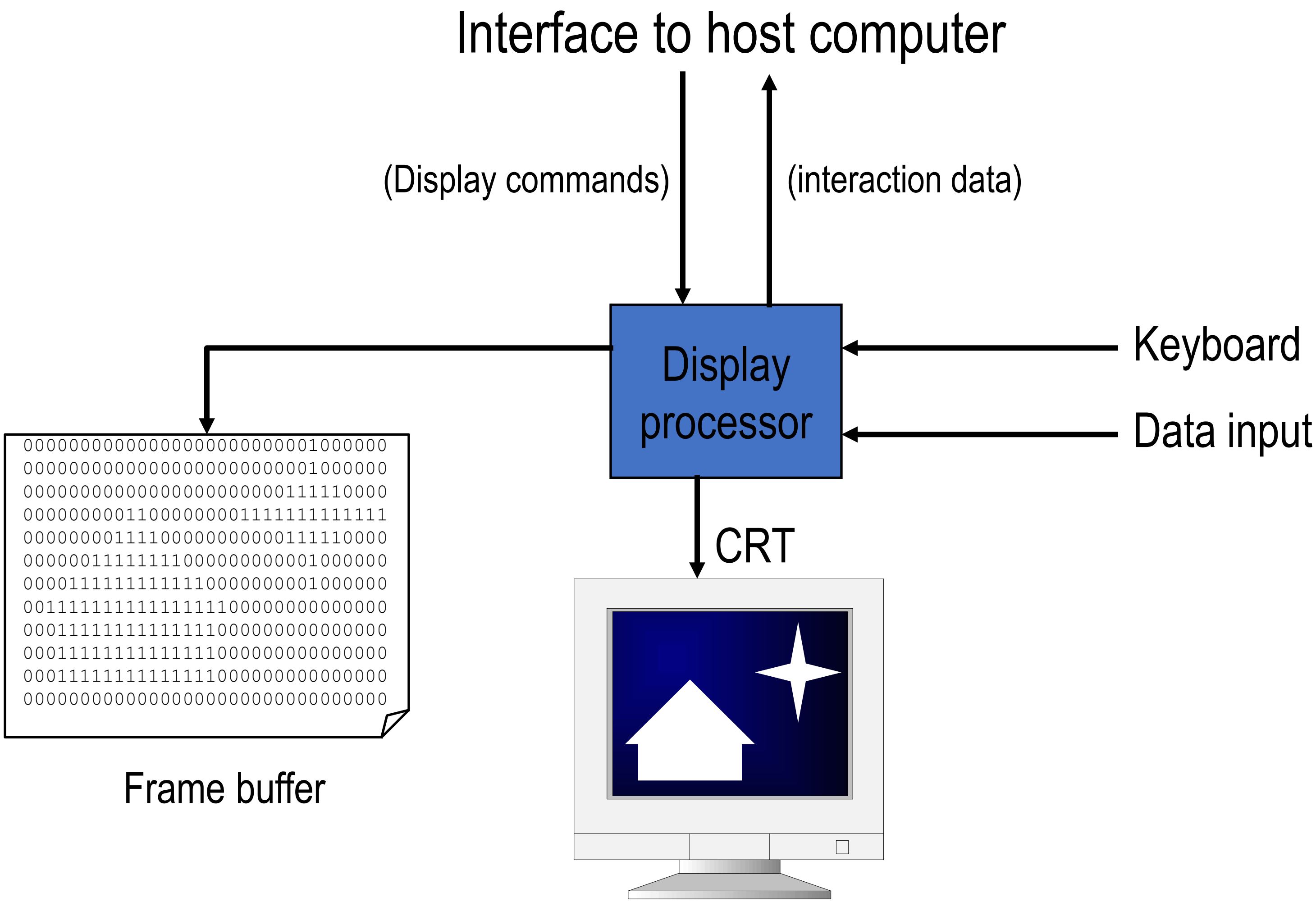


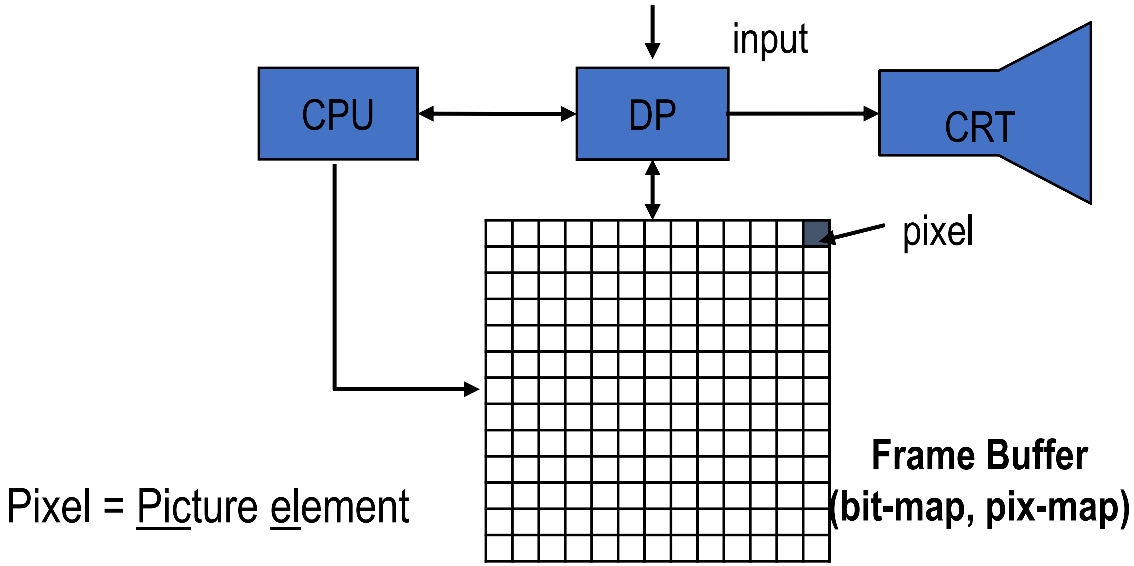
No refresh buffer !!!

Why ?

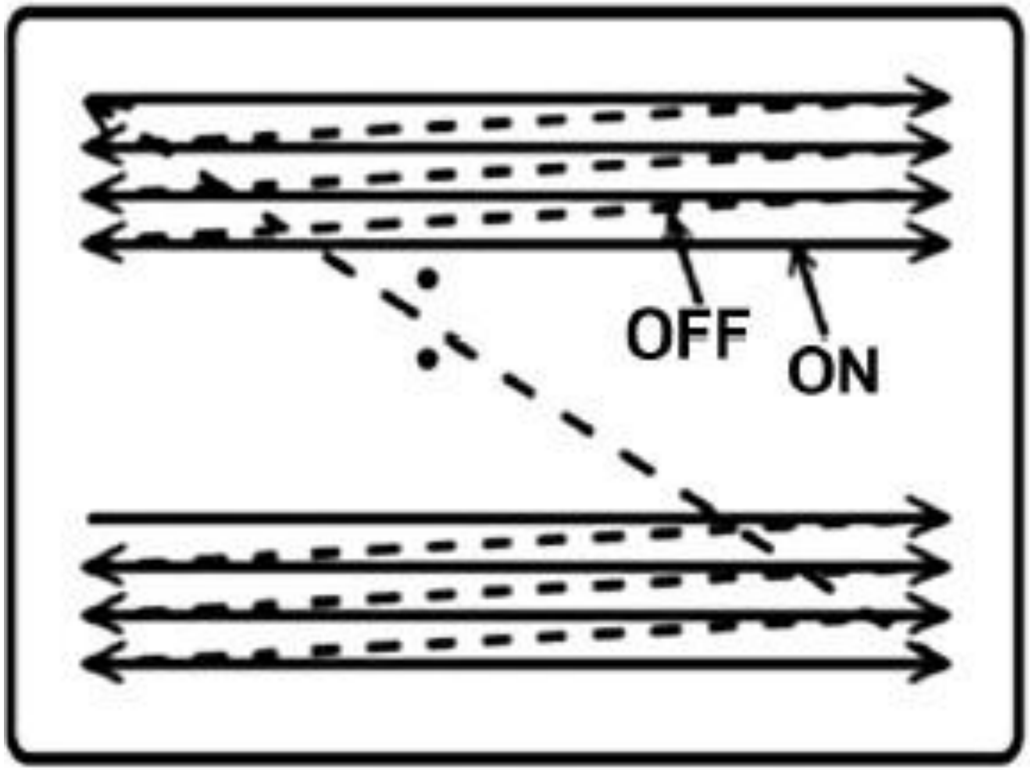


Raster-Scan Display

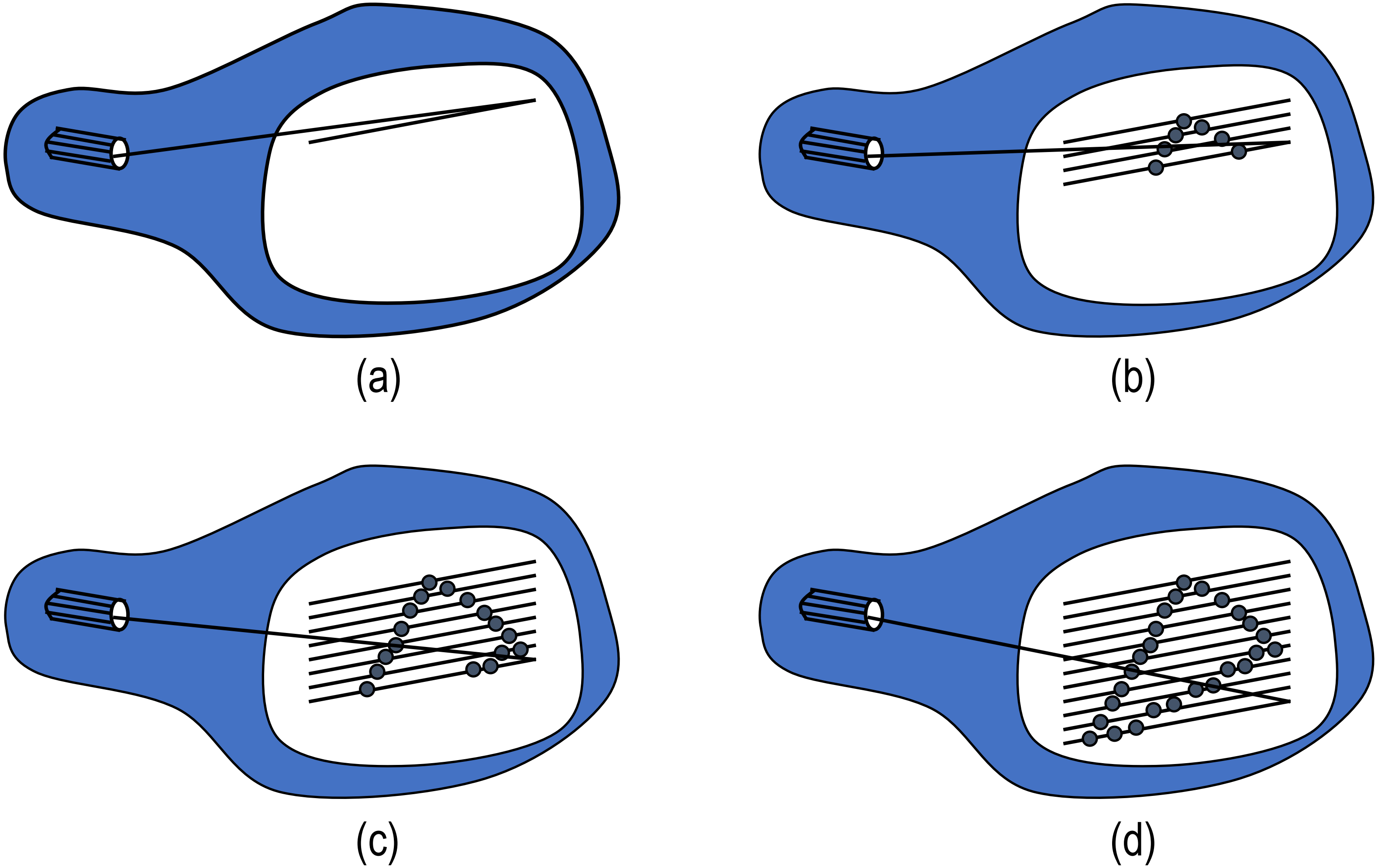




Selective erasing
Fixed frame buffer size
Independent of picture complexity

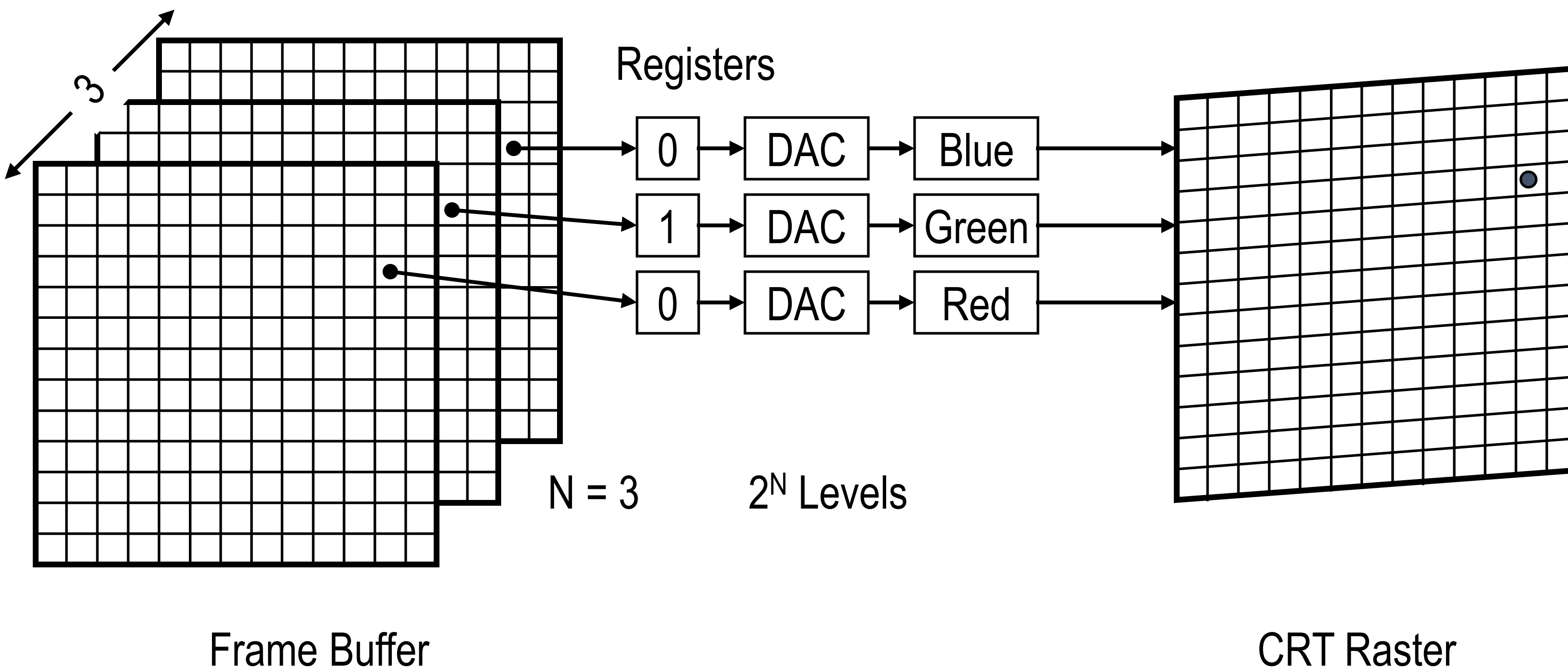


Raster scan CRT



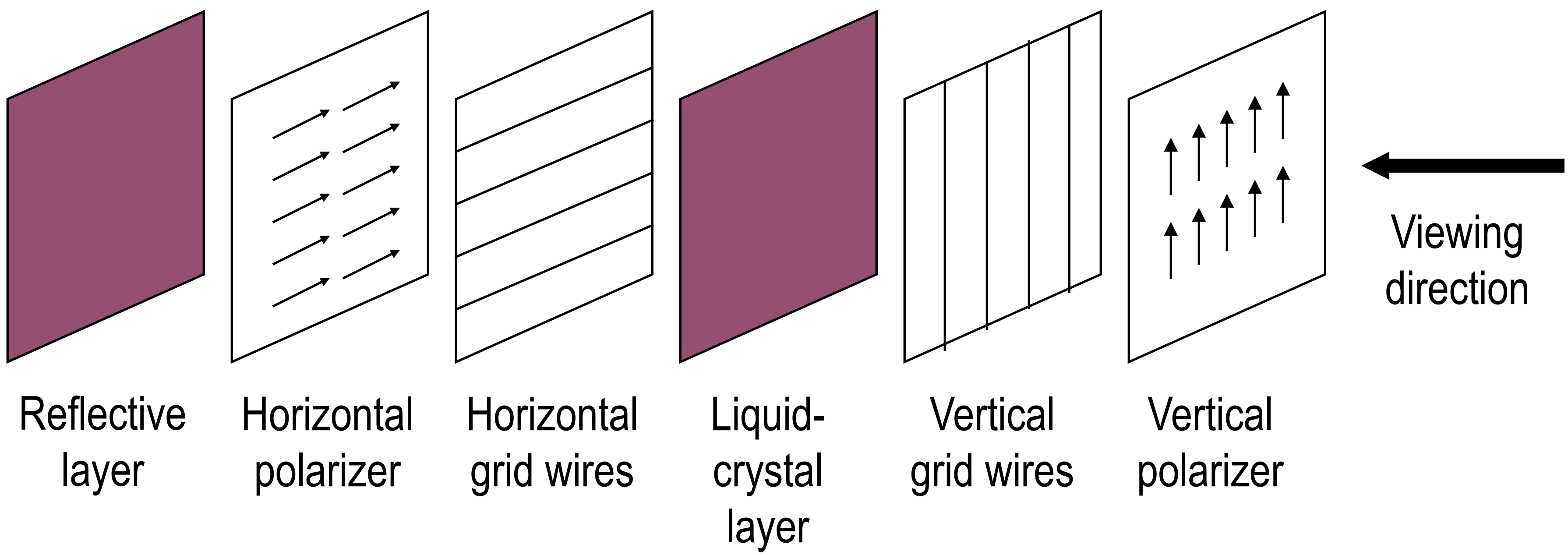
A raster-scan system displays an object as a set of points across each screen scan line

	Red	Green	Blue
Black	0	0	0
Red	1	0	0
Green	0	1	0
Blue	0	0	1
Yellow	1	1	1
Cyan	0	1	1
Magenta	1	0	1
White	1	1	1



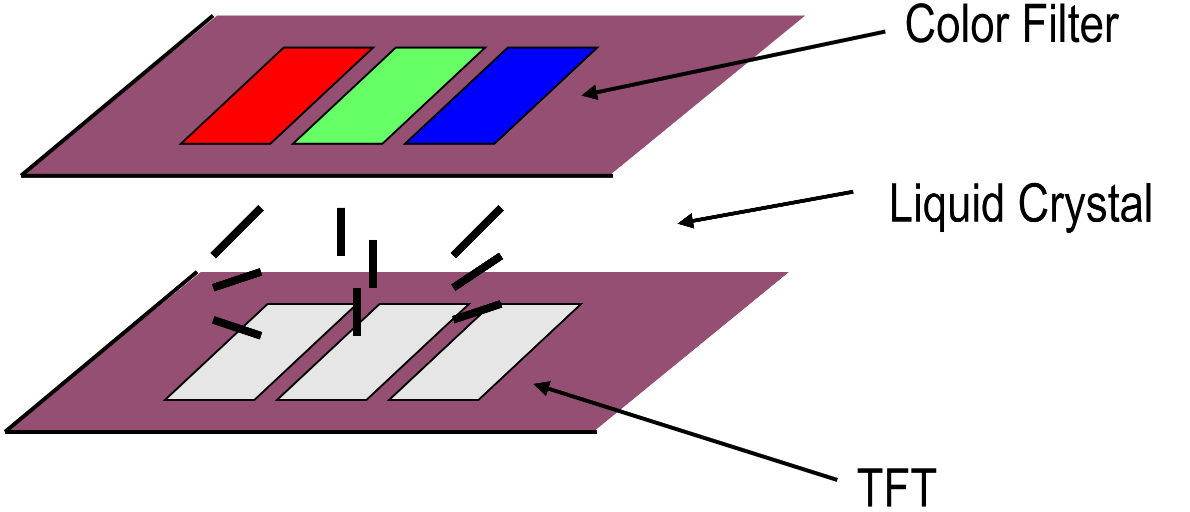
- Other Display Devices
  - Plasma-Panel Displays
  - Laser Devices
  - Three-Dimensional Monitors

LCD (Liquid Crystal Display) Basics



Color TFT (Thin Film Transistor) LCD

Color ?

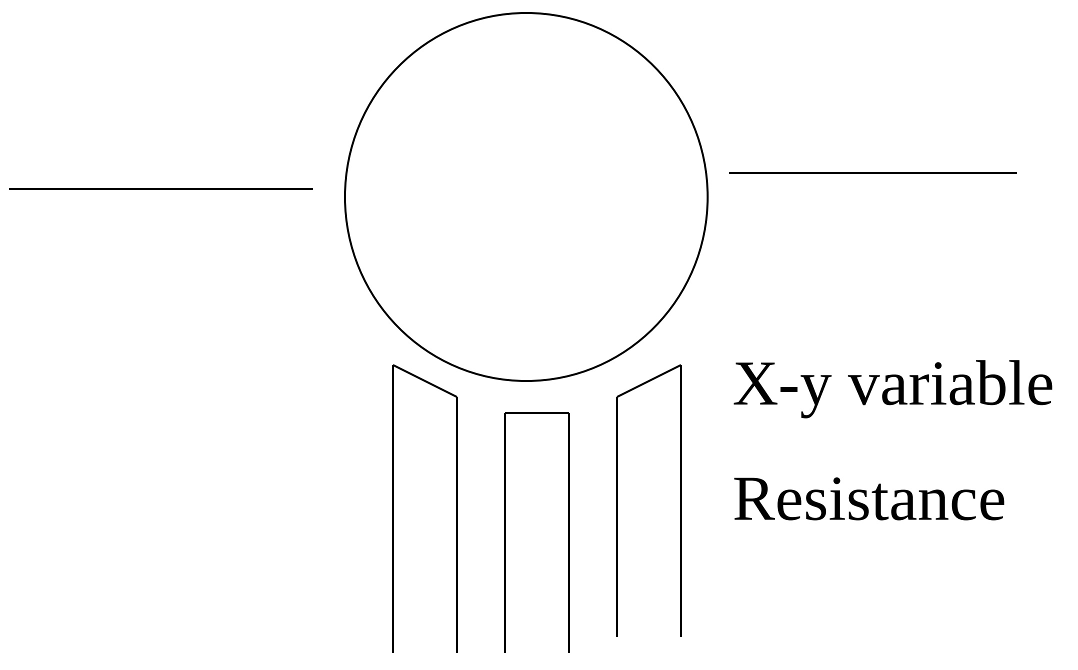


TFT (Thin Film Transistor)

- using a transistor at each grid point
- causing the crystals to change their state quickly
- controlling the degree to which the state has been changed
- holding the state until it changes

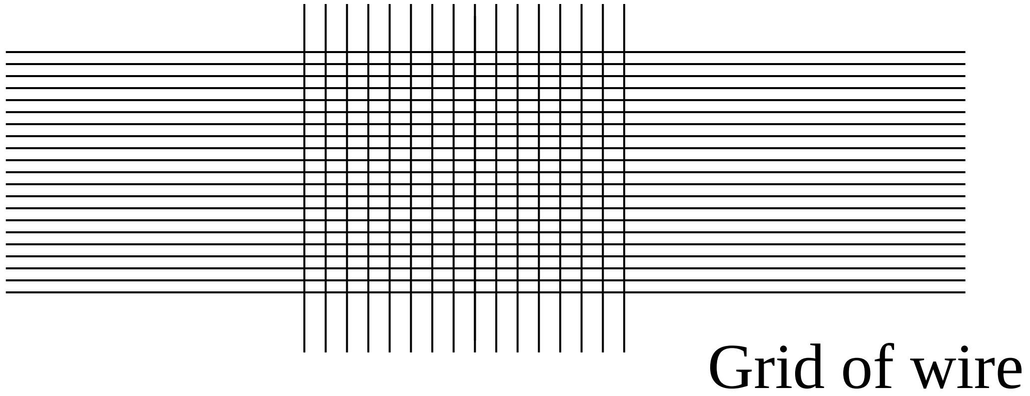
INPUT OUTPUT DEVICES

- Input devices
  - Analog type:mouse (ball type)
  -



- Track ball
- Joy stick
- Digital type
- Light pen
  - Light sensitive diode to point the screen
  - Positioned is sensed on basis of when pen senses light

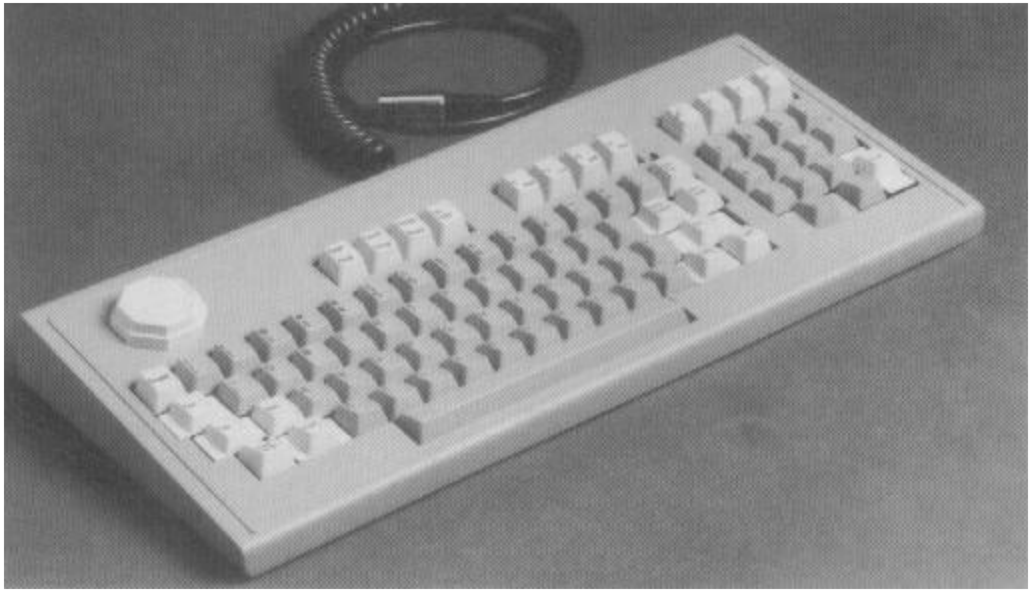
TABLET AND PEN



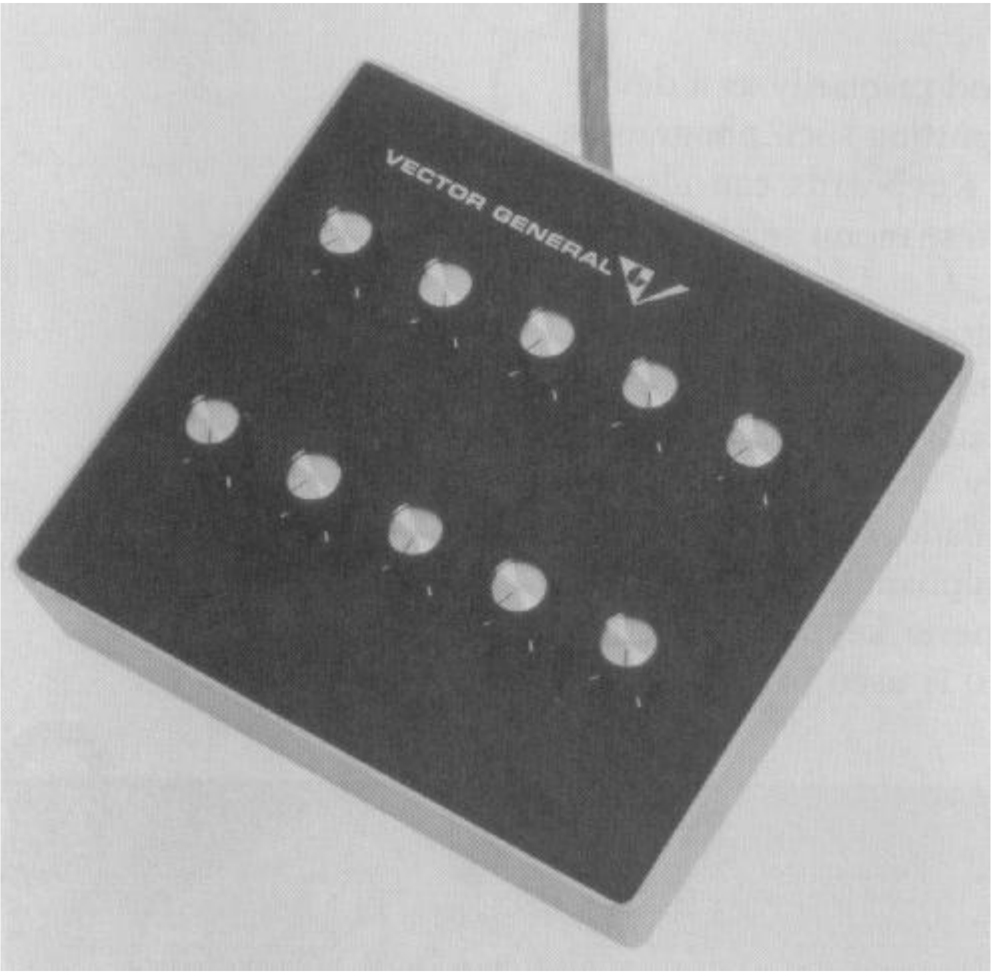
Pen emits radio frequency and intensity received by each wire tells the position

Input Devices

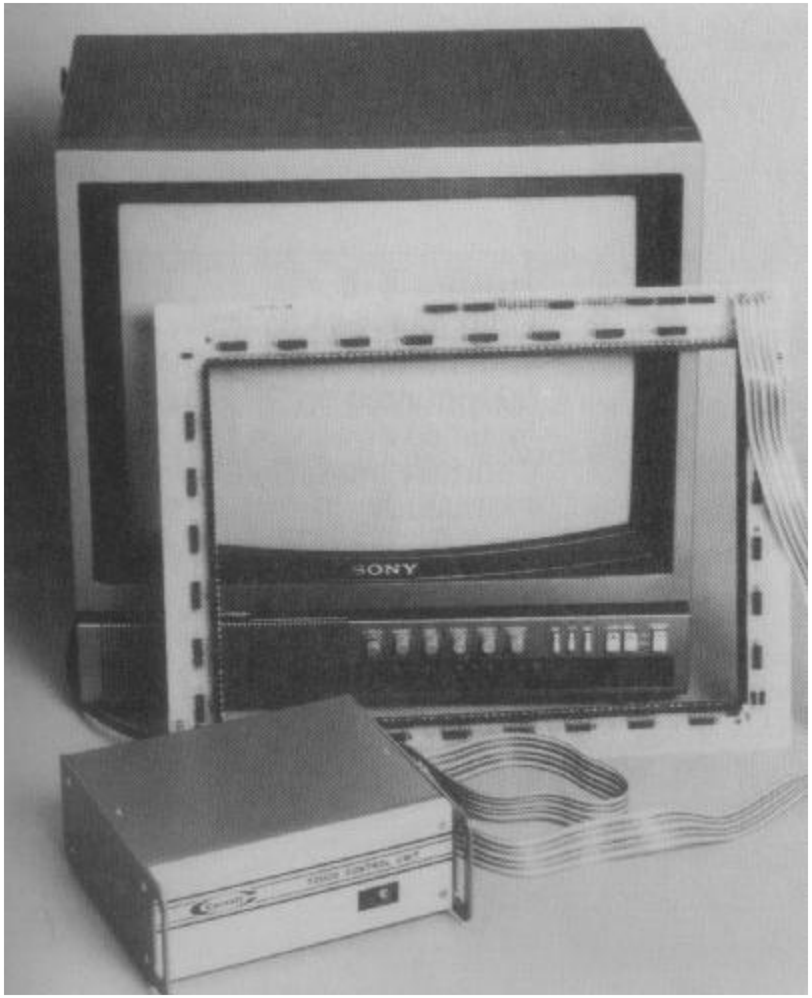
- Keyboards



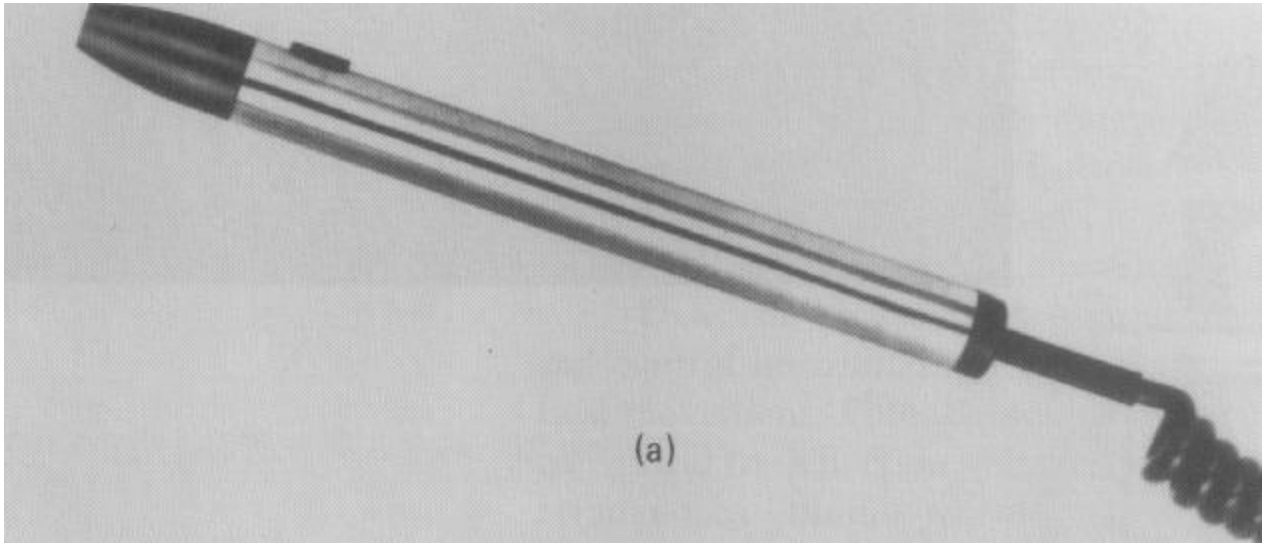
• Dials



- Touch Panels

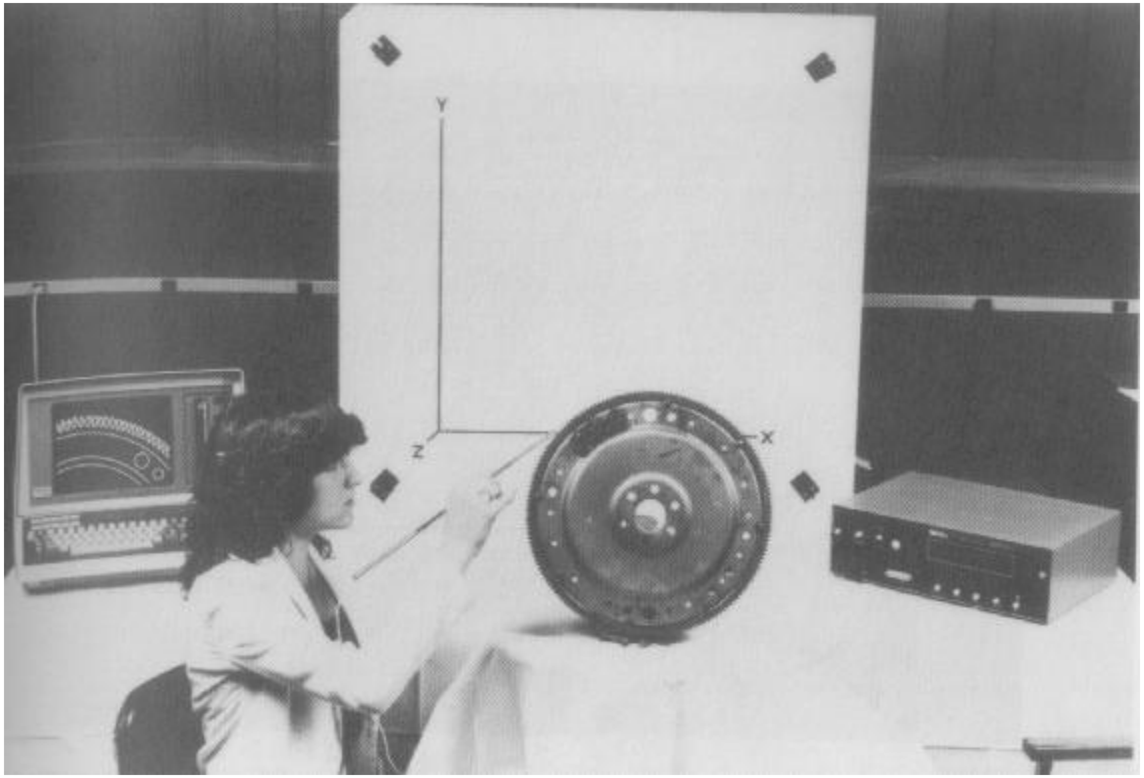


- Light Pens

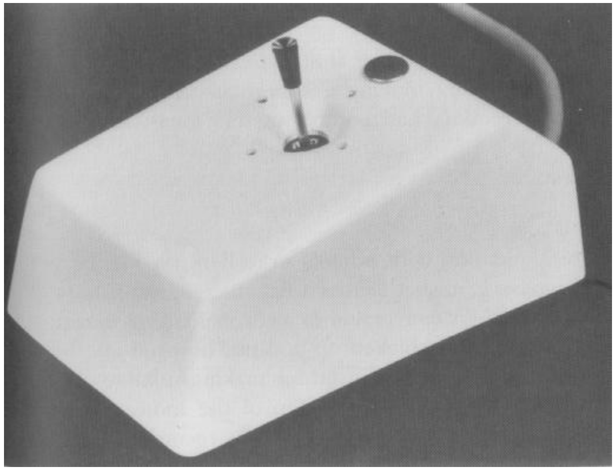


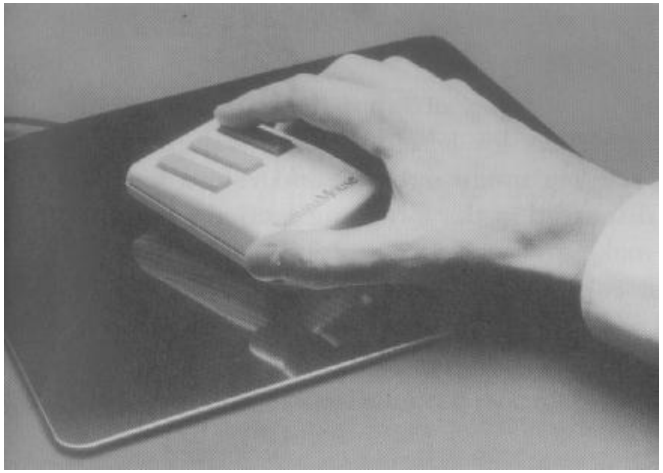
• Graphics Tablets

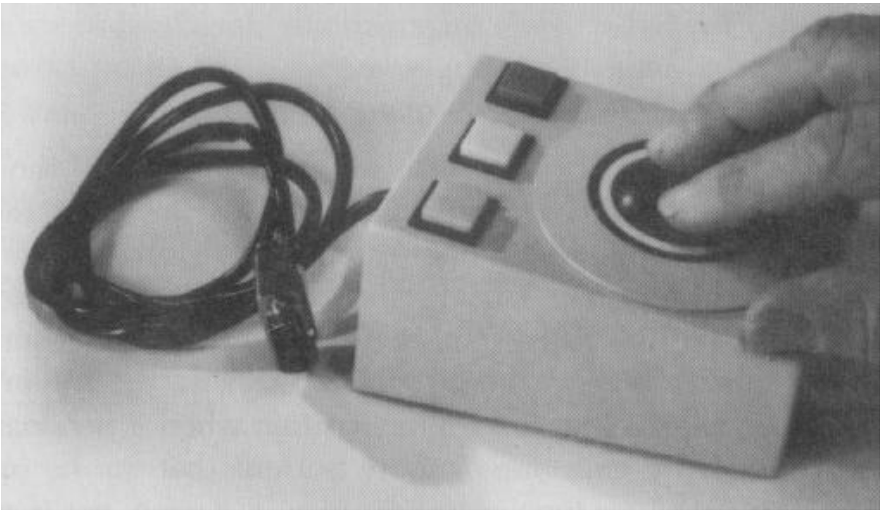
- 3D-Tablets



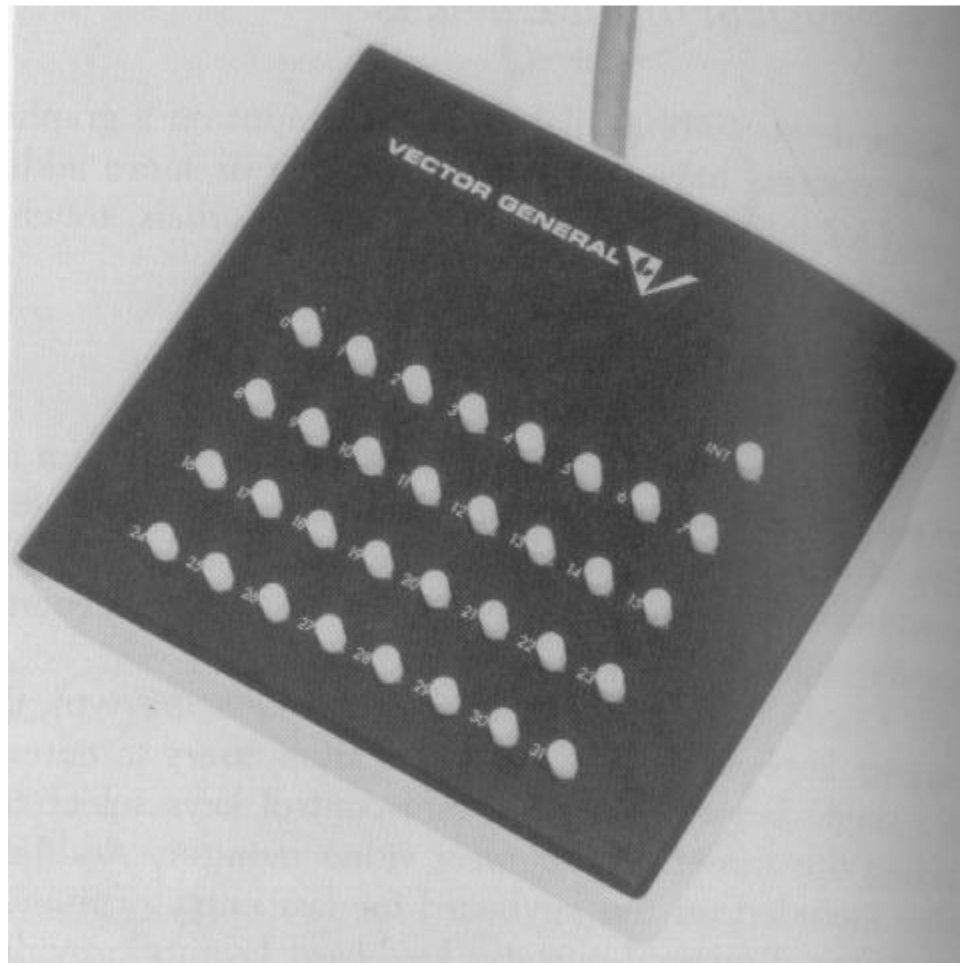
•Joysticks / Mice / Trackballs







• Buttons



- Voice Systems

- Hard Copy Displays
  - Printers
  - Plotters
  - 3D-printers

HARDCOPY AND OUTPUT DEVICES

- Flat bed plotters
  - Pen
  - X-drive motor & Y-drive motor
  - Pen raise & lower mechanism
  - Controller

  - Drum plotter
    - Pen
    - Raise and lower mechanism

- X-drive(for pen) & Y drive(for drum) motors
- Controller
- Printers
  - DMP
  - Laser
  - Inkjet

Lecture 13 & 14

Introduction to CAM

Basic concepts of NC system

NC Procedure

NC co-ordinate systems

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HISTORICAL DEVELOPMENT

- 15th century - machining metal.
- 18th century - industrialization, production-type machine tools.
- 20th century - F.W. Taylor - Tool metal - HSS

Automated production equipment -

Screw machines

Transfer lines

Assembly lines

using cams and preset stops

Programmable automation -

NC

PLC

Robots

Numerical Control
Definition and Applications

Introduction

The subject of this lecture is the interface between CAD and the manufacturing processes actually used to make the parts, and how to extract the data from the CAD model for the purpose of controlling a manufacturing process.

Getting geometric information from the CAD model is of particular relevance to the manufacture of parts directly by machining (i.e. by material removal), and to the manufacture of tooling for forming and molding processes by machining. The use of numerical information for the control of such machining processes is predominantly through the numerical control NC of machines.

Definition and Applications

Fundamentals of numerical control

Today numerically controlled devices are used in all manner of industries. Milling machines manufacture the molds and dies for polymer products. Flame cutting and plasma arc machines cut shapes from large steel plates. Lasers are manipulated to cut tiny cooling holes in gas turbine parts. Electronic components are inserted into printed circuit boards by NC insertion machines.

Numerical Control
Definition and Applications

Numerical Control NC is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumerical data.

Numerical control NC is any machining process in which the operations are executed automatically in sequences as specified by the program that contains the information for the tool movements.

The alphanumerical data represent relative positions between a workhead and a workpart as well as other instructions needed to operate the machine.

The workhead is a cutting tool or other processing apparatus, and the workpart is the object being processed.

A Definition of NC

- Numerical Control is a system in which actions are controlled by the direct insertion of numerical data at some point.
- In other words, Programmable automation in which the mechanical actions of a ‘machine tool’ are controlled by a program
- or
- It is defined Method of programmable automation in which various functions of machine tools are controlled by numbers , letters and symbols.

Applications of Numerical Control

1. Machine tool applications, such as drilling, milling, turning, and other metal working
2. Nonmachine tool applications, such as assembly, drafting, and inspection.

- The common operating feature of NC in all of these applications is control of the workhead movement relative to the workpart.

CNC TURNING

CNC MILLING

CNC LASER CUTTING

CNC PLASMA CUTTING

In NC machine numbers form of program of instructions are:

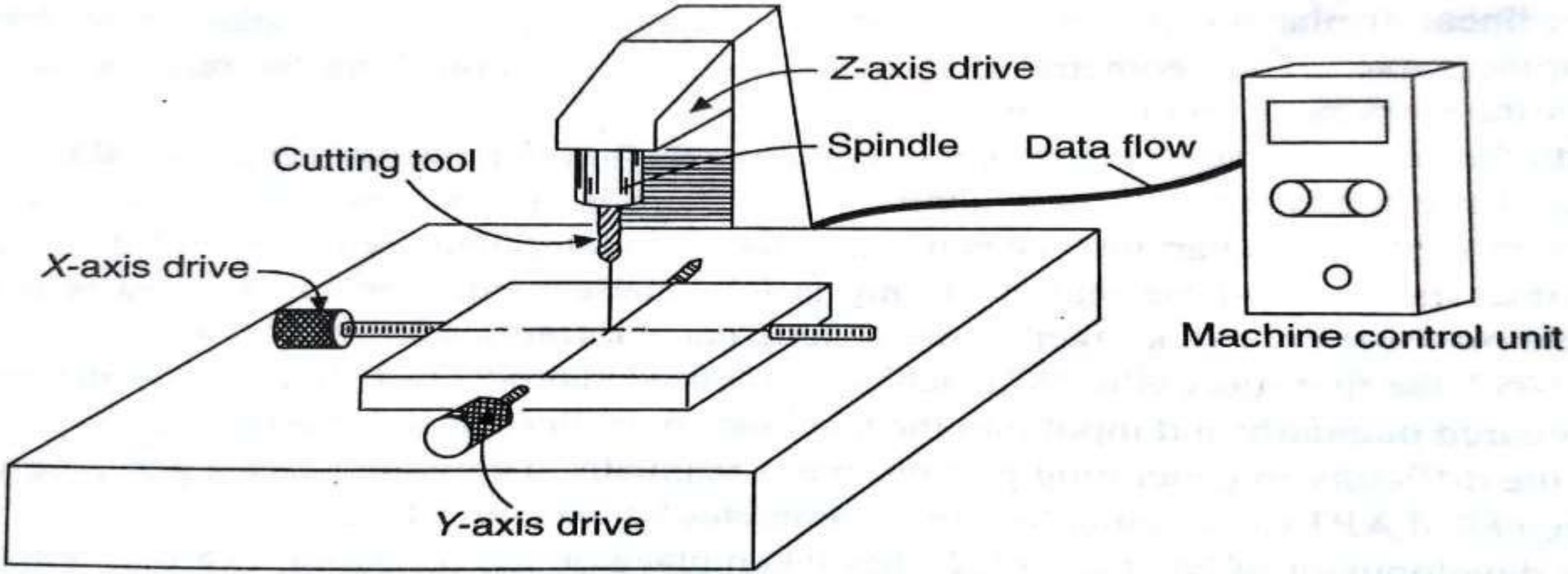
1. TO Start (or) Stop the machine tool spindle .
2. To control the spindle speed.
3. To change the tool.
4. To change the feed rate.
5. To switch the coolant on/off.
6. To position the tool at a desired position

Principle of operation:

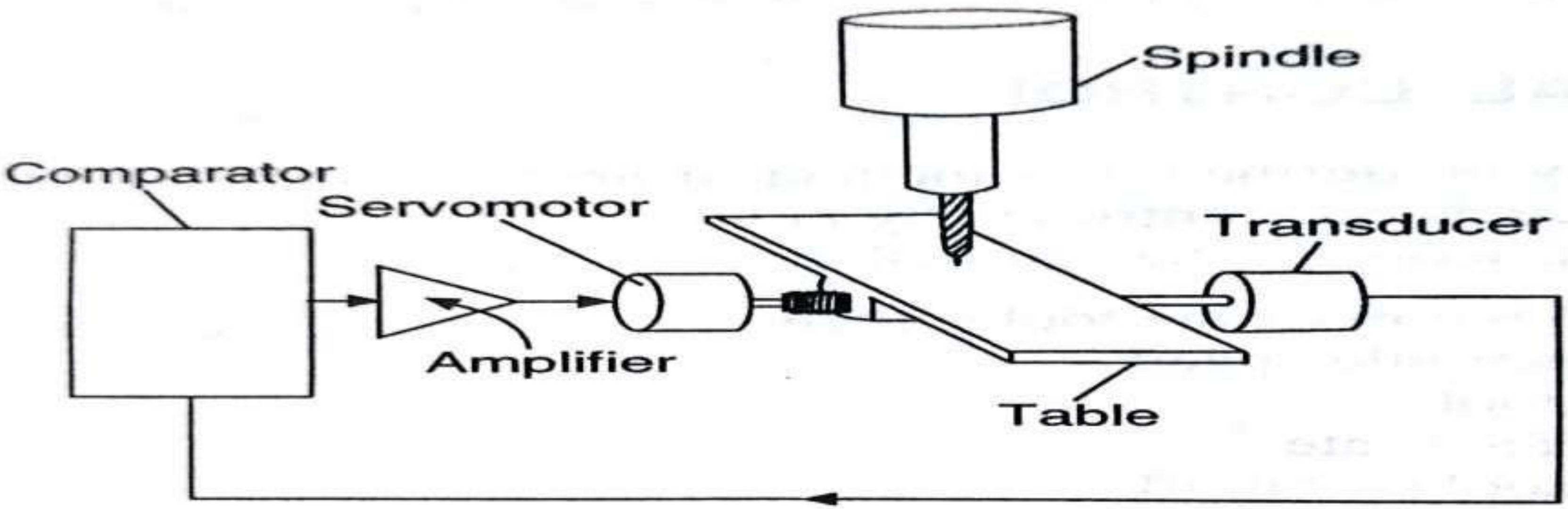
1.The program of instructions in terms of part geometry , cutting process parameters and type of tool serves as the input of machine control unit (MCU) which in turns commands the machine tool to make the product.

2.The machine axes are connected to servomotors , which work under the control of the machine control unit (MCU)

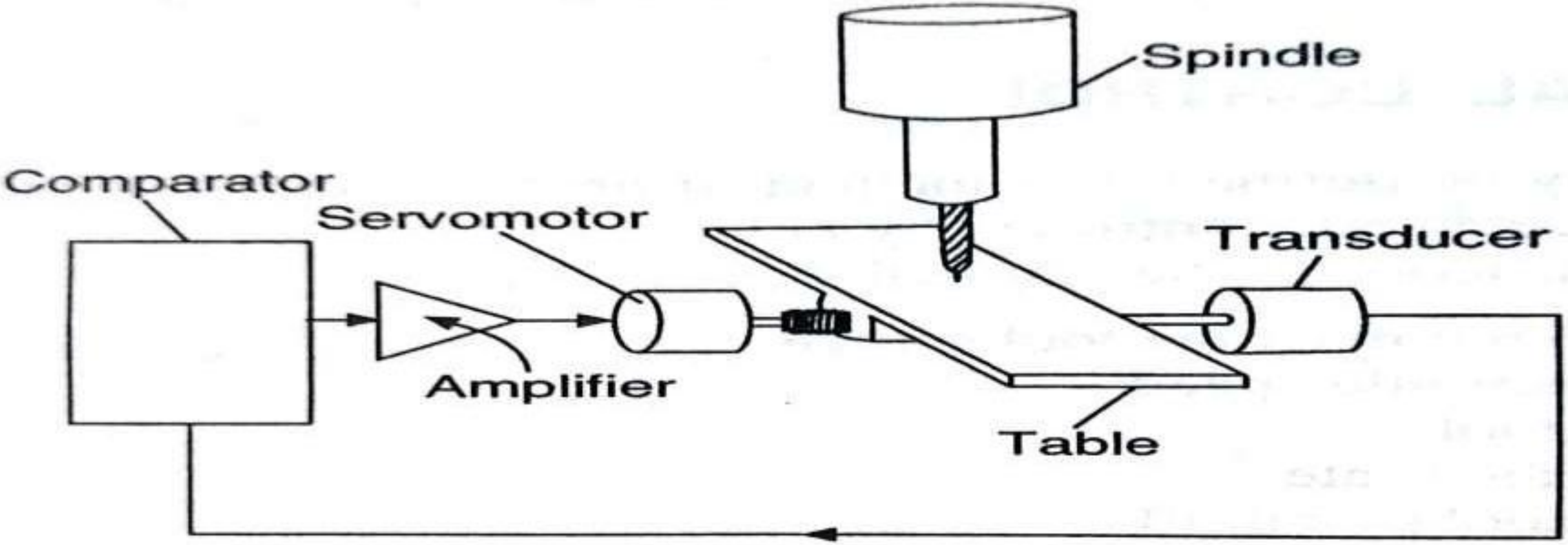
3.The servomotors control the movement of the cutting tool with respect to work piece.



Principle of operation of an NC machine.

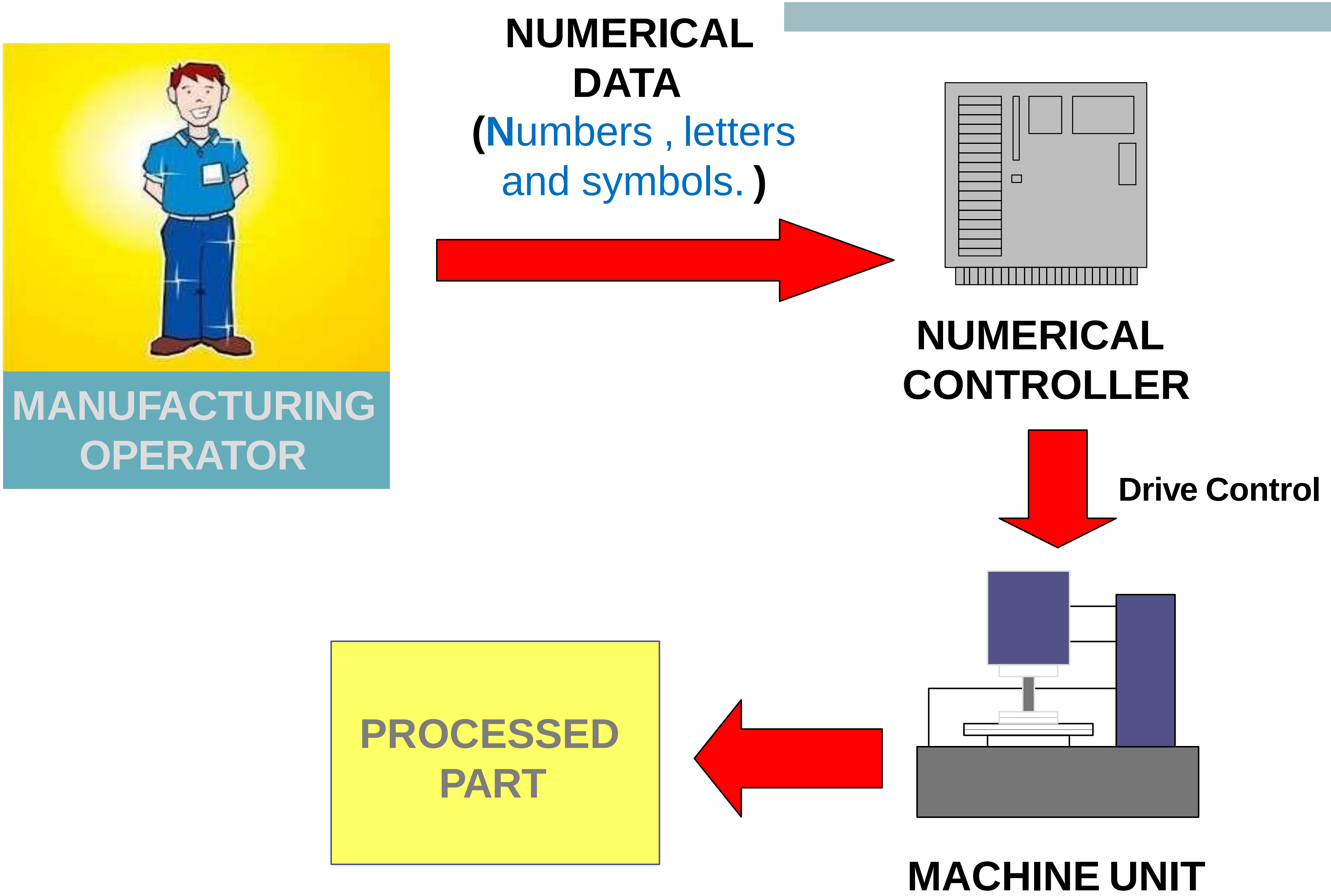


Control of an axis in an NC machine tool.



Control of an axis in an NC machine tool.

1. The control of an axis in an NC machine as shown
2. It is a closed loop positioning system
3. The MCU Generates a pulse signal until the signal returned from the feed back transducer agrees with the original number of pulses requires to execute the movement.
4. The comparator compares the count of feedback pulses with the original number, and the error signal is the output until the table reaches the desired position.
5. Feed back transducers are linear/rotary encoders used to obtain the correct position or velocity feedback.


MANUFACTURING OPERATOR
NUMERICAL DATA
(Numbers , letters and symbols.)
NUMERICAL CONTROLLER
Drive Control
MACHINE UNIT
PROCESSED PART

NC Procedure

1. Process Planning
2. Part Programming
3. Tape Preparation
4. Tape Verification
5. Production

NC Procedure

1. Process Planning:

- The drawing of work part must be interpreted in terms of manufacturing processes to be used.
- This step is referred as process planning and it is concerned with route sheet.
- The route sheet is listing of the sequence of operations which must be performed on work part.
- It is called rout sheet because it also lists machines through which the part must be routed .

NC Procedure

2. Part Programming:

The programmer plans the sequence of machining steps to be performed by NC and to document these in in a special format. The are two ways of programming:

- Manual part programming:
  The machining instructions are prepared manually on a form called program manuscript.
- Computer assisted part programming:
  Machining instructions are created with the aid of computer. This saves much time and is useful for complex parts.

NC Procedure

3. Tape Preparation:

• In manual programming, the punched tape is prepared directly from the part program manuscript on a type-writer like device equipped with the tape punching capability.

• In computer-assisted programming, the computer interprets the list of part programming instructions, performs the necessary calculations to convert this into a detailed set of m/c tool motion commands, and then controls a tape punch device to prepare tape for specific NC m/c.

NC Procedure

4. Tape Verification:

After the punch tape has been prepared, a method is usually provided for checking accuracy of tape. Some time the tape is checked by running it through a computer program which plots various tool movements (or table movements).

In this way, major errors in tape can be discovered. Another method is Acid test.

In this test, foam or plastic material is used to make a part. Then the error can be detected easily.

5. Production:

The final step in NC procedure is to use NC tape in production. Raw material is clamped in fixture, tools are selected and holded in spindle. The zero point on job is selected and machining is begun.

NC Coordinate Systems

In machine tools the cutter may typically move in multiple directions with respect to the workpiece, or vice versa, and therefore the controller normally drives more than one machine axis. Examples of machine applications and numbers of axes are as follows:

1. 2-axis motion, generally in two orthogonal directions in a plane, which applies to most lathes as well as punch presses, flame and plasma-arc and cloth cutting machines, electronic component insertion and some drilling machines.
2. 3-axis motion, which is generally along the three principal directions (x, y and z) of the Cartesian coordinate system, and applies to milling, boring, drilling and coordinate measuring machines.
3. 4-axis motion typically involves three linear and one rotary axis, or perhaps two x-y motions, as for example for some lathes fitted with supplementary milling heads.
4. 5-axis machines normally involve three linear (x, y and z) axes, with rotation about two of these, normally x and y, and are generally milling machines.

NC Coordinate Systems

To program the NC processing equipment, a standard axis system must be defined by which the position of the workhead relative to the workpart can be specified. There are two axis systems used in NC, one for ***flat and prismatic workparts*** and the other for ***rotational parts***. Both axis systems are based on the Cartesian coordinate system.

NC Coordinate Systems

- **Coordinate axes for flat and prismatic work**

  The axis system for flat and prismatic parts consists of three linear axes (x, y, z) in the Cartesian coordinate system, plus three rotational axes (a, b, c). In most machine tool applications, the x-and y-axes are used to move and position the worktable to which the part is attached, and the z-axis is used to control the vertical position of the cutting tool.

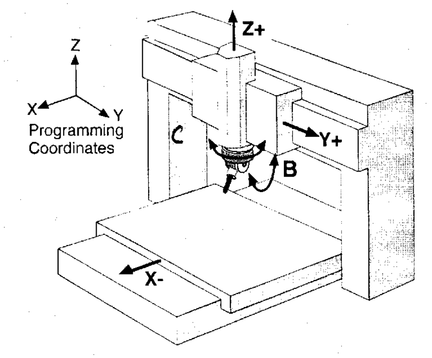
  The a-, b-, and c-rotational axes specify angular positions about the x-, y-, and z-axes, respectively.

The rotational axes can be used for:

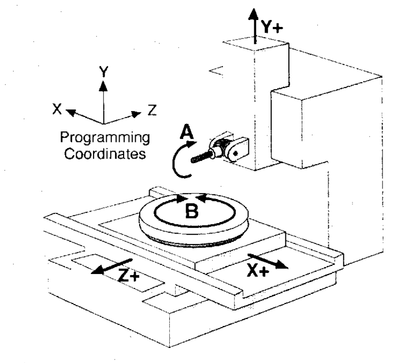
(1) Orientation of the workpart to present different surfaces for machining or

(2) Orientation of the tool or workhead at some angle relative to the part.

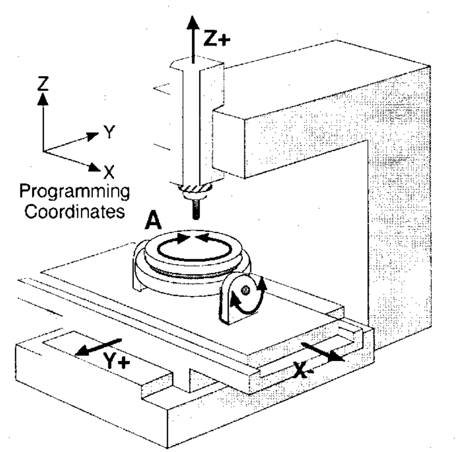
5-AXIS MACHINE CONFIGURATIONS



Rotational axes on the spindle



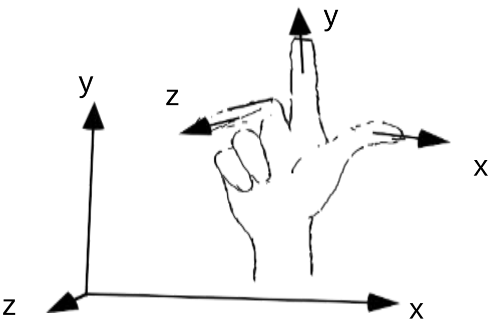
Rotational axes on spindle and the table

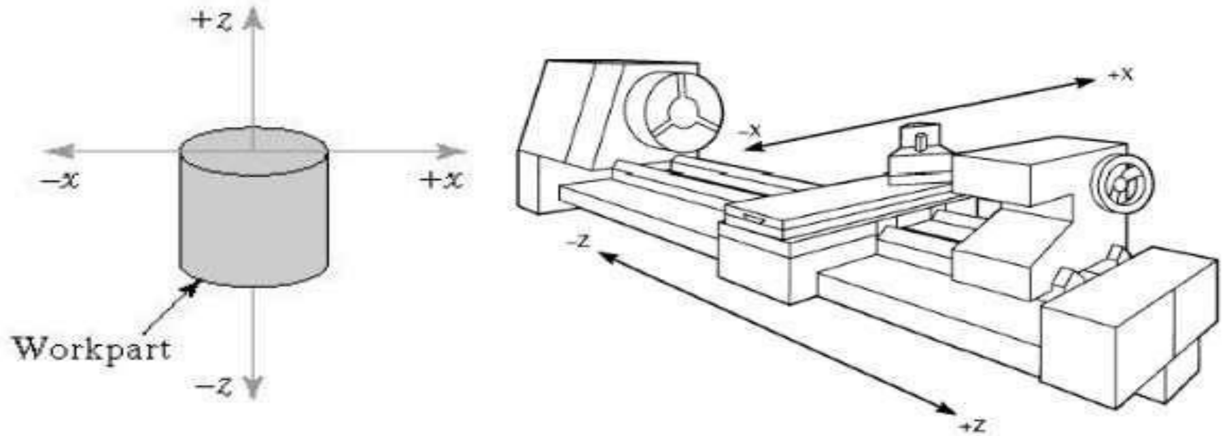


Rotational axes on the table

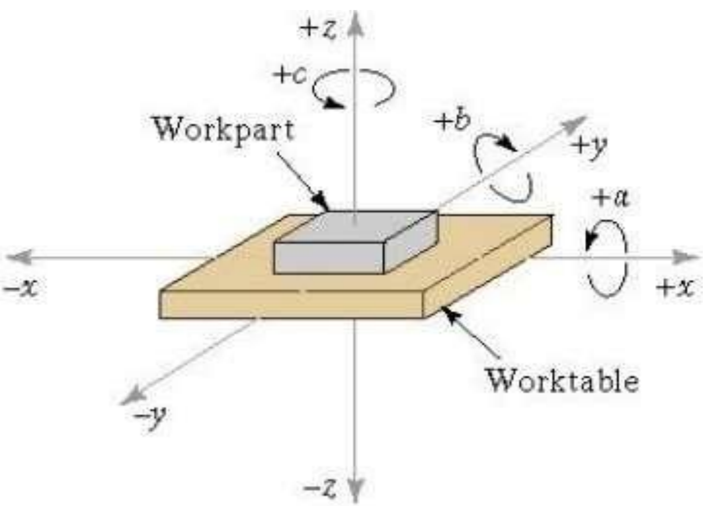
COORDINATE SYSTEMS

Right hand rule

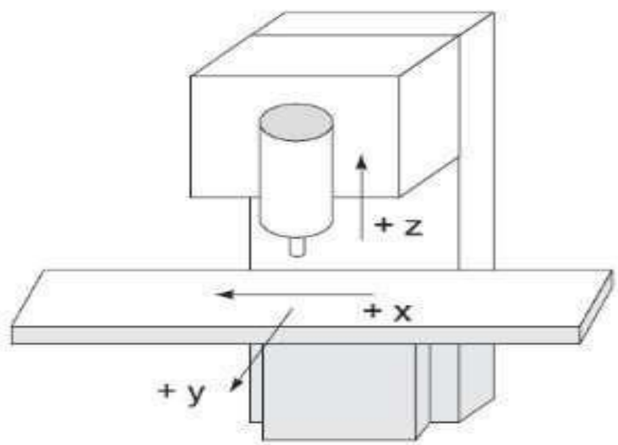




Coordinate System (Turning Operations)



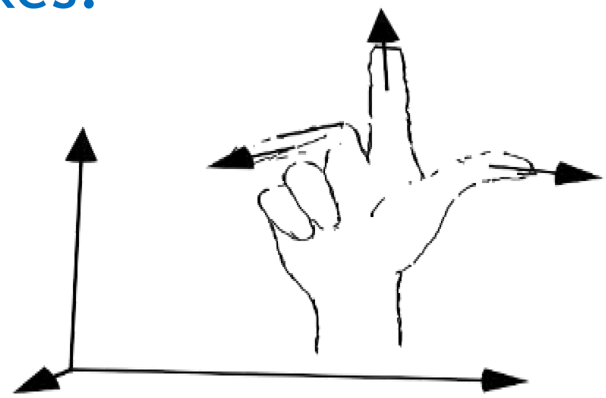
Coordinate System (Milling and Drilling Operations)



Coordinate System (Milling and Drilling Operations)

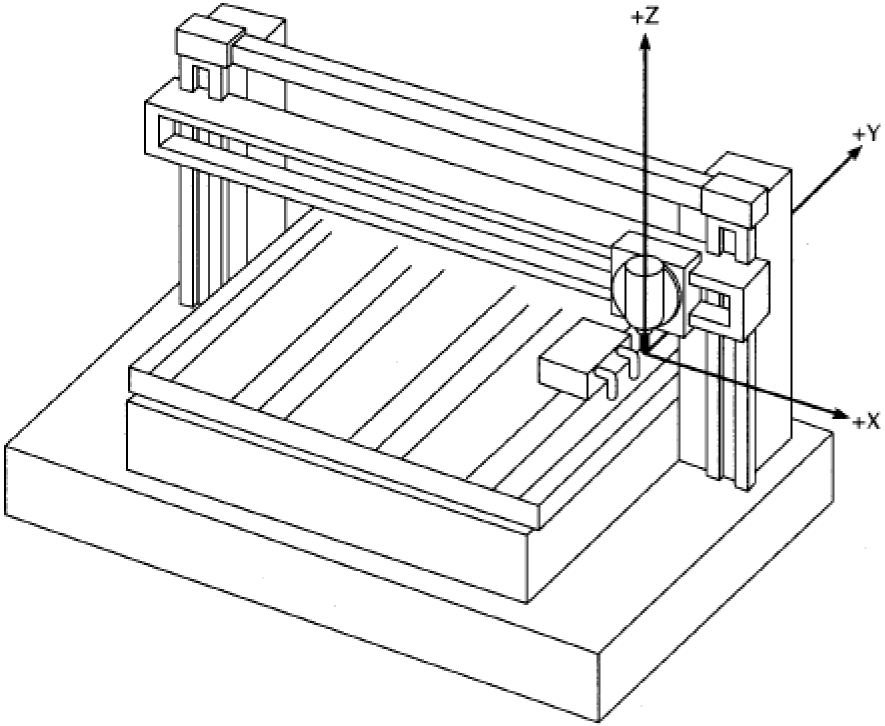
NC coordinate system :

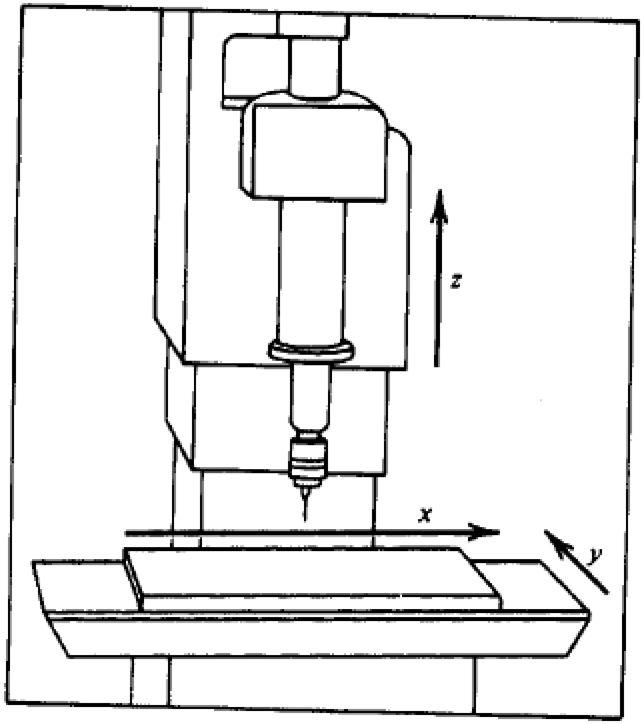
1. A Cartesian co-ordinate system consist of three axes positioned at 90^0 from each other.
2. the nomenclature of the three main axis (x , y, z) is based on the right hand rule.
3. (x ,y , z) axes are represented by the thumb , index and middle fingers of the right hand.
4. the right hand rule is used the positive direction of the co-ordinate axes.
5. the three rotational axes defined in NC are the a, b, c axes.



For Drilling and milling operations:

1. Two axes x and y are defined in the plane of the table and the z- axes is perpendicular to the plane and the movement in the z- direction is controlled by the vertical motion of the spindle.





NC Coordinate Systems

- **Coordinate axes for rotational work**

  The coordinate axes for a rotational NC system are associated with NC lathes and turning centers. *Although the work rotates, this is not one of the controlled axes on most of these turning machines.* Consequently, the y-axis is not used. The path of the cutting tool relative to the rotating workpiece is defined in the x-z plane, where the x-axis is the radial location of the tool, and the z-axis is parallel to the axis of rotation of the part.

NC Coordinate Systems

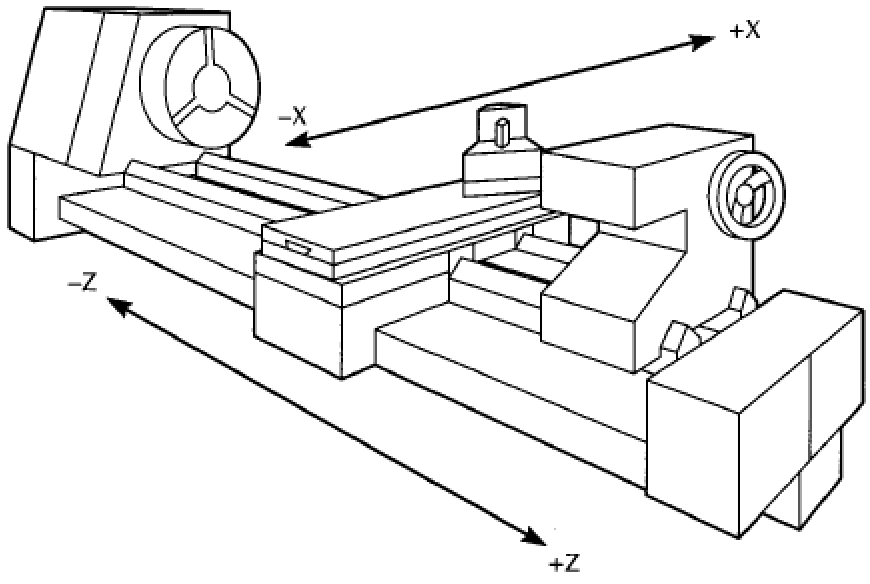
Coordinate axes for rotational work

Standard Lathe Coordinate System

For turning operations:

1. Two axes are normally required to control the movement of the tool relative to the rotating work piece.
2. The z- axis is the axis of rotation of the work piece

    and the x- axis radial location of the cutting tool.



Lecture 15 & 16

Introduction to CAM

Problems of conventional NC systems
CNC and DNC systems, their advantages, and applications

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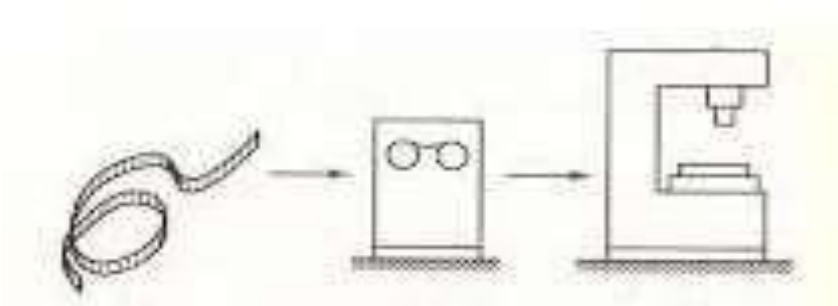
Types of Numerical Control

- Conventional Numerical Control (NC)
- Direct Numerical Control (DNC)
- Computer Numerical Control (CNC)

Conventional Numerical Control (NC)

- Data is sent to the machine tool by means of **punch cards or tapes**.
- The reader at the machine performs no calculations or interpolations.



11.8 ADVANTAGES OF NUMERICAL CONTROL

NC machine tools have manifold advantages over conventional machines. These are listed below:

1. The manufacturing lead time in NC machines is less. This is owing to fewer set-ups, reduced work handling time, automatic tool changes, etc.
2. Close tolerance can be maintained on the products.
3. Parts can be produced more accurately.
4. Parts can be processed in small batches.
5. NC fixtures are simple and less costly. Since the part program can take care of the geometry generated, the need for expensive fixtures is minimised.
6. Operator fatigue is highly reduced, because the operator involvement is the manufacturing of part if very less.
7. The manufacturing flexibility is highly improved in view of the fact that machining centres can perform a variety of machining operations and alterations of the production schedule, etc.
8. Floor space requirements are reduced because one NC machine centre can accomplish the production of several conventional machines.
9. The quality of the products is improved because of automation and the absence of inter-related human factors.
10. Cutting tools can be used at optimum speeds and feeds.
11. The inventory is reduced due to shorter lead times and fewer set-ups.

Limitations of NC

1. The cost is high.
2. The maintenance cost is high on account of its complex and sophisticated technology.
3. NC machines require part programmers. There is problem of finding , hiring and training the programmers.

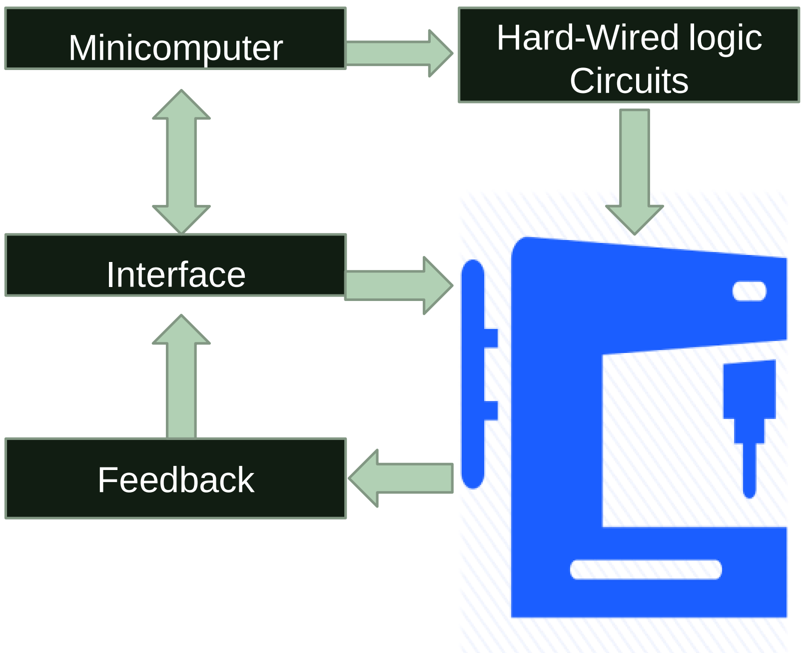
Computer Numerical Control

Today, NC means computer numerical control. Computer numerical control CNC is defined as an NC system whose MCU is based on a dedicated microcomputer rather than on a hard-wired controller.

Features of CNC

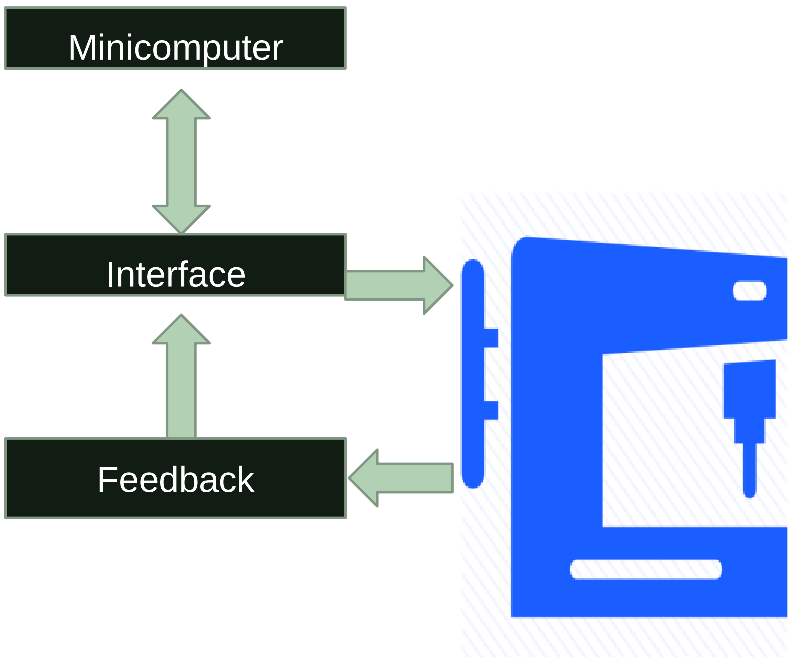
1. Storage of more than one part program
2. Various forms of program input
3. Program editing at the machine tool
4. Using programming subroutines and macros.
5. Interpolation.
6. Positioning features for setup
7. Cutter length and size compensation
8. Acceleration and deceleration calculations
9. Communication interface
10. Diagnostics

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

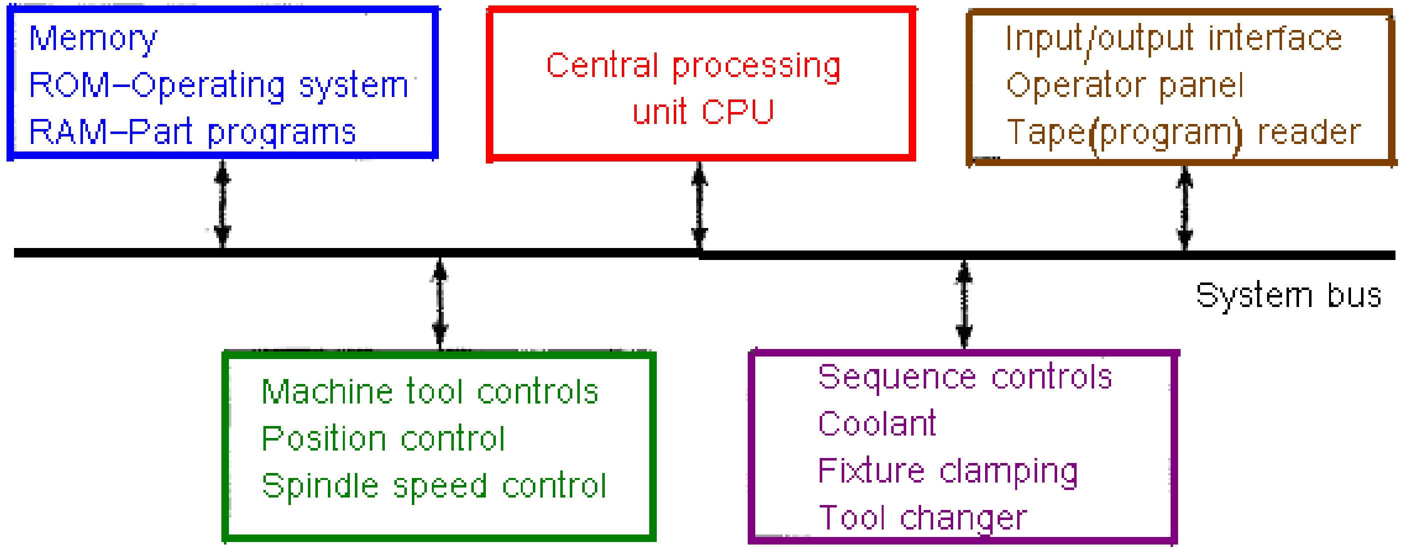


- It uses a computer to perform all the functions.
- The interpolation, feed rate generation and all other functions are performed by the computer with the help of software.
- The only hard-wired elements are those required to interface the computer with machine tool and operator’s console.

Computer Numerical Control

The Machine Control Unit for CNC

The MCU is the hardware that distinguishes CNC from conventional NC.



The general configuration of CNC MCU

Computer Numerical Control

The Machine Control Unit for CNC

MCU consists of the following components and subsystems:

(1) Central processing unit

(2) Memory

(3) I/O interface

(4) Controls for machine tool axes and spindle speed

(5)Sequence controls for other machine tool functions

These subsystems are interconnected by means of a system bus.

Computer Numerical Control

Central Processing Unit

Manages the other components in the MCU based on software contained in memory. The CPU can be divided into three sections:

(1) Control section

(2) Arithmetic-logic unit

(3) Immediate access memory

Computer Numerical Control

Memory

Consists of main memory and secondary memory.

Main memory (Primary storage) consists of ROM (read-only memory) and RAM (Random access memory) devices.

Operating system software and machine interface programs are generally stored in ROM. Numerical control part programs are stored in RAM devices. Current programs in RAM can be erased and replaced by new programs as jobs are changed.

High-capacity secondary memory (also called auxiliary storage or secondary storage) devices are used to store large programs and data files, which are transferred to main memory as needed.

Computer Numerical Control

Input/Output Interface

Provides communication between the various components of the CNC system, other computer systems, and the machine operator.

Computer Numerical Control

- Controls for Machine Tool Axes and Spindle Speed
- These are hardware components that control the position and velocity (feed rate) of each machine axis as well as the rotational speed of the machine tool spindle

Computer Numerical Control

- Sequence Controls for other Machine Tool Functions
- In addition to control of table position, feed rate, and spindle speed, several additional functions are accomplished under part program control. These auxiliary functions are generally ON/OFF (binary) actuations and interlocks.

Computer Numerical Control

Machining Operations and NC Machine Tools

Machining is a manufacturing process in which the geometry of the work is produced by removing excess material. By controlling the relative motion between a cutting tool and the workpiece, the desired geometry is created.

There are four common types of machining operations: (a) turning, (b) drilling, (c) milling, and (d) grinding.

Each of the machining operations is carried out at a certain combination of speed, feed, and depth of cut, collectively called the cutting conditions for the operation.

Computer Numerical Control

Applications of NC

Two categories:

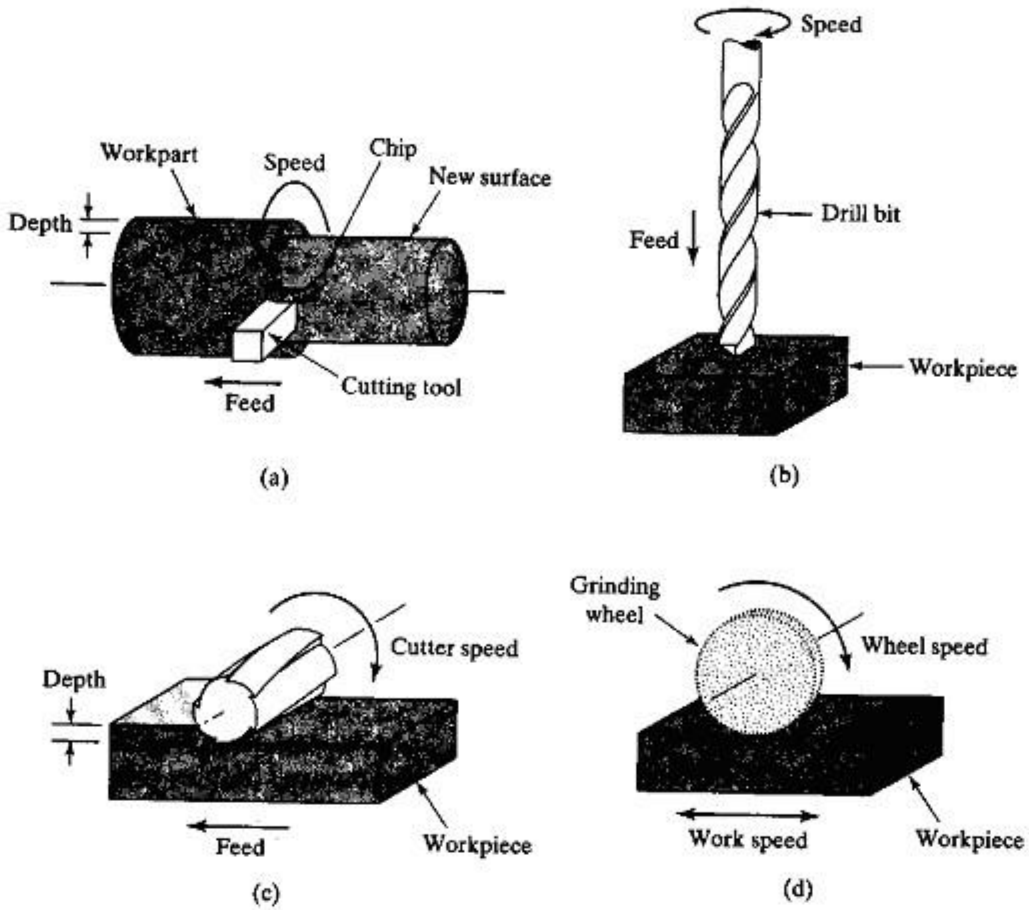
(1) machine tool applications, and (2) non-machine tool applications.

Machine tool applications are those usually associated with the metalworking industry. Non-machine tool applications comprise a diverse group of operations in other industries.

Machine Tool Applications

The most common applications of NC are in machine tool control. Machining was the first application of NC, and it is still one of the most important commercially.

Computer Numerical Control



The four common machining operations: (a) turning, (b) drilling, (c) peripheral milling, and (c) surface grinding.

Computer Numerical Control

Advantages of CNC machines

CNC machines have many advantages over conventional machines. Some of them are:

1. There is a possibility of performing multiple operations on the same machine in one setup.
2. More complex part geometries are possible.
3. The scrap rate is significantly reduced because of the precision of the CNC machine and lesser operator impact.
4. It is easier to perform quality assurance by a spot-check instead of checking all parts.
5. Production is significantly increased.
6. Shorter manufacturing lead time.

Computer Numerical Control

Disadvantages of CNC machines

1. They are quite expensive.
2. They have to be programmed, set up, operated, and maintained by highly skilled personnel.

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

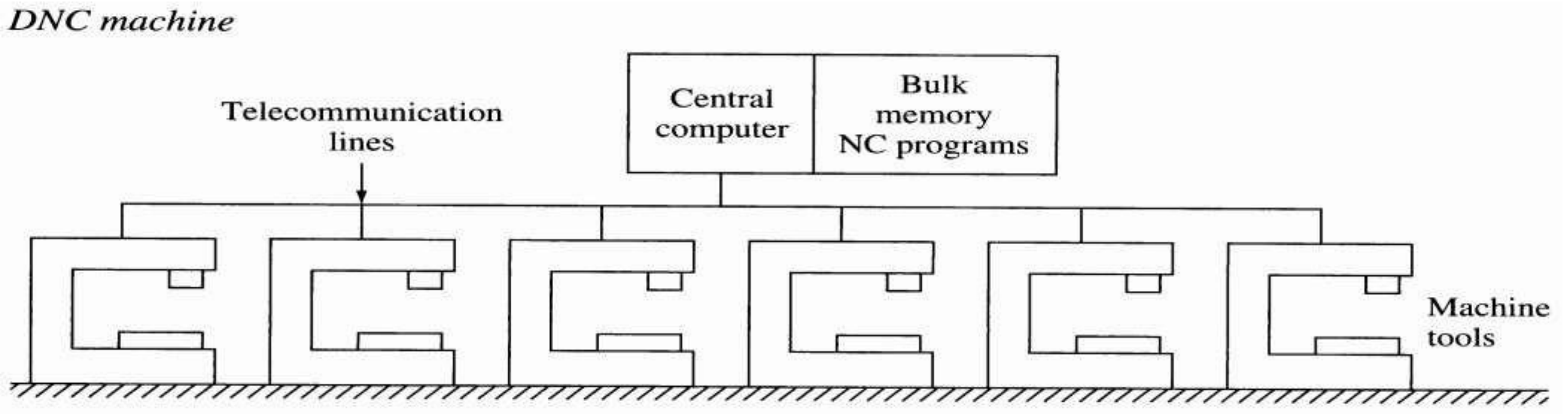
- DNC is a manufacturing system in which a number of machines are controlled by a computer through direct- connection and in real time.
- Also, defined by EIA as: DNC is a system connecting a set of NC machines to a common memory for part program or machine program storage with provision for on- demand 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.

Principle

- 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



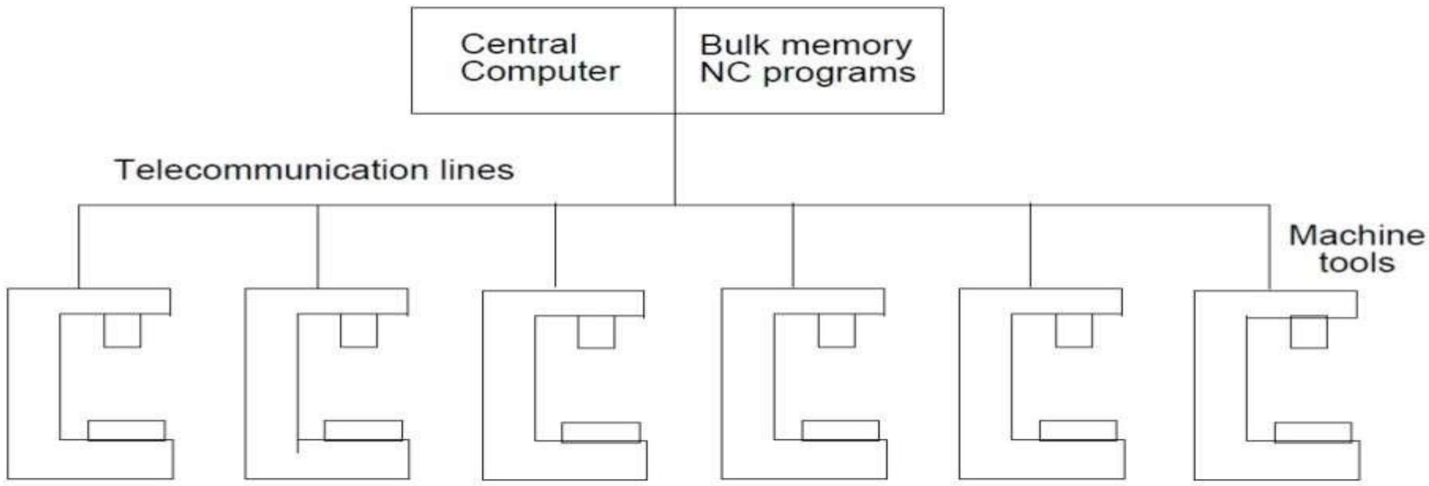
The configuration of the DNC system can be divided into:

1. DNC system without satellite computer.

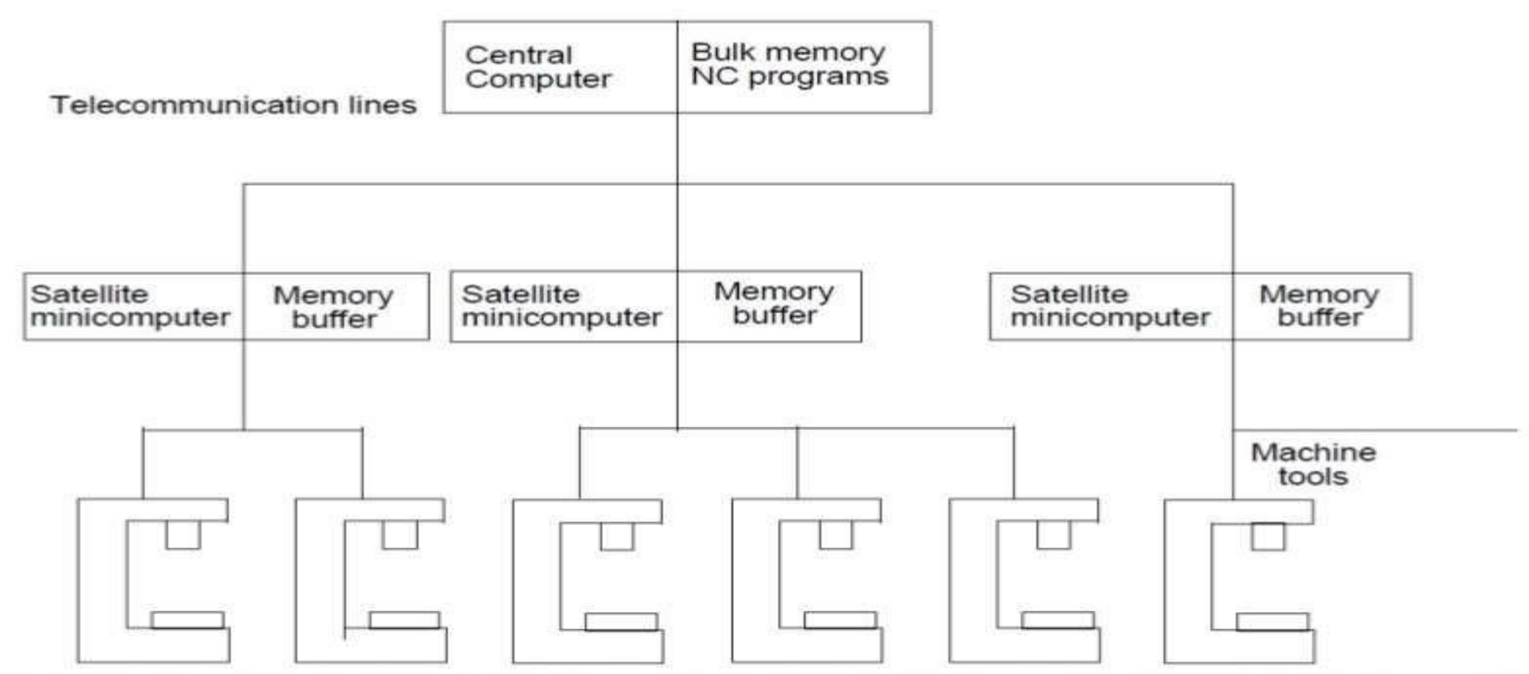
2. DNC system with satellite computer.

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

DNC system without satellite computer



DNC system with satellite computer

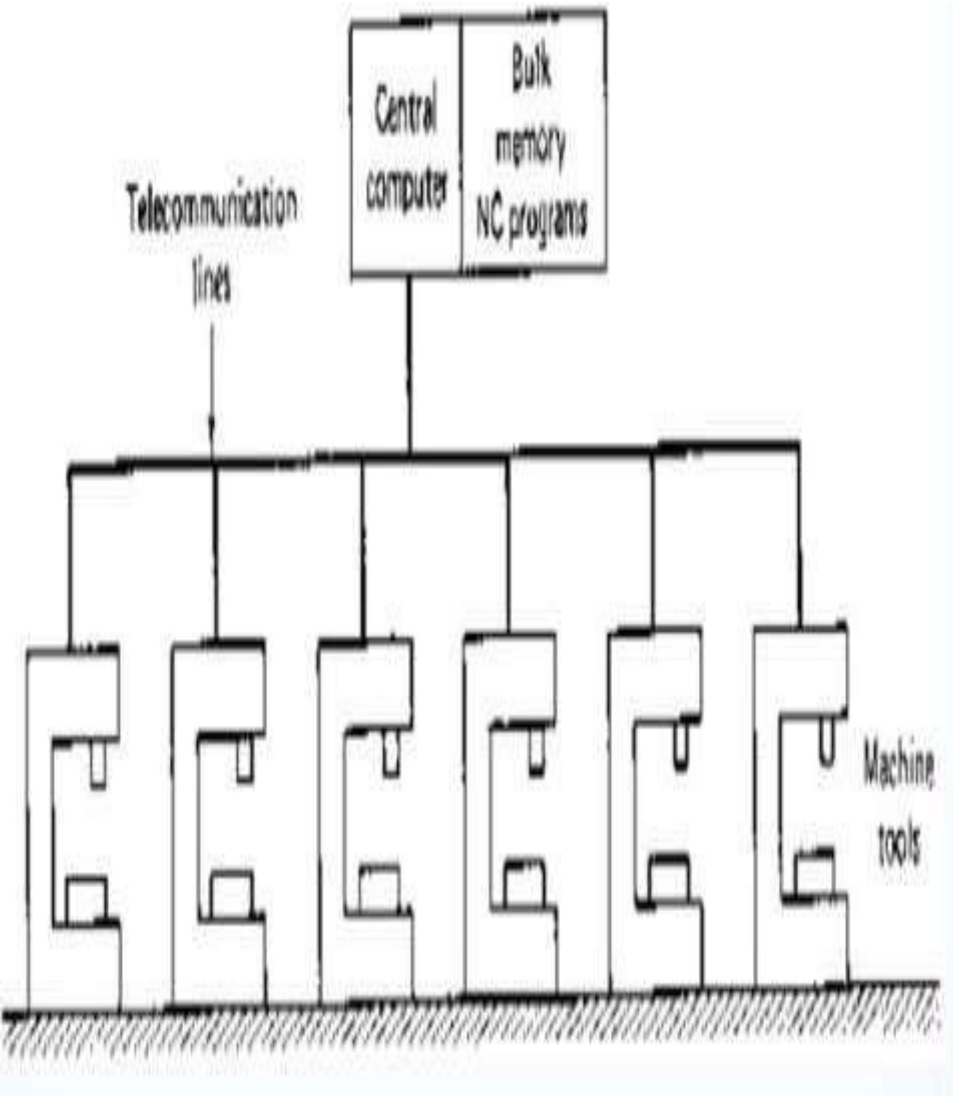


DNC

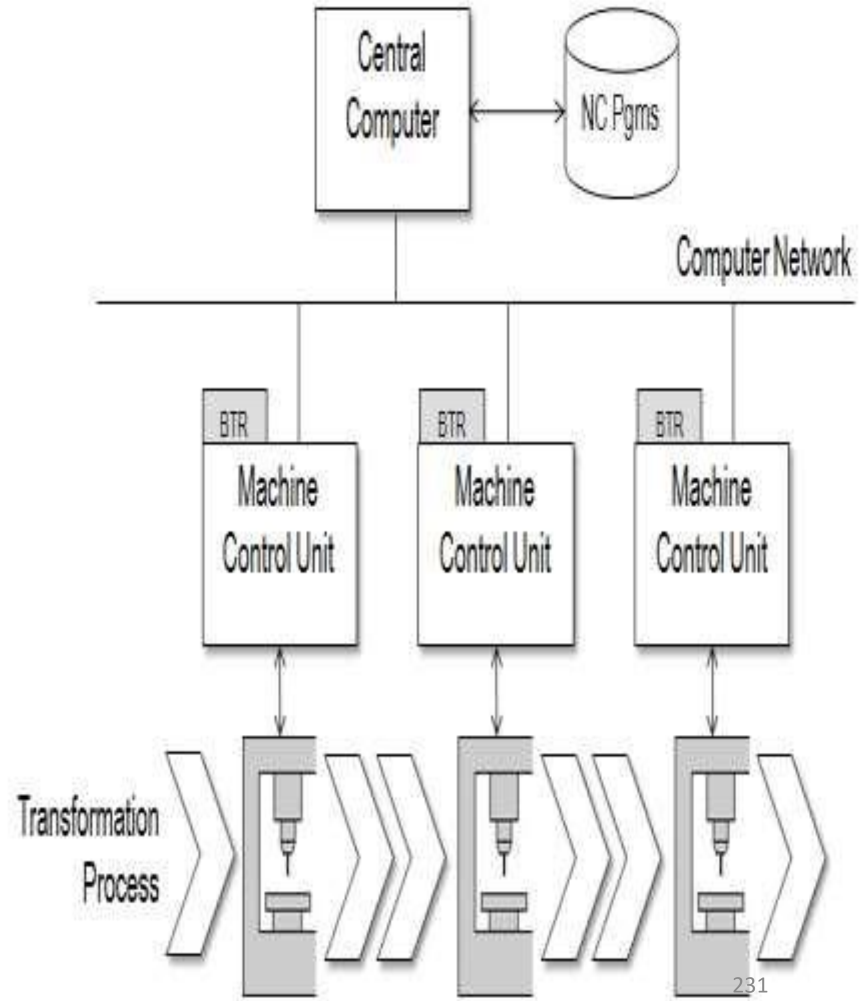
- Direct numerical control (DNC) – control of multiple machine tools by a single (mainframe) computer through direct connection and in real time
  - 1960s technology
  - Two way communication

- Distributed numerical control (DNC) – network consisting of central computer connected to machine tool MCUs, which are CNC
  - Present technology
  - Two way communication

Direct numerical control (DNC)

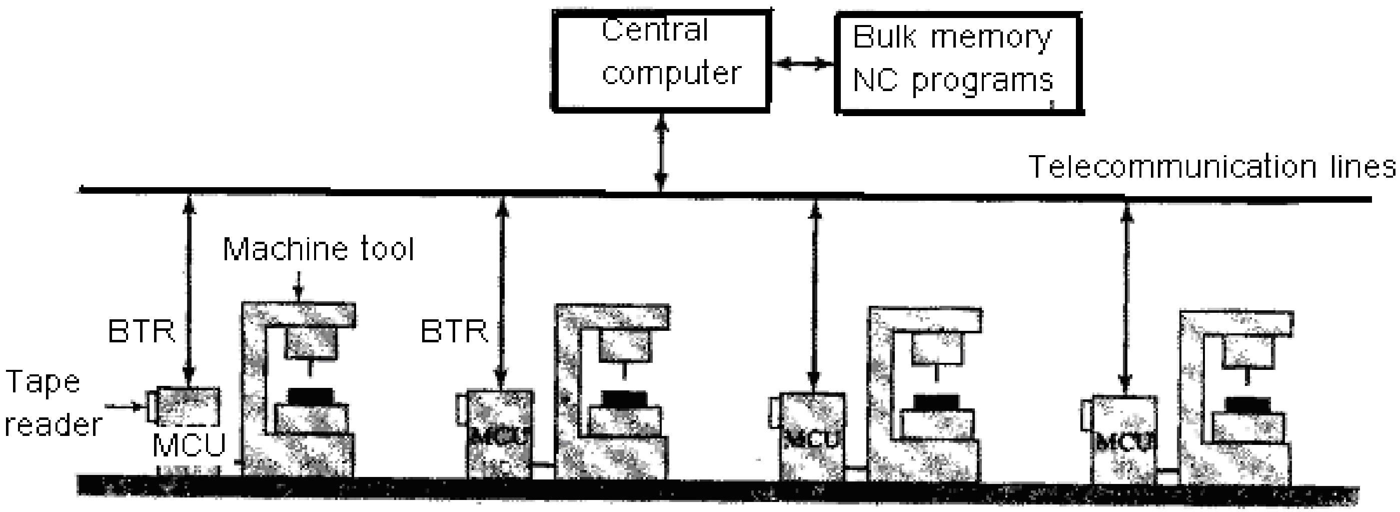


Distributed numerical control (DNC)



Computer Numerical Control

Direct Numerical Control



General configuration of a DNC system. Connection to MCU is behind the tape reader. Key: BTR=behind the tape reader, MCU=machine control unit.

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.

Direct Numerical Control

DNC involved the control of a number of machine tools by a single (mainframe) computer through direct connection and in real time. Instead of using a punched tape reader to enter the part program into the MCU, the program was transmitted to the MCU directly from the computer, one block of instructions at a time. This mode of operation was referred to by the name behind the tape reader BTR. The DNC computer provided instruction blocks to the machine tool on demand; when a machine needed control commands, they were communicated to it immediately. As each block was executed by the machine, the next block was transmitted.

In addition to transmitting data to the machines, the central computer also received data back from the machines to indicate operating performance in the shop. Thus, a central objective of DNC was to achieve two-way communication between the machines and the central computer.

Comparison between NC, CNC and DNC machine tools

NC Machine Tool System

1. The part program is fed to the machine through the tapes or other such media.
2. In order to modify the program, the tapes have to be changed.
3. In NC machine tool system, tape reader is a part of machine control unit.
4. System has no memory storage and each time it is run using the tape.
5. It can not import CAD files.
6. It can not use feedback system.
7. They are not software driven.

CNC Machine Tool System

1. In CNC machine tool system, the program is fed to the machine through the computer.
2. The programs can be easily modified with the help of computer.
3. The microprocessor or minicomputer forms the machine control unit. The CNC machine does not need tape reader.
4. It has memory storage ability, in which part program can be stored.
5. System can import CAD files and convert it to part program.
6. The system can use feedback system.
7. The system is software driven.

DNC Machine Tool System

1. The part program is fed to the machine through the Main computer
2. In order to modify the program, single computer is used
3. Large memory of DNC allows it to store a large amount of part program.
4. Same part program can be run on different machines at the same time.
5. The data can be processed using the MIS software so as to effectively carry out the Production planning and scheduling.

NC APPLICATIONS:

1. Material removal process:
   Turning, drilling, boring, milling and grinding
2. welding and cutting processes:
   spot welding ,arc ,laser beam and plasma cutting
3. Automatic drafting
4. Assembly of parts
5. Automatic riveting
6. Tube bending
7. cloth cutting
8. automated knitting (craft)
9. plastic moulding process
   Injection moulding and Blow moulding

NC MACHINE RATING

- Accuracy
- Repeatability
- Spindle and axis motor horsepower
- Number of controlled axes
- Dimension of workspace
- Features of the machine and the controller.

Lecture 17 & 19

NC Machines

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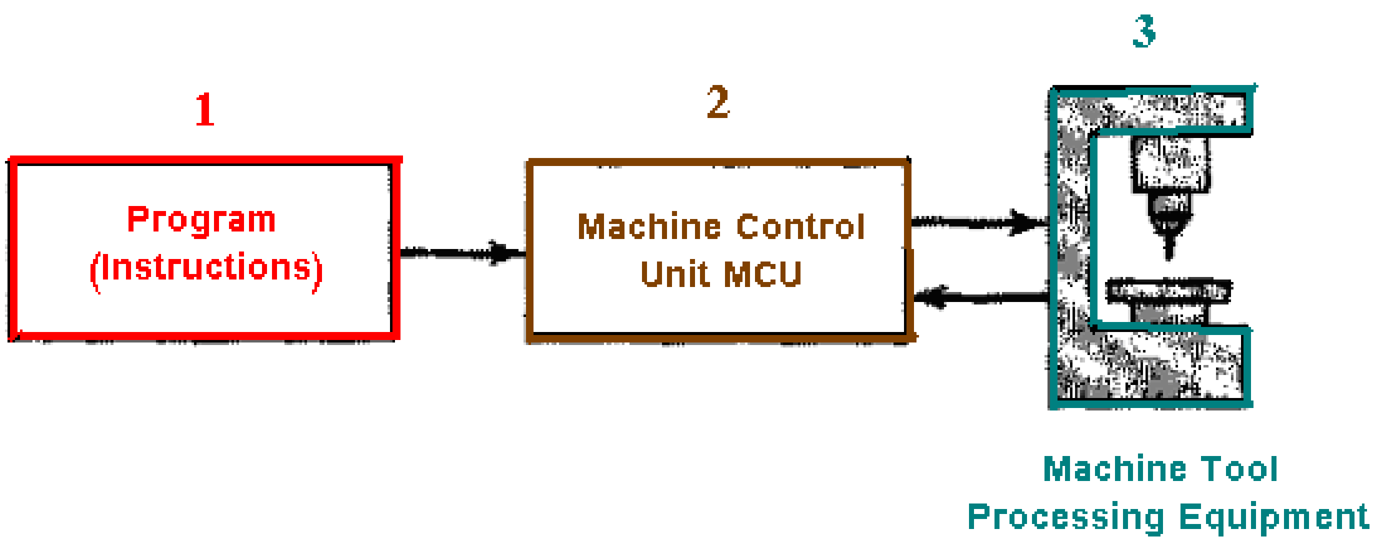
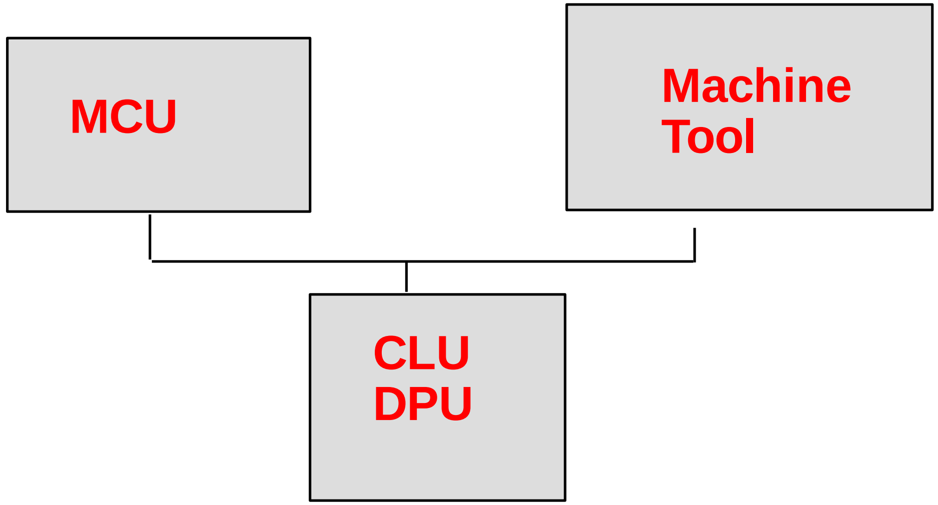
Basic Components of an NC System



COMPONENTS OF NC MACHINES

Hardware Configuration of NC Machine

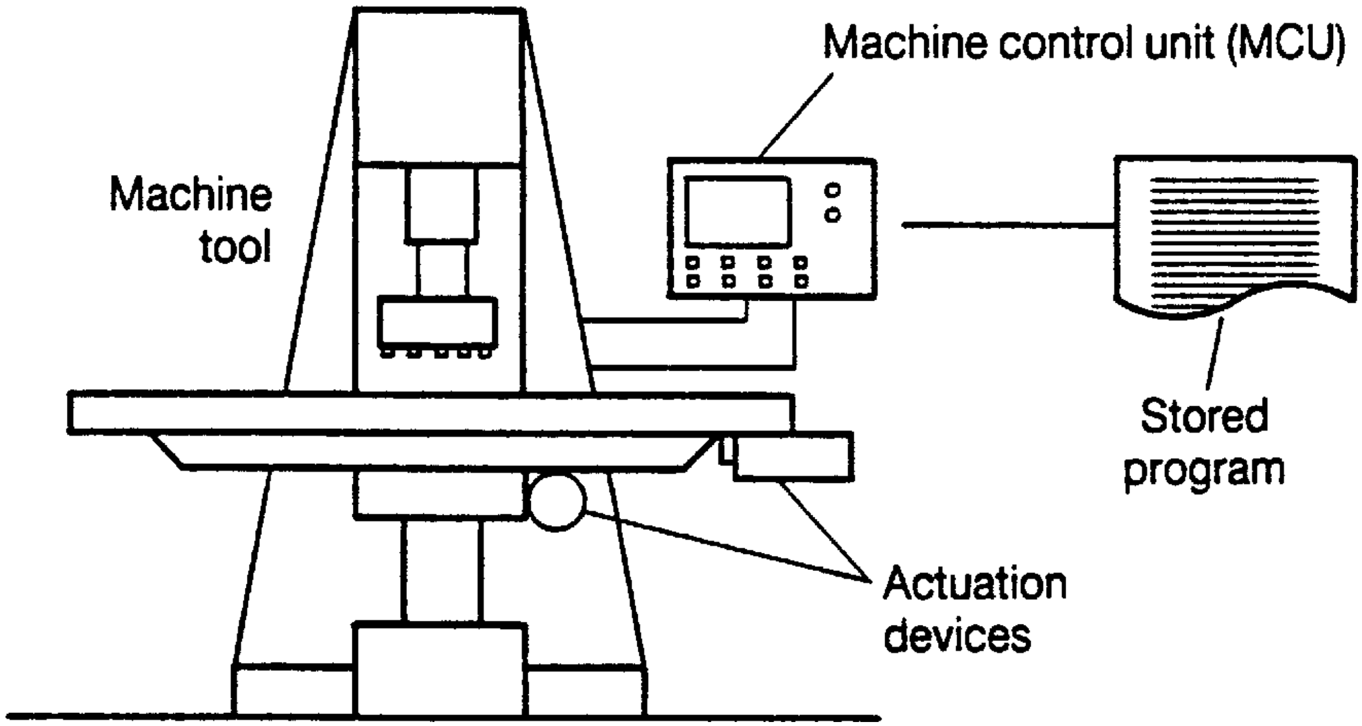


MCU - Machine control unit

CLU - Control-loops unit

DPU - Data processing unit

Basic Components of an NC System



1.Program of instructions.

2.Machine control unit (MCU).

3.NC machine tool.

4.NC Cutting tools.

1.Program of Instructions:

1. The program of instructions is the detailed step - by - step of operations which are implemented by MCU .
2. The program is coded in alphanumerical form on an input medium to the MCU
3. The input medium is a punched tape or a magnetic tape .
4. Two method are used to program for NC
   I. Manual part programming
   II. Computer – aided part programming

Program of instructions: The detailed step-by-step commands that direct the actions of the processing equipment. In machine tool applications, the program of instructions is called a **part program**, and the person who prepares the program is called a part programmer. In these applications, the individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured. Additional instructions are usually included, such as spindle speed, feed rate, cutting tool selection, and other functions. The program is coded on a suitable medium for submission to the machine control unit.

2. Machine Control Unit (MCU)

- NC machine tool has a main unit, which is known as Machine Control Unit.
- It consists of some electronic hardware that reads theNC programme, interprets it and conversely translates it for mechanical actions of the machine tool.
- MCU consists of two parts : Data processing unit (DPU) and
- control loops unit (CLU).
- Function of DPU: read the decode the instructions available on the tape & to provide the decoded data to the control loops unit (CLU).
- Function of (CLU): To control the drives attached to the axes and receive the feedback signals from machine tool
- CLU also prompts a signal that the previous data segment is completed and that the DPU can read the next block of the part program.

Basic Components of an NC System

Machine control unit MCU: Consists of a microcomputer and related control hardware that stores the program of instructions and executes it by converting each command into mechanical actions of the processing equipment, one command at a time. The related hardware of the MCU includes components to interface with processing equipment and feedback control elements. The MCU also includes one or more reading devices for entering part programs into memory. The MCU also includes control system software, calculation algorithms, and translation software to convert the NC part program into a usable format for the MCU.

NC and CNC:

Because the MCU is a computer, the term computer numerical control CNC is used to distinguish this type of NC from its technological predecessors that were based entirely on a hard-wired electronics. Today, virtually all new MCUs are based on computer technology; hence, when we refer to NC we mean CNC.

DPU consists of the following elements:

1. Input device example: Tape reader
2. Reading circuit
3. parity checking logic (transmission error).
4. Decoding circuits
5. interpolator

CLU consists of the following:

1. Position control unit with a feedback device such as a linear encoder.
2. Velocity control unit with a feedback such as a rotary encoder.
3. Acceleration , retardation and backlash correction circuits.
4. Auxiliary function control unit for coolant on and off ,etc.

3 .NC Machine Tool :

•Machine tool is the main components of a numerical control system, which executes the operations.

•It may consist of worktable, cutting tools, jigs and fixtures, motors for driving spindle and coolant and lubricating system.

•The latest development in the numerical control machine tool is the versatile machining center.

•This is a single machine capable of doing a number of operations such as milling, boring, drilling, reaming, and tapping by Automatic Tool Changer (ATC) under the control of tool selection instruction.

The MCU may be of three types :

•*Housed MCU*

Machine Control Unit may be mounted on the machine tool or may be built in the casing of the machine.

•*Swing Around MCU*

Machine Control Unit is directly mounted on the machine, which can swing around it and can be adjusted as per requirement of the operator’s position.

•*Stand Alone MCU*

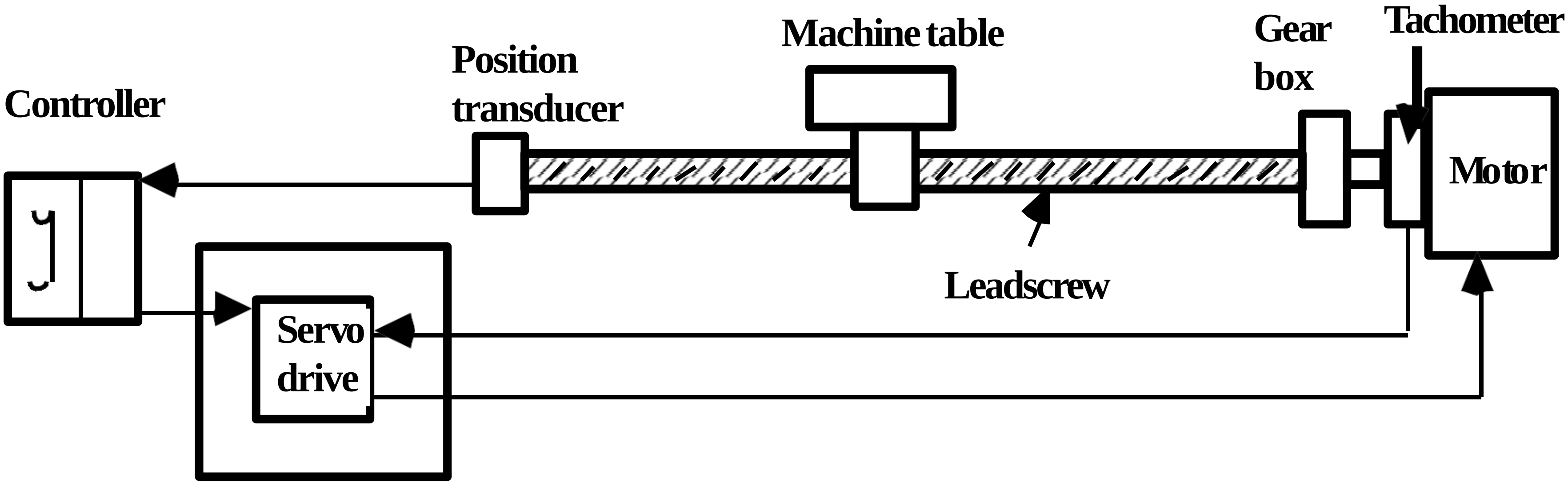
Machine Control Unit is enclosed in a separate cabinet which is installed at some remote or same place near to the machine.

Processing equipment: Performs useful work and accomplishes the processing steps to transform the starting workpiece into a completed part. Its operation is directed by the MCU, which in turn is driven by instructions contained in the part program.

In the most common example of NC, machining, the processing equipment consists of the worktable and spindle as well as the motors and controls to drive them

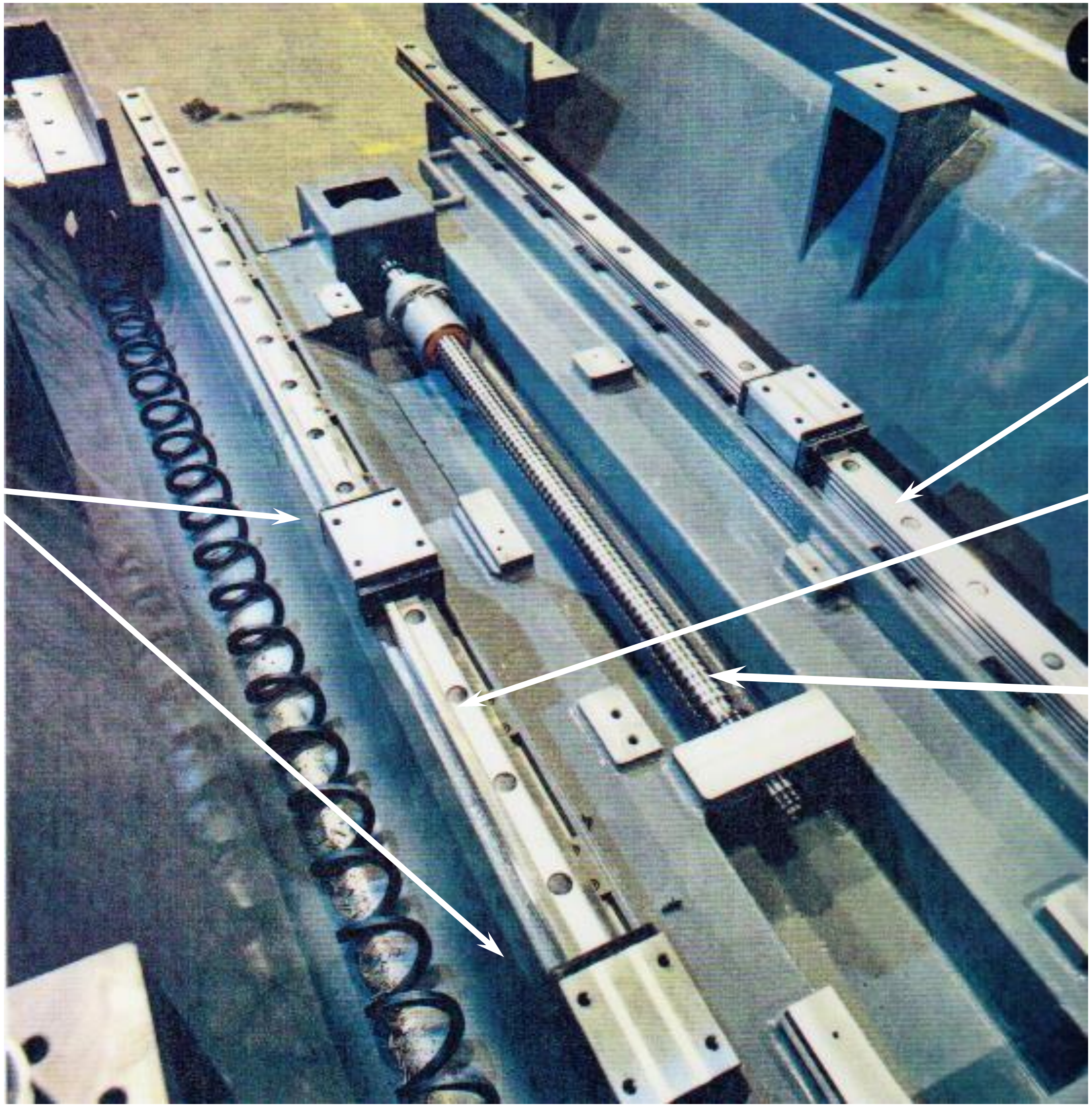
MAJOR COMPONENTS OF

AN NC MACHINE TOOL



Magnetics control cabinet

MACHINE BED



Bearing

Linear ways

Leadscrew

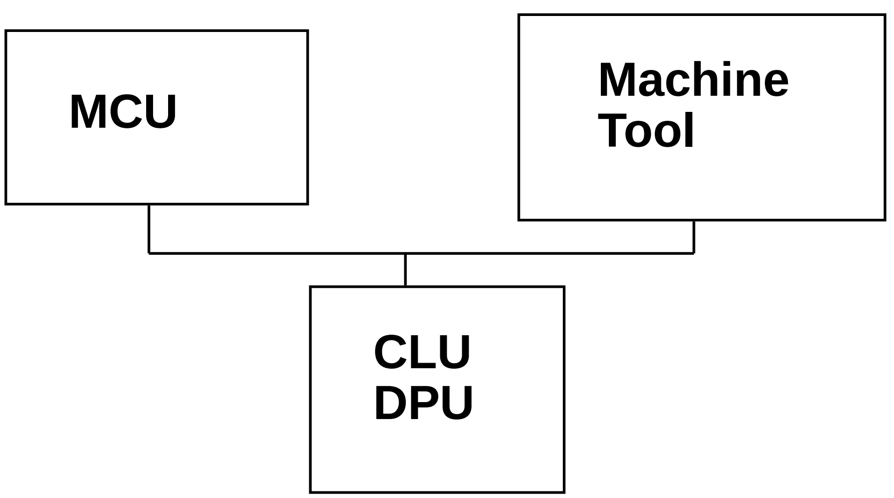
NC Machines

- Computer control
- Servo axis control
- Tool changers
- Pallet changers
- On-machine programming
- Data communication
- Graphical interface

MCU - Machine control unit

CLU - Control-loops unit

DPU - Data processing unit



Lecture 20

Classifications of NC Machines

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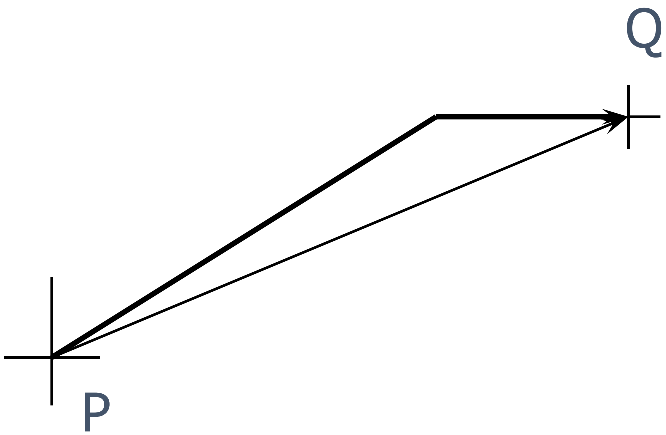
Classification of NC

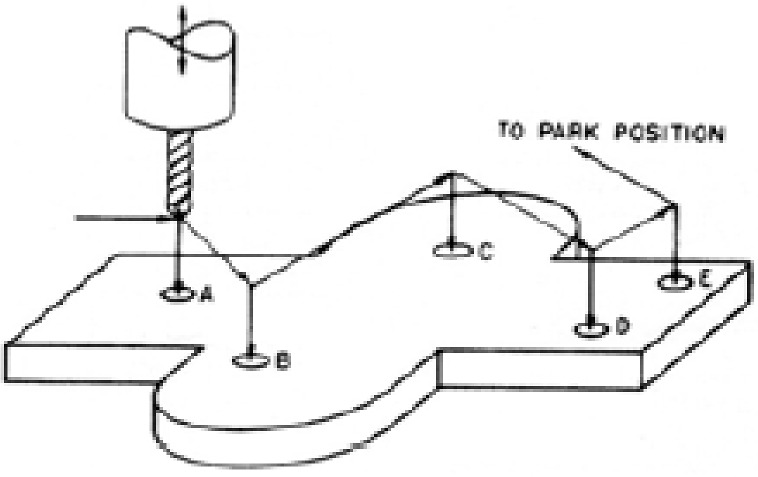
- Motion control
  - point to point (PTP)
  - Straight Line Motion Control System
  - continuous (contouring) path
- Control loops
  - open loop
  - closed loop
- Power drives
  - Hydraulic
  - Electric
  - Pneumatic
- Positioning systems
  - Incremental positioning
  - Absolute positioning
- Hardwired NC and Softwired Computer Numerical Control (CNC)

Motion control

Point to Point

- **Moving at maximum rate from point to point**
- **Accuracy of the destination is important but not the path**
- **Drilling is a good application**



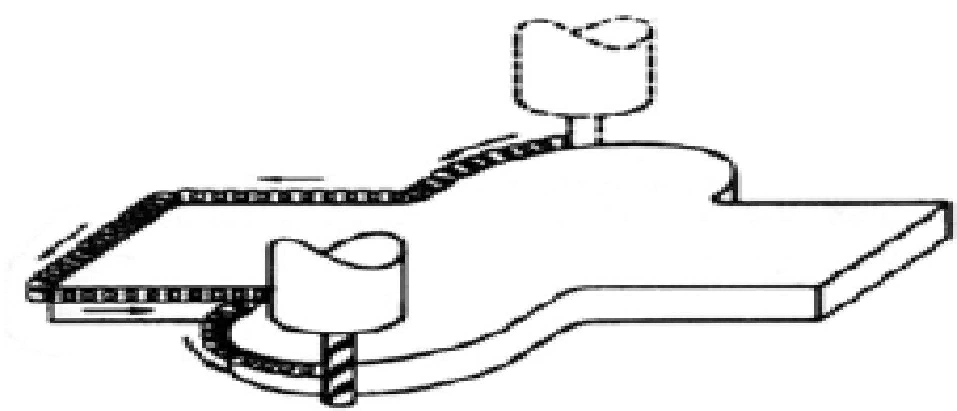


Straight Line Motion Control System

The NC systems, in which the tool works along a straight line in the direction of a major coordinate axis, such as along the direction of feed during turning, boring or milling operation at a controlled rate, are known as Straight line control system.

Continuous Path

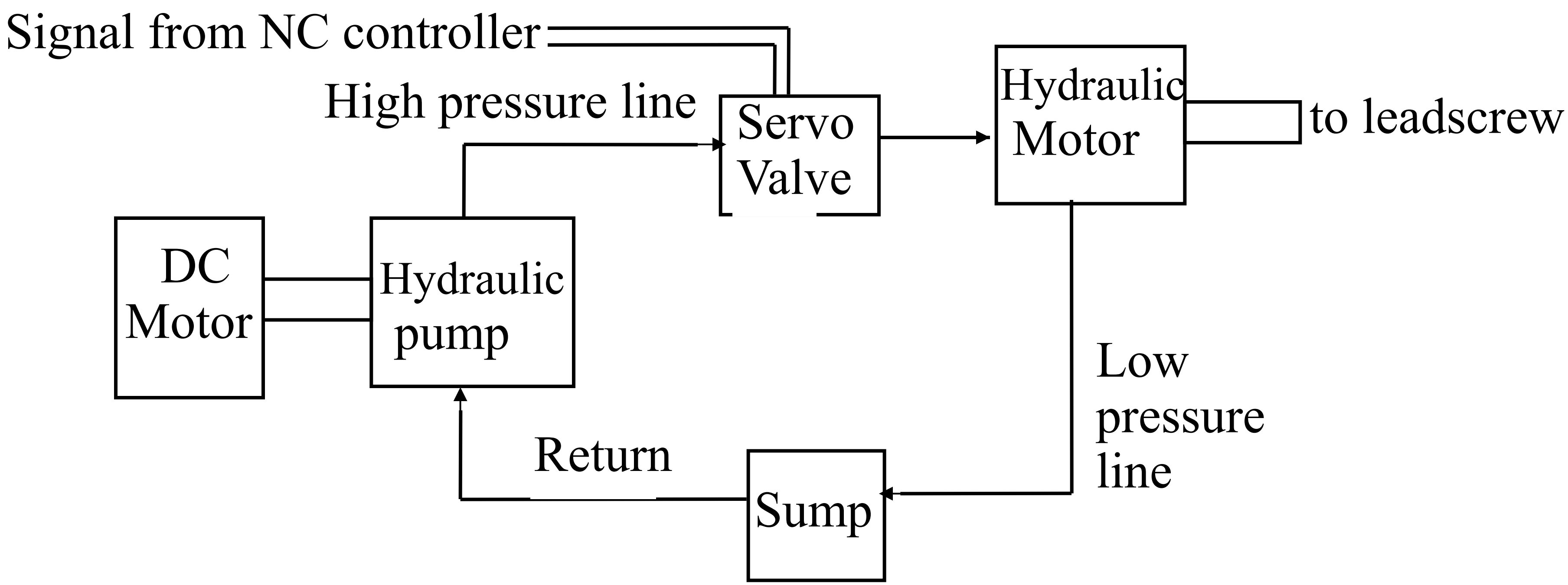
- Controls both the displacement and the velocity
- Machining profiles
- Precise control
- Use linear and circular interpolators



Prime Movers

- Prime mover of a machine is the power source that moves the table and spindle
- Determines
  - The range of machine’s performance capabilities => feasibility for various operations
- Two major power sources:
  - Hydraulic
  - Electric

A Hydraulic Power Drive



Prime Movers: Hydraulic power drive

Advantages:

- Large torques and fast responses
- Large power/size ratio
- Use for large and heavy-duty machines

Disadvantages:

- High cost
- Additional peripherals
- Noise
- Response lag due to hydraulic fluid viscosity
- Contamination from leaking fluid

Hydraulic Power Drive (i)

The servo valve output flow rate:

$$q = k_v V$$

where:

- q : **output flow rate, in^3/s**
- k_v : **valve constant**
- V : **signal voltage, volt**

The power of the motor:

$$p\, q = T_m\, \omega$$

where:

- p : **input pressure, psi**
- q : **input flow rate, in^3/s**
- T_m: **output torque, in lb**
- ω : **angular speed, rad/s**

The steady state rotational speed of the motor:

$$\omega = K\, q$$

where:

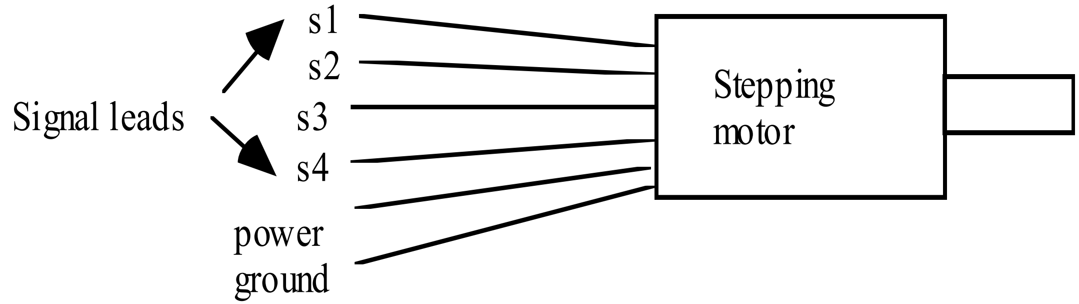
K: motor constant

Electric Power Drives

- Most applicable for precision jobs
- Two major groups of electrical drives
  - Stepper motors
  - Servo motors
- Stepper motors
  - Rotates in angular increments
  - Used in NC, robots, printers, plotters, VCRs, cameras, etc.
  - Rating: torque, from 1 oz-in to several HP
  - Step angle: 0.72° to 90°; 1.8°, 7.5°, and 15° are most popular
  - For each input pulse (signal), the motor shaft advances one step

Stepper Motor Control

Rotation controlled by pulse sequence on the signal



Step	S1	S2	S3	S4
1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	0
1	1	0	1	0

Clockwise stepping

Counter clockwise stepping

Example

Turn a 1.8° step angle motor 2000 steps at 360 rpm, what is the number of pulses and pulse rate to be sent to the motor?

The number of pulses should be the same as the desired steps. It, therefore, is 2000 pulses.

360 rpm = 360 (rotation/min) / 60 (second/min)
= 6 rotation/second

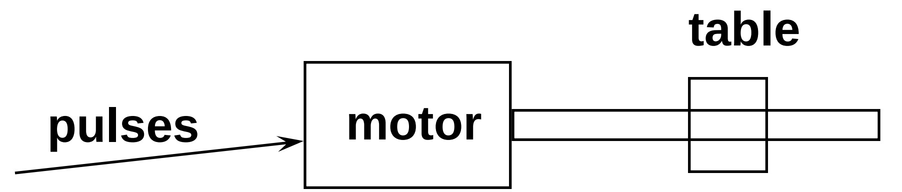
Number of steps per rotation, N:

N = 360°/1.8° = 200 steps/rotation

Pulse rate = 6 (rotation/second) x 200 (steps/revolution)
= 1,200 pulses/second

Control Loops

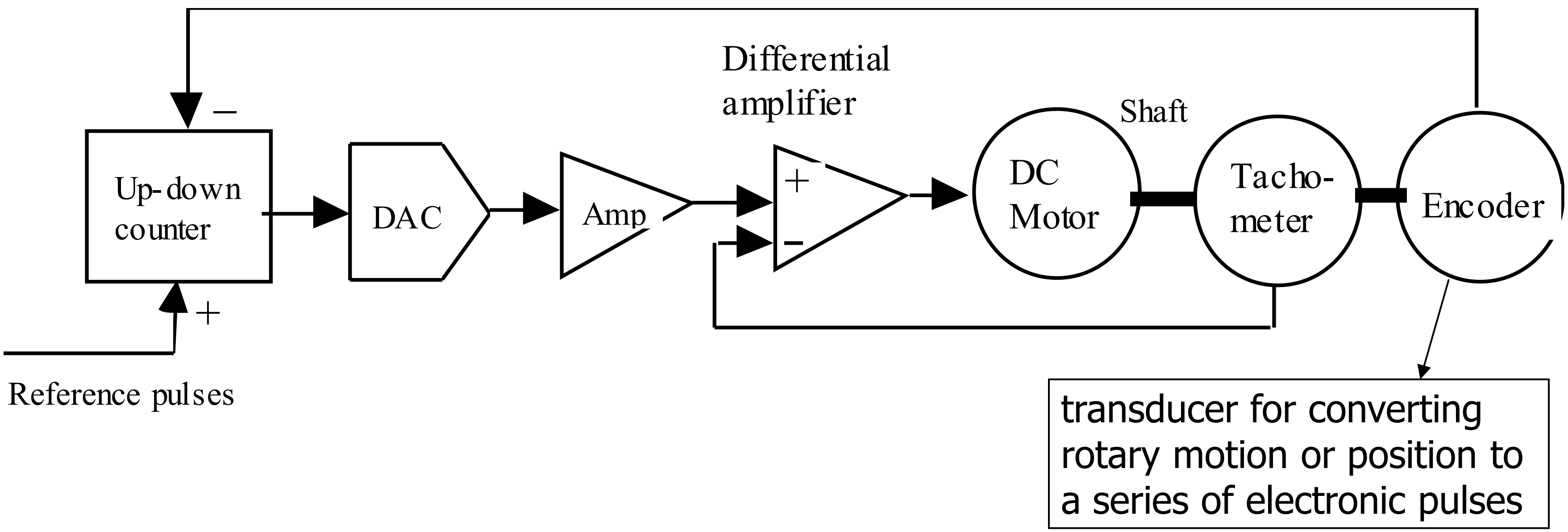
- Open loop



  - No position feedback
  - Uses stepping motor
  - Controller converts speed and displacement into pulse rate and pulse count
  - Pulse rate is sent to stepping motor
  - Pulse count sent to “pulse” counter
  - When count reaches zero, motor stops
  - Example
    - A machine has 1 BLU = 0.001".To move the table 5” on X axis at a speed (feed rate) of 6 ipm.
    - Pulse rate = speed/BLU = 6 ipm/0.001 ipp = 6,000 pulses/min
    - Pulse count = distance/BLU = 5/0.001 = 5,000 pulses

Closed Loop NC

- Closed-loop feedback control system
  - Ability to compare a desired set of results with actual results
  - Take corrective action

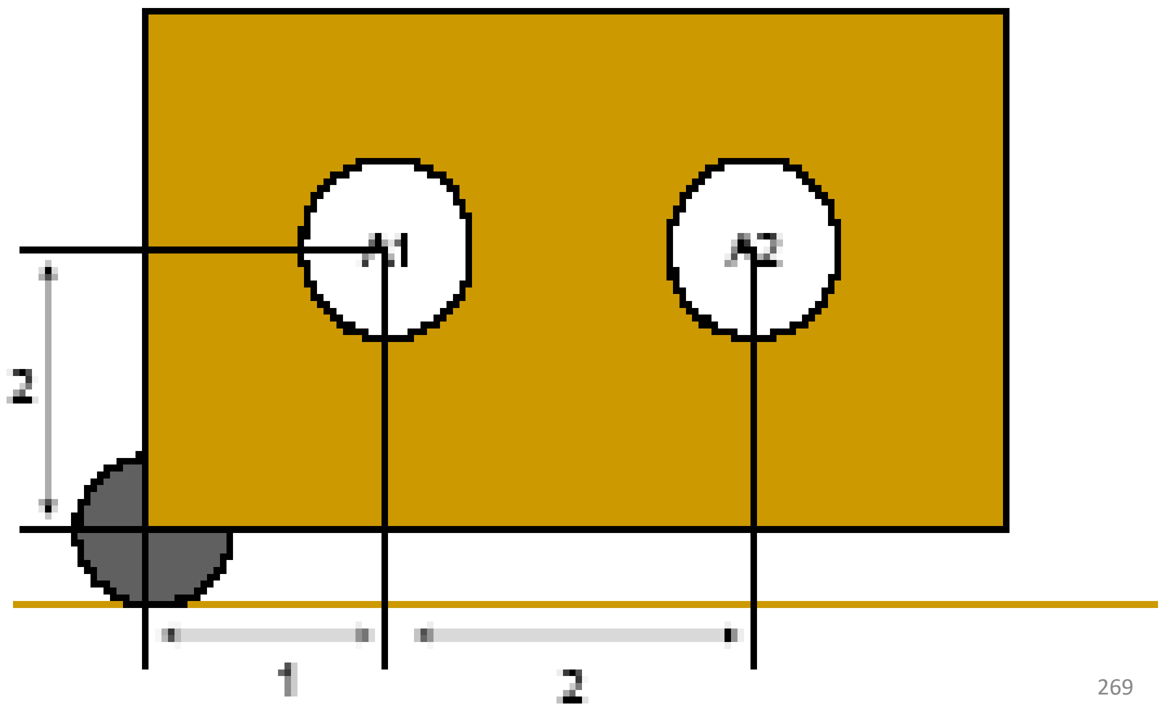


Positioning Systems

- Function:
  - To specify location on the part to which the cutting tool is moved
  - Location tool change
  - Location fixture holder
- Two types of positioning systems:
  - Absolute
  - Incremental

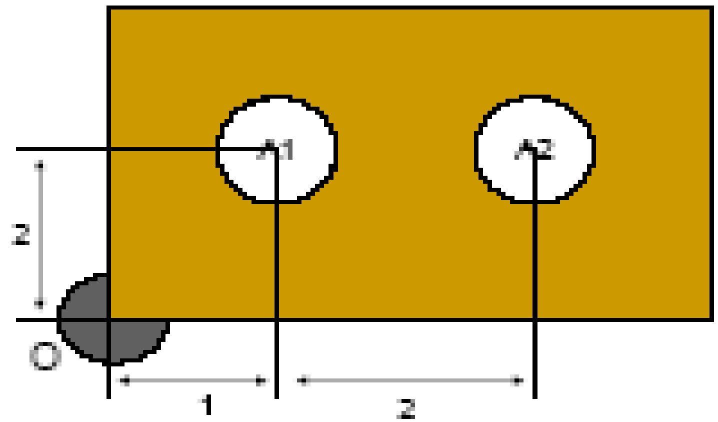
Absolute Positioning System

- Measured from a single fixed point or origin
- In most NC system, the origin can be specified at any convenient location
- Example
  - A1:(1,2)
  - A2:(3,2)



Incremental Positioning System

- The reference point is not fixed
- Each position is defined in relation to the previous one
- Example



A1 = X = 1, Y = 2 refer to O
A2 = X = 2, Y = 0 refer to A2

Lecture 21-24

Construction details of NC machines

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Construction details of NC machines

A) Slideways/Guideways

B) Spindle Drive

C) Automatic tool changers (ATC)

D) Sensors and Feedback Mechanism

E) Safety Instructions

SLIDEWAYS/GUIDEWAYS

A slideway is used to control the direction or line of action of the translational movement of the table or carriage on which the tools or work are held.

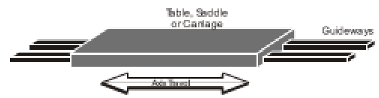


Fig. 1: Guideways

The purpose of the guideway (or slideway) is to accommodate the axis movement of the machine slides, worktables and spindles. The guideway also provides the geometric alignment (parallelism, perpendicularity, roll, pitch and yaw) for the axis. The surface must support the static and dynamic loads (including machining forces) with as little friction as possible, but at the same time dampen the effect of a movable joint on the machine.

Guideways : Some silent points

- Guideways control the direction of the table on which tool or work is held
- It absorb all static and dynamic forces and transferred to base of machine
- Size and shape of the work produced depends on accuracy of movements and geometric and kinematics accuracies of guide ways.
- Straightness, parallelism and flatness errors in guide ways result in tracking errors
- Alignment of guide ways as to each other and to the axis of spindle is critical
- Wear in guide ways reduces accuracy of movement.

Guideway Geometries:

Standard guideway geometries commonly use following geometries

- Round
- Flat
- Vee
- Dovetail
- Box
- Ball or Roller

NOTE: The selection of the proper shape is based on the magnitude and direction of the load to be carried, position of transmission, wear characteristics and provisions for wear adjustments, ease of assembly and economy in fabrication, effective lubrication and the easy chip disposal.

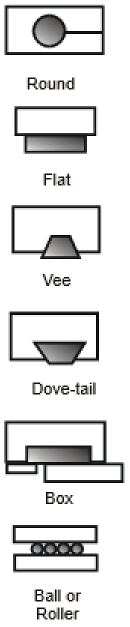


Fig. 2: Common Guideway Geometries

Round type : Limited used on surface grinders as well as feeding spindle bars (e.g. boring mill).

Flat type : Slideways are simple in construction and offer quite a large bearing area to the moving parts and used for alignment only. The advantages of flat slideways are that they require devices for adjusting the clearances, have tendency to accumulate dust and found application on a wide range of machines including grinding machines

V-type : Slideways are advantageous because of the automatic adjustment due to gravity action which always keeps the surfaces in contact, thus the possibility of any play is eliminated. In addition, the wedging action due to cross winding is also prevented and there is no possibility of chips falling on the V-surface and getting entrapped into it. It has no tendency to accumulate dust. The drawback of V-type guides is that it wears away rapidly due to lack of bearing surface, and is difficult to manufacture.

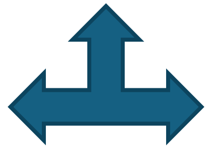
Dovetail type : This guideway is seldom seen on today's machine tools. However, it has some application in tool slides (e.g. gang tool slide on a Swiss-type turning machine). It features extremely good rigidity and alignment characteristics. It is an expensive guideway to produce

Box (square/rectangular) type : This is a common guideway on machining centers and lathes. It is used in heavy machining (e.g. milling) applications. The box can either be a bolted-on steel rail or an integral part of the machine's casting. When they are integral, the cast iron surface is flame or induction heat-treated and then ground and/or hand scraped.

Ball or Roller type : These slideways are used to move heavy loads positively and accurately. In this system rollers retained in a brass cage are interposed between the sliding members. This arrangement reduces the friction between the two members of the slide because rolling friction is substituted for sliding friction.

TYPES OF GUIDEWAYS

Friction guideways



Anti-friction guideways

Friction guideways : In this type of guideways one surface is slide over the other that is why friction

guideways also called guideways with sliding friction. Metal to metal contact has a relatively high coefficient of friction and results in higher wear and heat generation

Examples : V guideway, Flat guideway, Dovetail guideway, Cylindrical guide way

Features :

1. Used on conventional machines
2. Low manufacturing cost
3. Good damping properties
4. Problem of stick slip occurs
5. Can not be Preloaded
6. Guide ways are integral part of structure and hence can not be replaced
7. Turcite / PTFE lining to reduce stick slip

Anti-friction guideways : In these type guideways balls or rollers are between the two moving surfaces. main purpose is to convert sliding friction into rolling friction since rolling friction is less than sliding friction due to this these guideways are called antifriction guideways.

Example :

- Non re-circulating ball or roller cages.
- Re-circulating ball bushings.
- Re-circulating roller bearings.

Features :

1. Low frictional resistance
2. No stick slip
3. Assembly time is minimized
4. Ease of availability
5. High load carrying capacity
6. Heavier preloading possibility
7. High traverse speeds
8. Reduce to amount of wear
9. Reduce heat generation
10. Improve the smoothness of the movement

LUBRICATION

Lubrication of slideways can be accomplished by one of the following systems:

1. **Hydrodynamic -** Lubricant (oil) applied with little or no pressure.
2. **Hydrostatic -** Lubricant (oil) applied with pressure.
3. **Aerodynamic -** Lubricant (air) applied with little or no pressure.
4. **Aerostatic -** Lubricant (air) applied with pressure

DESIGN CRITERIA

Important design criteria for slideways are:

1. **Support of Machine Members** : A machine is consists of a series of movable machine components built one upon another, with a movable joint between each component. Each movable joint is equipped with a slideway, which should provide adequate support and strength to support the subsequent machine component

2. **Static and Dynamic Characteristics** : The slideway should have adequate characteristics for both static (parked) and dynamic (moving) performance. An example of needing good static performance is during precision boring operations when slides are parked. Dynamic characteristics are important for the cutting and traversing motions of the slide.

3. **Alignment** : The design must provide a straight path for the machine slide. Cast iron constructed slideways can be brought into flatness and alignment by finish milling, grinding and/or hand scraping.

4. **Bearing Surfaces & Lubrication** : To reduce friction between the matching slideway members some type of bearing must be incorporated. Bearings fall into three categories: 1) sliding, 2) rolling and 3) pressurized (oil or air). The surface of the slide must provide stability and strength for the transfer of machining forces but also have minimal friction

SPINDLE DRIVE

Spindle provides the necessary power to rotate the tool or workpiece. Without adequate speed, horsepower and torque the machine tool will fail at its intended purpose. Most machine tools require variable-speed spindle drives to meet changing metal cutting conditions. Each machine type has its own requirements for speed, torque and horsepower

Types:

1. **Integral direct drive**
2. **External direct drive**

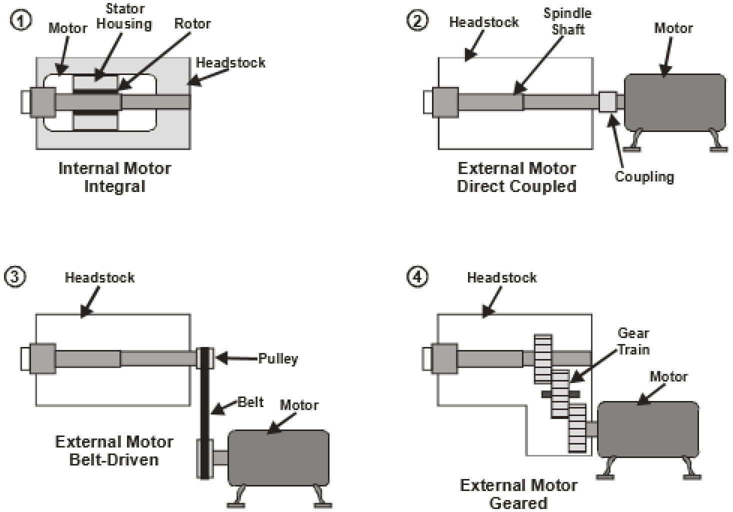


Fig. :Spindle Driver Configurations

External direct drive : In this type of drives, motor drives the main spindle shaft by means of a directly-coupled external motor. In contrast to “geared” designs, the direct in-line design will have different horsepower/torque characteristics. These units develop full horsepower at a higher rpm than a geared design.. **Advantages** :

- Eliminates gears, belts and pulleys and the associated power loss and vibration.
- Motor repair or replacement is easy.

Limitations :

- Coupling misalignment.
- With no gear ranges, lack of full HP rating at lower RPM’s.
- The in-line design requires more dimensional length in the machine design. Some heat may be transferred from the motor to the spindle bar through the solid coupling.

Configurations :

- **External Belt System** (Configuration #3) where the motor drives the main spindle shaft by means of a belt and pulley to an external motor.

Benefits – Eliminates gears and the associated power loss and gear vibration. Motor repair or replacement is easy. Low cost. Heat transfer is minimized

Limitations : Belt stretch, wear and vibration. Some systems are a single gear range while others offer multiple gear ranges through a variable pulley scheme. The machine may require a larger footprint or height.

- **External – Gear System** (Configuration #4) where the motor drives the main spindle shaft by means of gears and shafts to an external motor.

Benefits : Provides a wider speed range and full horsepower at lower RPM's. Gear ranges can accommodate a wide range of machining applications.

Limitations – Some power loss and vibration. Gear systems generate heat. The gear train requires maintenance and lubrication.

Integral direct drive : In this type of drive rotor of the electric motor becomes the main spindle shaft. This is a common type of spindle drive system on CNC machines. The integral design allows for reduced vibration and noise while increasing top rpm and efficiency. In contrast to "geared" designs, the "integral" design will have different horsepower/torque characteristics. These units develop full horsepower at a higher rpm than a geared design

Advantages : Eliminates gears, belts and pulleys and the associated power loss and vibration. Smaller machine footprint. Higher RPM’s are normally possible

Limitation : Heat buildup in spindle head requires a chiller which adds cost. Repair or replacement of spindle motor can be harder than an external motor. However, cartridge-style spindles are a relatively easy replacement. They may not be able to deliver full HP at lower RPM’s

AUTOMATIC TOOL CHANGER (ATC)

An Automatic tool changer or ATC is used in computerized numerical control (CNC) machine tools to improve the production and tool carrying capacity of the machine. ATC changes the tool very quickly, reducing the non-productive time. Generally, it is used to improve the capacity of the machine to work with a number of tools. It is also used to change worn out or broken tools. It is one more step towards complete automation in ATC a storage is provided for the tool from which a desired tool is to be opted according to the requirement of operation and tool are returned automatically to the machine tool after carrying out the required operations

The tools are stored on a magazine. It allows the machine to work with a large number of tools without an operator. The main parts of an automatic tool changer are the base, the gripper arm, the tool holder, the support arm and tool magazines. Although the ATC increases the reliability, speed and accuracy, it creates more challenges compared to manual tool change, for example the tooling used must be easy to centre, be easy for the changer to grab and there should be a simple way to provide the tool's self-disengagement. Tools used in ATC are secured in tool holders specially designed for this purpose

ATC Mechanism

After receiving the tool change command, the tool to be changed will assume a fixed position known as the "tool change position". The ATC arm comes to this position and picks up the tool. The arm swivels between machine turret and magazine. It will have one gripper on each of the two sides. Each gripper can rotate 90°, to deliver tools to the front face of the turret. One will pick up the old tool from turret and the other will pick up the new tool from the magazine. It then rotates to 180° and places the tools into their due position

TYPES OF ATC

Depending on the shape of the magazine, ATC can be of two types:

Drum Type : Changers are used when the number of tools is lower than 30. The tools are stored on the periphery of the drum.

Chain Type : Changers are used when the number of tools is higher than 30(The number is different depending on the design and manufacturer.

Note : The number of tools for the drum type is fewer than the chain type). But the tool search speed will be lower in this case

NOTE: Although the ATC increases the reliability, speed and accuracy, it creates more challenges compared to manual tool change, for example the tooling used must be easy to centre, be easy for the changer to grab and there should be a simple way to provide the tool's self-disengagement.

SENSORS

Machine tool monitoring can be done with sensors. The aim of tool condition monitoring is to detect early the disturbances in the machining process and wear of machine tool components. The condition of tool has been researched extensively in the past and have focused on detection of tool wear, tool breakage and the estimation of remaining tool life. It is very important for on-line identification of tool condition in machining process for enhanced productivity, better quality of parts and lower costs for unmanned, automated manufacturing systems.

Using additional sensors, monitoring can be done by measuring:

- The cutting force
- Vibration amplitude using multi-channel accelerometers
- Audible sound from the machining process
- High-frequency sound or acoustic emission

CNC machine tool monitoring by sensors:

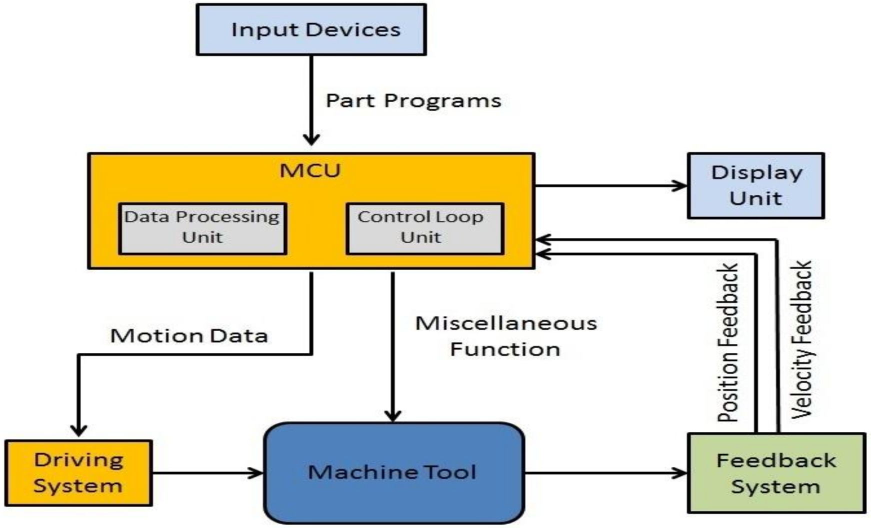
Acoustic emission sensor : AE sensor is commonly defined as the sound emitted as an elastic wave by a solid when it is deformed or struck, caused by the rapid release of localized stress energy. Therefore, it is an occurrence phenomenon which releases elastic energy into the material, which then propagates as an elastic wave. The detection frequency range of acoustic emission is from 1 kHz to 1 MHz. Rapid stress-releasing events generate a spectrum of stress waves starting at 0 Hz and typically falling off at several MHz. AE can be related to an irreversible release of energy. It can also be generated from sources not involving material failure including friction, cavitation and impact.

Major applications of AE sensors phenomena are:

- Source location - determine the locations of occurrence of an event
- Material mechanical performance - evaluate and characterize materials/structures
- monitoring – monitors the safety operation

FEEDBACK SYSTEM

- The feedback system is kind of measuring system. It uses position and speed transducers to continuously monitor the position at which the cutting tool is located at any particular instant.



- The MCU uses the difference between reference signals and feedback signals to generate the control signals for correcting position and speed errors.

The feedback in a closed loop system is the information delivered from the CNC machine to the controller. Feedback data is data that either confirms or denies that the motors have moved the machining table to the correct position and at the correct speed. Feedback can be accomplished in one of two ways.

Feedback devices are that device which sends the information back to the controller in close loop system. Encoder is a device that used to convert linear or rotational position information in to electrical output signal.

Different type of encoders are:

- Rotary optical encoder.
- Incremental Encoder.
- Absolute Encoder.
- Resolver

Lecture 25-26

Maintance of CNC

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SAFETY OPERATIONAL INSTRUCTIONS

A. GENERAL SAFETY

- Protect your eyes by wearing safety glasses.
- Wear shoes with oil resistant soles.
- If you have long hair, tie is back.
- Do not wear long sleeves, loose clothing or neck ties.
- Make sure that your area is free from chips, oil and coolant spills, air hoses or anything that may get in your way and make you to fall or slip.
- Make sure that all cutting tools and work holding equipment are tight before running the spindle or moving the slides.
- All maintenance and repair work should be done with the power off. If any work requires power ON, extreme care should be taken.
- Keep the machine always clean and keep away the tools

B. MECHANICAL SAFETY

- Care should be taken when removing a part for replacement or repair. Make sure that any connected or supported part can be safety left in the machine. If not, they should be removed also. Where orientation of adjacent parts may be important, matchmark parts before removing them.
- When performing power ON maintenance or checking of moving parts, extreme caution should be taken. These parts can cause serious injury.
- The machine should be lubricated according to the machine lubrication information given in this manual.
- When performing maintenance of the hydraulic systems, the power must be OFF and there should be no pressure in the lines.
- If you have removed any cover/guard for some reason, don't forget to refit them before you start the machine.

C. SAFETY CHECK ON THE MACHINE – BEFORE START

- Check the voltage and current.
- Check the lubricant tank oil level.
- Check the hydraulic tank oil level.
- Check the clamping devices.
- Check and clean the machine.
- Check the clamping stock.

D. SAFETY CHECK ON THE MACHINE

- Check the main pressure of the hydraulic/pneumatic system
- Check the clamping pressure of the hydraulic/pneumatic system for chuck/fixture.
- Check the chuck function.
- Lubricate the clamping device if any manual.
- Move the slides to Ref. point in Ref. point return mode.
- Jog the slides to and fro and check the sliding movement.
- Check the Centralized lubricant System manual of pressing app. Switches.
- Check the coolant supply by pressing app. Switches.
- Check the selectable zero offset entries.

MAINTENANCE

A. PREVENTIVE MAINTENANCE

- Many of the service problems that occur over the lift of any Machine tool can be avoided through the application of proper Preventive maintenance practices. The purpose of this section Of the manual is to help you in setting up a regular schedule of Periodic preventive maintenance measures for your CNC lathe.
- Keeping the machine clean is an important part of preventive Maintenance. Cleaning the machine takes only a few minutes Each shift when done on a regular basis. A program of this type Helps in keeping the point from becoming stained and the bright Metal parts from becoming rusted or discolored. Wipe the Machine thoroughly with a rig soaked in kerosene., if the machine Is in an atmosphere where bright metal parts rust quickly , wipe them with a rag soaked in clear mineral oil .never use Caustic cleaner or cleaning compounds on the machine because the abrasion can Ruin the finish . Do not use air for cleaning purpose. The pressure will drive dirt and Chips into bearing surfaces.

B PREVENTIVE MAINTENANCE CHECK LIST

The following maintenance intervals are suggested for use under Optimum conditions. If environmental conditions warrant, the Frequency of maintenance intervals should be increased.

Every eight hours of machine operation:

1) Check cleanliness of slideways.
2) Check slideway lubrication.
3) Check hydraulic oil reservoir level.

Every forty hours of machine operation:

1) Wash the machine throughly and wipe down.

Every one hundred and sixty hours of machine operation:

1) Clean oil filters.
2) Check for dirt, oil and water inside the machine electronic cabinet.
3) Check for an air tight seal of the machine electronic cabinet.
4) Check tightness of screws on terminal boards and relays

Every thousand hours of machine operation:

1) Check all motor drive belts for deterioration, wear and tension.
2) Clean and wash all way wipers and check for wear condition.
3) Drain and flush main hydraulic oil reservoir and refill with fresh hydraulic oil.

C. NORMAL OVERHAUL CHECK LIST FOR HYDROLIC SYSTEM

1) Send sample oil drawn from tank for laboratory or makers test.
2) Drain off oil, store top 90 percent in clean, dry drums. Drain off remaining ten percent and scrap.
3) Clean out sludge in tank, check for rust and condition of paint. Scrape and paint if required with correct paint.
4) Change element of air breather on tank or clean element in solvent and replenish with correct oil, according to type.
5) Clean strainer in tank filling plug.
6) Replace elements in main filters.
7) Examine flexible hoses for signs of deterioration of lining, proper attachment of end fittings and possible cracking here and at points of maximum flexing.
8) Check free running of pump and motor.
9) Check for end play and side play in pump and motor shafts, indicating bearing wear.
10) Check free movement of valve spool etc.
- Check for operations of solenoids and relays.
11) Top up oil to correct level.
12) Tighten oil pipe connections. Do not over strain.

MACHINING CENTRES

These are very important types of CNC Machine Tools and are multifunction Machines equipped with automatic tool changers and are capable of carrying out milling, drilling, teaming, tapping, boring, counter boring and allied operations-without operator intervention for change of tools

ACCORDING TO THE SPINDLE CONFIGURATION

- Horizontal spindle machining centers
- Vertical spindle machining centers
- Universal machining centers

Types of Maintenance

- Corrective Maintenance
- Preventive Maintenance
- Backlog Maintenance
- Deferred Maintenance
- Total Productive Maintenance

SAFETY INSTRUCTIONS

1. Obtain instructor's permission.

2. Do not alter or modify any machinery, tooling or accessory unless you contact an instructor and obtain permission.

3. Review all NC set up and operating procedures provided.

4. Review all NC programming instructions provided.

5. Prepare and review your program carefully.

6. Edit your program for safety, format, correctness and clarity.

7. It is highly recommended that all programs be verified before the actual trial on the machine.

8. Wear safety shoes.

9. Secure long hair or loose clothing that could become caught or tangled in the moving parts of machine

10. Wear your safety glasses.
11. Use caution when changing tools – no interference with fixture or work.
12. Clamp all work securely before starting machine. Only approved materials can be machined.
13. Avoid bumping any NC machine or controls. Work must not be held by hand while machining. Clamp it properly and securely in the vise.
14. Avoid using machine in wet, damp or poorly lighted work areas.
15. Perform all setup work with spindle stopped. Always stop the spindle completely before changing or adjusting the work piece, fixture or tool.
16. Wrenches, tools, and other parts should be kept off the machine and all its moving units. Do not use machine elements as a workbench.
17. Do not remove any guards or shields from any piece of equipment.
18. It is very unsafe to use gloves while operating rotating machinery.
19. Press the green Power on button so you can load your program to the machine controller.
20. Stop the machine immediately if you notice any irregularity! In all emergency situations, always push emergency STOP button.

Lecture 27-29

CNC Programming

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What is a Part Program?

- CNC Part Program is a detailed or step by step list of instruction that need to be executed by the Machine Control Unit to achieve the final component shape.
- This step by step instruction is written in a manner the MCU can understand as well as the operator for a repair, or to debug the program

What Does Part Program Entail?

Generating a Part Program for a part involves lot of preparatory work.

This also involves thorough understanding of the machine tool functionality, cutting tools, Feed and Speeds, surface finish, work holding, tool pre-setting, in-process measurement, corrective measurements and such.

The main steps are,

1. Process Planning
2. Machining Datum selection
3. Tool Selection
4. Cutting Parameters
5. Job and Tool Setup planning
6. Machining Planning
7. Part Program Writing
8. NC Proving

- Manual [Write code directly]
- Computer-assisted [Draw cutter path]
- CAD/CAM [Draw the part, Cutter path is generated]

- Offline programming linked to CAD programs.
- Conversational programming by the operator.
- MDI ~ Manual Data Input.
- Word-Address Coding using standard G-codes and M-codes.

Basics of NC Part Programming:

During secondary motion either the tool motion, moves relative to the workpiece or the workpiece moves relative to the tool.

In NC programming, it is always assumed that the tool moves relative to the workpiece no matter what the real situation is.

The position of the tool is described by using a **Cartesian coordinate system**. If (0,0,0) position can be described by the operator, then it is called *floating zero.*

Structure of an NC Part Program:

Commands are input into the controller in units called *blocks or statements.*

Block Format:

1. Fixed sequential format
2. Tab sequential format
3. **Word address format**

Example: Assume that a drilling operation is to be programmed as:

1. The tool is positioned at (25.4,12.5,0) by a rapid movement.
2. The tool is then advanced -10 mm in the z direction at a feed rate of 500 mm/min., with the flood coolant on
3. The tool is then retracted back 10 mm at the rapid feed rate, and the coolant is turned off.

Word address format

N50 G00 X25400 Y125 Z0 F0
N60 G01 Z-10000 F500 M08
N70 G00 Z0 M09

INFORMATION NEEDED by a CNC

1. **Preparatory Information**: units, incremental or absolute positioning
2. **Coordinates**: X,Y,Z,RX,RY,RZ
3. **Machining Parameters**: Feed rate and spindle speed
4. **Coolant Control**: On/Off, Flood, Mist
5. **Tool Control**: Tool and tool parameters
6. **Cycle Functions**: Type of action required
7. **Miscellaneous Control**: Spindle on/off, direction of rotation stops for part movement rotation,

This information is conveyed to the machine through a set of instructions arranged in a desired sequence – **Program**.

BLOCK FORMAT

Sample Block

N135 G01 X1.0 Y1.0 Z0.125 F5

Restrictions on CNC blocks

- Each may contain only one tool move
- Eachmay contain any number of non-tool move Gcodes
- Eachmay contain only one feedrate
- Eachmay contain only one specified tool or spindle speed
- The block numbers should be sequential
- Both the program start flag and the program number must be independent of allother commands (on separate lines)
- The data within a block should follow the sequence shown in the above sample block

Example CNC Program

```
N5 G90 G20
N10 M06 T3
N15 M03 S1250
N20 G00 X1 Y1
N25 Z0.1
N30 G01 Z-0.125 F5
N35 X3 Y2 F10
N40 G00 Z1
N45 X0 Y0
N50 M05
N55 M30
```

Eachinstruction to the machine consists of a letter followed bya number.

Eachletter is associated with a specific type of action or pieceof information needed by the machine.

Letters used in Codes

N,G,X,Y,Z,I,J,K,F,S,T,M

Word Format

N070 G01 X5 Y4 F200 S100 T05 M08

Tab Sequential Format

N070	G01	X5	Y4	F200	S100	T05	M08
71	01	10	tab				
72	G00	tab	Y10			T06	

Fixed block Format

N	G	X	Y	F	S	T	M
70	01	5	4	200	100	05	08
71	01	10		200	100	05	08
72	00	0	10	200	100	06	09

Part Programming Basics

- Typically the part program starts with a %, indicating beginning of the tape or beginning of a program
- A series of Alphabets and a number constitutes a block (Similar to a sentence in a paragraph)
- Each Block starts with a Block Number using N and a 3 digit number, EX: N115, N001…
- In each Block, the sequence of addresses is important. (You don't want the tool to start moving in Z direction, without the spindle being switched on)

Part Programming Basics

- Preparatory codes like G codes have a number ranging from 00 – 99 soon after the alphabet G, Ex; G00, G90 etc.
- For real values like motion in X, Y or any axis, decimals can be used. EX: X540.11 Y-40.301 etc.
- A plus sign is not necessary, it is assumed to be a positive number if not sign is indicated.
- Feed functions is indicated using F150 where in 150 is the feed rate of 150 mm/minute
- Spindle speed is indicated by S1500, where

Part Programming Basics

- Tools function is represented by T 11 where in 11 indicates the 11th tool. Some times tool offset values also can be linked to the specific tool. EX: T1513 indicates tool no. 15 with offset values in the registry no. 13.
- Comments are necessary to communicate between various machine tool operators. These are indicated by using brackets.

EX: N010 G00 Z50.0 M05 (Spindle stops and moves up rapidly)

O0500 (II shift operator must load tool offset values from T0123)

Programming consists of a series of instructions in the form of letter codes

Preparatory Codes:

- N codes- specify program line number to executed by the MCU
- G codes- Initial machining setup and establishing operating conditions
- Axis Codes:
  - X,Y,Z - Used to specify motion of the slide along coordinates related X, Y, Z direction
  - U,V,W- mostly are related to home position coordinates set by manufacturer of machine
  - i,j,k- coordinate representation in incremental related to X, Y, Z direction,
    mostly used in rotation motion or some specific commands

- Feed and Speed Codes: F and S- Specify feed and spindle speed
- Tool codes: T – specify tool number

Miscellaneous codes – M codes are used for program on/off or coolant control or other such activities

Programming Key Letters

O - Program number (Used for program identification)

N - Sequence number (Used for line identification)

G - Preparatory function

X - X axis designation

Y - Y axis designation

Z - Z axis designation

R - Radius designation

F – Feed rate designation

S - Spindle speed designation

H - Tool length offset designation

D - Tool radius offset designation

T - Tool Designation

M - Miscellaneous function

N Codes

Gives an identifying number for each block of information.

It is generally good practice to increment each block number by 5 or 10 to allow additional blocks to be inserted if future changes arerequired.

X,Y, and Z Codes

X, Y,and Zcodes are used to specify the coordinate axis.

Number following the code defines the coordinate at the end of the move relative to an incremental or absolute reference point.

I,J, and K Codes

I, J,and Kcodes are used to specify the coordinate axis when defining the center of acircle.

Number following the code defines the respective coordinate for the center of thecircle.

F-code: used to specify the feed rate

S-code: used to specify the spindle speed

T-code: used to specify the tool identification number associated with the tool to be used in subsequent operations.

Preparatory Functions

These are denoted by G. Typically followed by a two digit number. Ex. G01, G00, G40…

Some of the standard ISO G codes are,

CODE	FUNCTION
G00	Point to Point positioning
G01	Line interpolation
G02	Circular Interpolation, Clockwise
G03	Circular Interpolation Counter CW
G04	Dwell
G05	Hold/ Delay
G06	Parabolic Interpolation
G08	Acceleration of Feed rate
G09	Deceleration of Feed rate

Preparatory Functions

CODE	FUNCTION
G10	Linear Interpolation for Long Dimensions (10-100 in)
G11	Line interpolation for short dimensions (up to 10 in.)
G13-16	Axis Designation
G17	XY plane designation
G18	YZ plane designation
G19	ZX plane designation
G20	Circular Interpolation CW for long dimensions
G21	Circular Interpolation CW for Short dimensions
G30	Circular Interpolation CCW for long dimensions
G31	Circular Interpolation CCW for Short dimensions

Preparatory Functions

CODE	FUNCTION
G33	Thread Cutting Constant Lead
G34	Thread Cutting Linearly increasing Lead
G35	Thread Cutting Linearly decreasing Lead
G40	Tool Compensation cancels to Zero
G41	Tool Radius Compensation- Offset left
G42	Tool Radius Compensation- Offset Right
G43	Tool compensation Positive
G44	Tool compensation Negative
G54-59	Datum Point / Zero Shift
G63	Tapping Cycle
G70	Units in Inches
G71	Units in Metric

Preparatory Functions

CODE	FUNCTION
G80	Canned Cycle Cancelled
G81-G89	Canned Drilling and Boring Cycles
G90	Absolute Dimensions
G91	Incremental Dimensions
G94	Feed Rate in mm/min
G95	Feed Rate in Rate/Rev

Miscellaneous Functions, M

These help function some of the machine tool controls. Typically used with M and associated two digit number. Two or more M terms are permitted in a block as long as they are not mutually exclusive.

EX: M03 Spindle ON CW

M04 Spindle OFF CCW

Table of Important M codes

- M00 Program stop
- M01 Optional program stop
- M02 Program end
- M03 Spindle on clockwise
- M04 Spindle on counterclockwise
- M05 Spindle stop
- M06 Tool change
- M08 Coolant on
- M09 Coolant off
- M10 Clamps on
- M11 Clamps off
- M30 Program stop, reset to start

Program Number

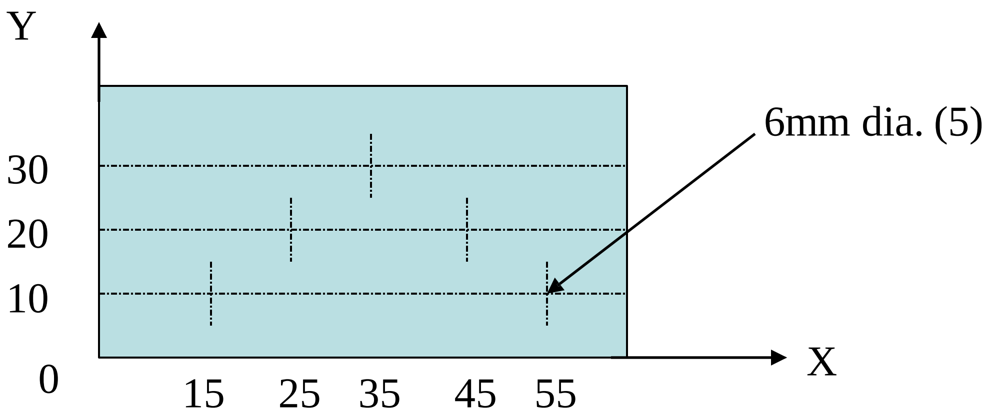
Each program has an assigned program number to help identify it. Most of the latest CNC systems use “O” or “:” as the indicator for the program number.

EX: O0500 or :0500

Sub programs which can be called in anytime during the course of the main program are represented with “P”

EX:	M98 P0100	Calls sub-routine P0100
	M99	Ends sub routine

Absolute and Incremental Systems, G90 and G91



<u>Absolute System:</u>

N001 G90 G01 X15 Y10

N002 X25 Y20

N003 X35 Y30

N004 X45 Y20

N005 X55 Y10

<u>Incremental System:</u>

N001 G91 G01 X15 Y10

N002 X10 Y10

N003 X10 Y10

N004 X10 Y-10

N005 X10 Y-10

Unit Groups G70, G71

- G70 stands for programming in Inch Units G71 stands for programming in Metric Units Based on the type of the machine control
  - system program, one of these will be a default entry. It can be changed as needed. Once reset using M02 or M30, default unit will take effect.

Motion Groups, G00, G01, G02, G03

<u>Rapid Positioning G00</u>

By using G00, the machine will traverse at the maximum available feed rate. Such rapid feeds can vary from 8,000 to 40,000 mm/min along the major linear axes.

This is a modal code. That means, it stays active until it is cancelled by one other G code of the same family like, G01, G02 or G03.

N001 G90 G00 X100 Y100 Z65

Motion Groups, G00, G01, G02, G03

- Linear Positioning G01
- By using G01, the machine will traverse at the feed rate set by the F code. This F number depends on material being cut, type of tool used, rigidity of the machine tool and such parameters.
- This is a modal code. That means, it stays active until it is cancelled by one other G code of the same family like, G00, G02 or G03.
- N001 G90 G00 X100 Y100 Z65

N002 G01 Z-10.0 F100 S1500 M03

Motion Groups, G00, G01, G02, G03

Circular Interpolation CW G02

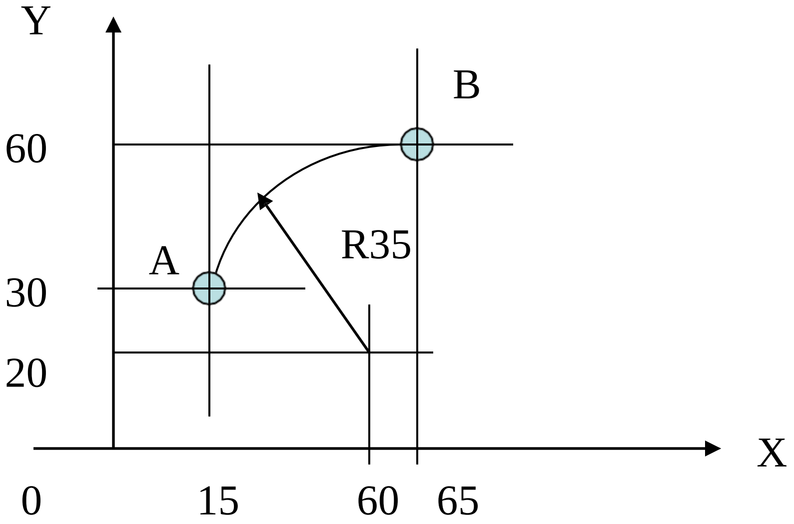
Two G codes are used with circular motion. G02 is commonly used to specify clockwise motion while G03 is used to specify counter clockwise motion. To evaluate which to use, you simply view the movement from the same perspective the machine will view the motion. For example, if making a circular motion in XY on a machining center, simply view the motion from the spindle's vantage point. If making a circular motion in XZ on a turning center, simply view the motion from above the spindle. In most cases, this is as simple as viewing the print from above.

G02 and G03 can be used to traverse along a full circle or partial circle (Arc).

To program a circular path, two sets of information are needed. First is the destination point co-ordinates (X,Y) and second is the distance along X and Y from the center of the arc to the starting point of the arc. (I, J).

Motion Groups, G00, G01, G02, G03

Circular Interpolation CW G02



Motion Groups, G00, G01, G02, G03

Circular Interpolation CW G02

In the above picture, to travel from A to B, in XY plane, the program block can be written as below.

N050 G02 X65 Y60 I35 J-10 F100

However, if the travel is from B to A, the program block will be,

N060 G03 X15 Y30 I-5 J-40

Motion Groups, G00, G01, G02, G03

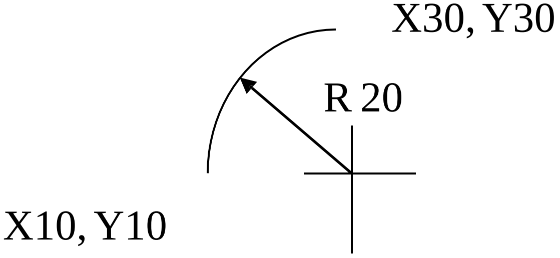
Circular Interpolation CW G02

Some systems let you use the Radius value directly, however a full circle can not be made with the R value.

To use R value, the tool is placed at the start of the arc and end point co-ordinates and R value are indicated.

N001 X10 Y10

N005 X30 Y30 R20.0 F100



Dwell, G04

This function lets the tool to stay in its place without turning off the spindle.

Typically denoted by G04 followed by X and a number indicating dwell period in seconds.

EX: N001 G04 X3.0

Used during reaming operation, or sometimes to perform in-process inspection operation.

Part program: A computer program to specify.

- Which tool should be loaded on the machine spindle;
- What are the cutting conditions (speed, feed, coolant ON/OFFetc)
- The start point and end point of a motion segment
- How to move the tool with respect to the machine.

Standard Part programming language: RS274-D (Gerber, GN-code)

The RS274-D is a **word address format**

Each line of program == 1 **block**

Each block is composed of several instructions, or (**words**)

Sequence and format of words:

N3 G2 X+1.4 Y+1.4 Z+1.4 I1.4 J1.4 K1.4 F3.2 S4 T4 M2

sequence no

destination coordinates

dist to center of circle

tool

feed rate

spindle speed

preparatory function

miscellaneous function

Product Name
Code

Billet [$\overset{d}{x}$ y $\overset{L}{z}$] Size of work pi product

N001 G71 G90 94 F80

G71 → metric mm

G90 → absolute

94 → Feed mm/min

N002 M06 T01 M03 M06 → coolant on

M06 → tool selection

M03 → spindle start

Return

coolant stop

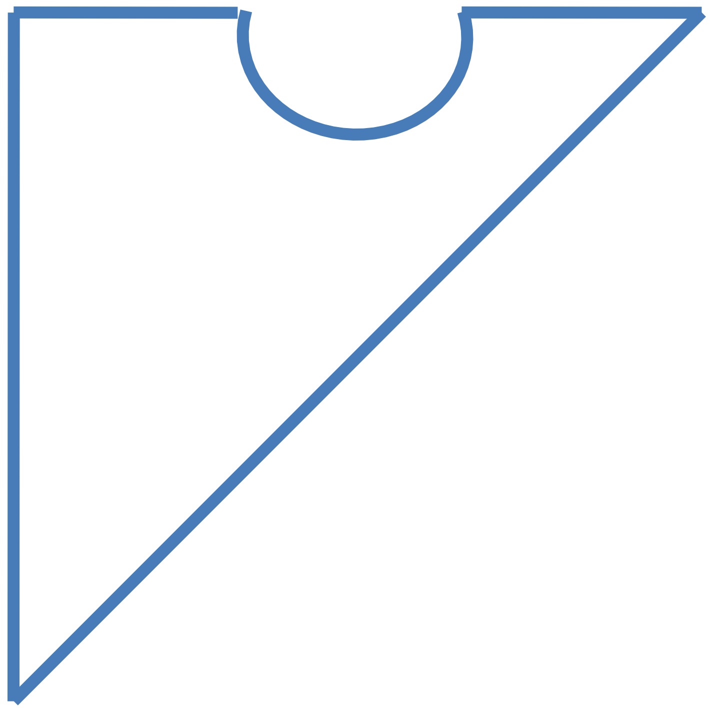
Program End

N.. M99, M08, M30

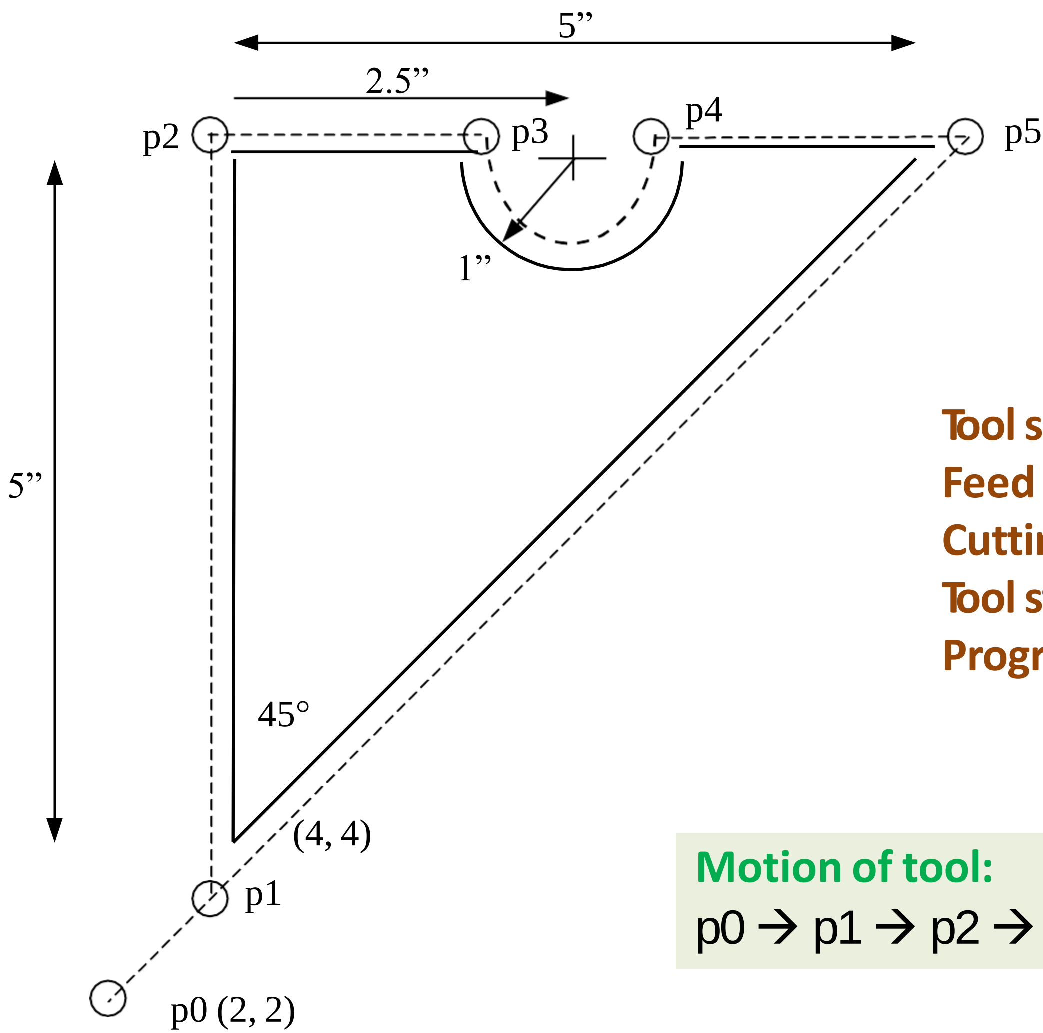
M31

Manual Part Programming Example

Write a G-code program for the part shown below



```
N010 G70 G90 G94 G97 M04
N020 G17 G75 F6.0 S300 T1001 M08
N030 G01 X3.875 Y3.698
N040 G01 X3.875 Y9.125
N050 G01 X5.634 Y9.125
N060 G03 X7.366 Y9.125 I6.5 J9.0
N070 G01 X9.302
N080 G01 X3.875 Y3.698
N090 G01 X2.0 Y2.0 M30
N100 M00
```

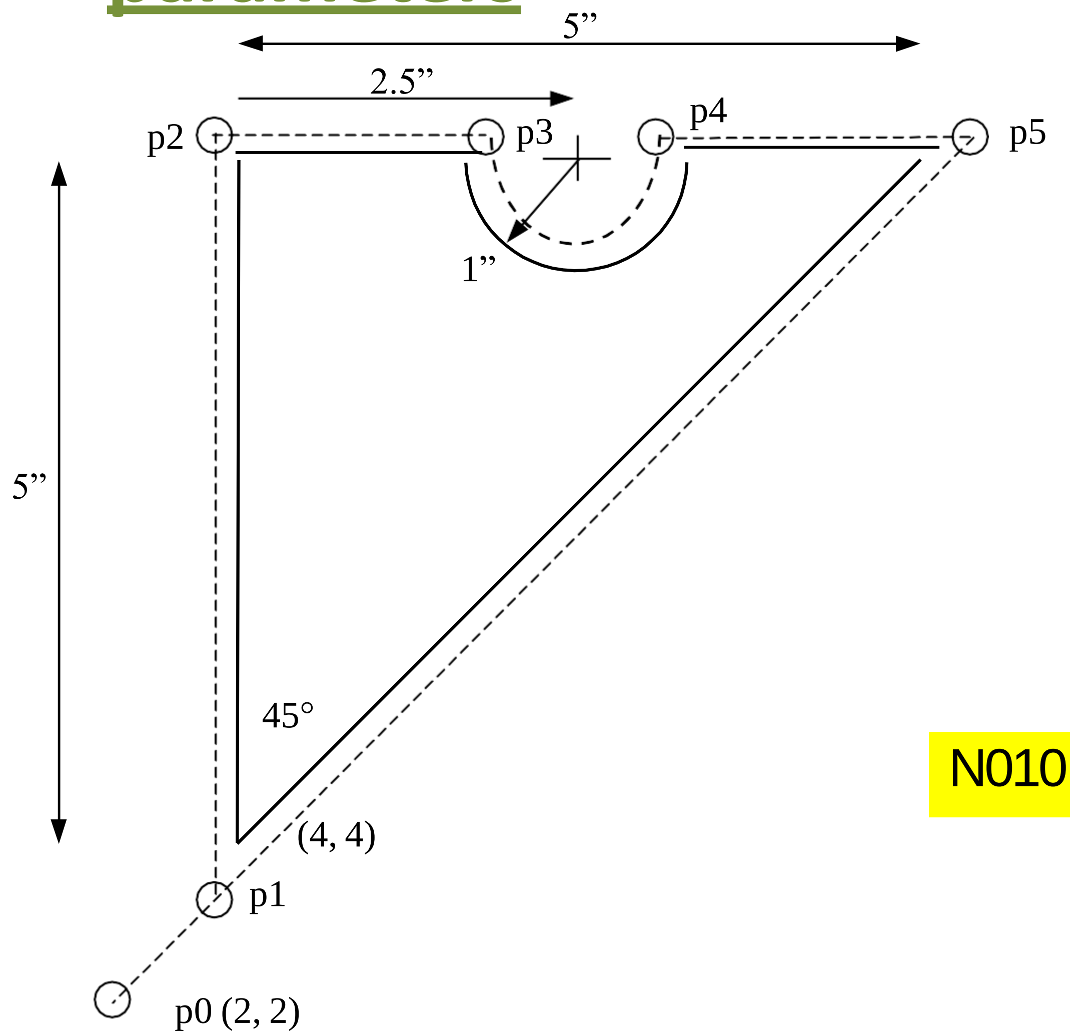


Tool size = 0.25 inch,
Feed rate = 6 inch per minute,
Cutting speed = 300 rpm,
Tool start position: 2.0, 2.0
Programming in inches

Motion of tool:

p0 → p1 → p2 → p3 → p4 → p5 → p1 → p0

1. Set up the programming parameters



Programming in inches

Use absolute coordinates

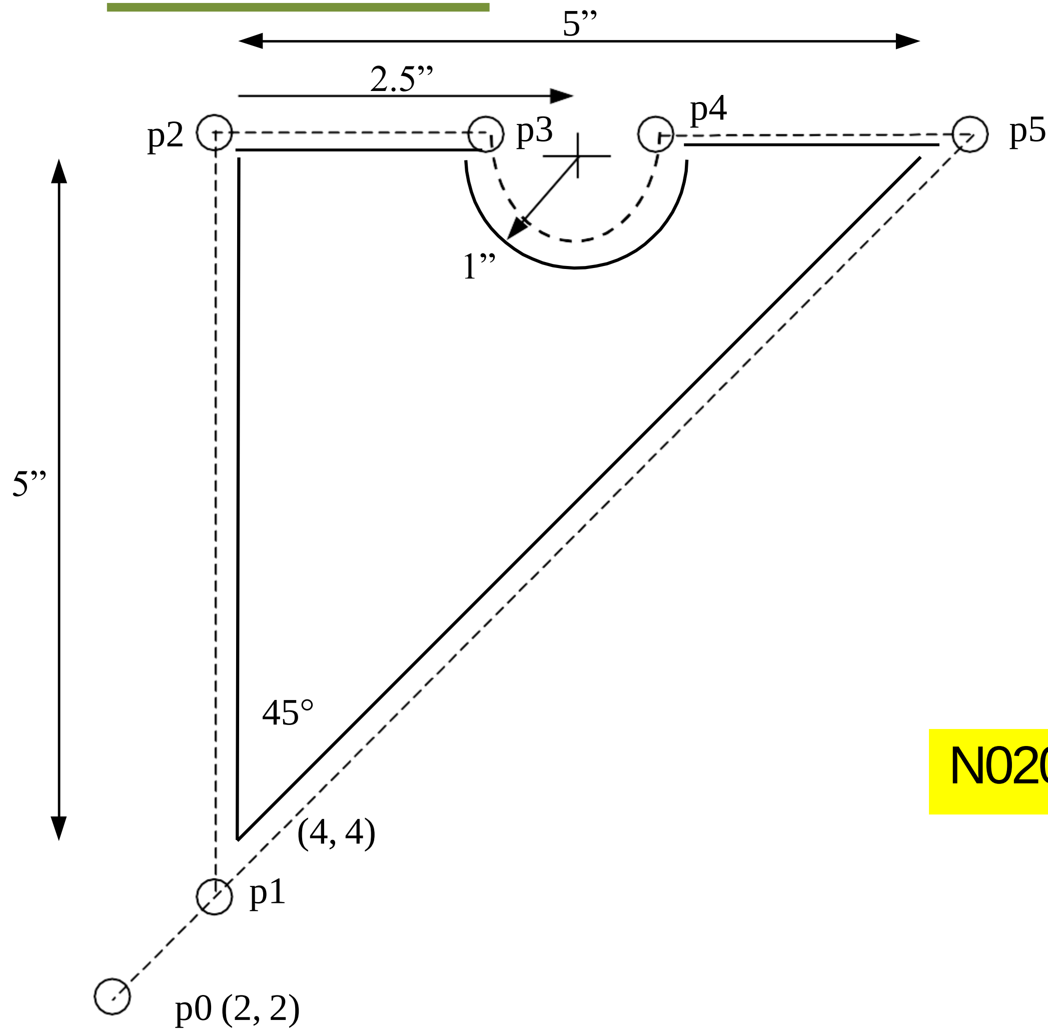
Feed in ipm

N010 G70 G90 G94 G97 M04

Spindle speed in rpm

Spindle CCW

2. Set up the machining conditions



Machine moves in XY-plane

Use full-circle interpolation

Feed rate

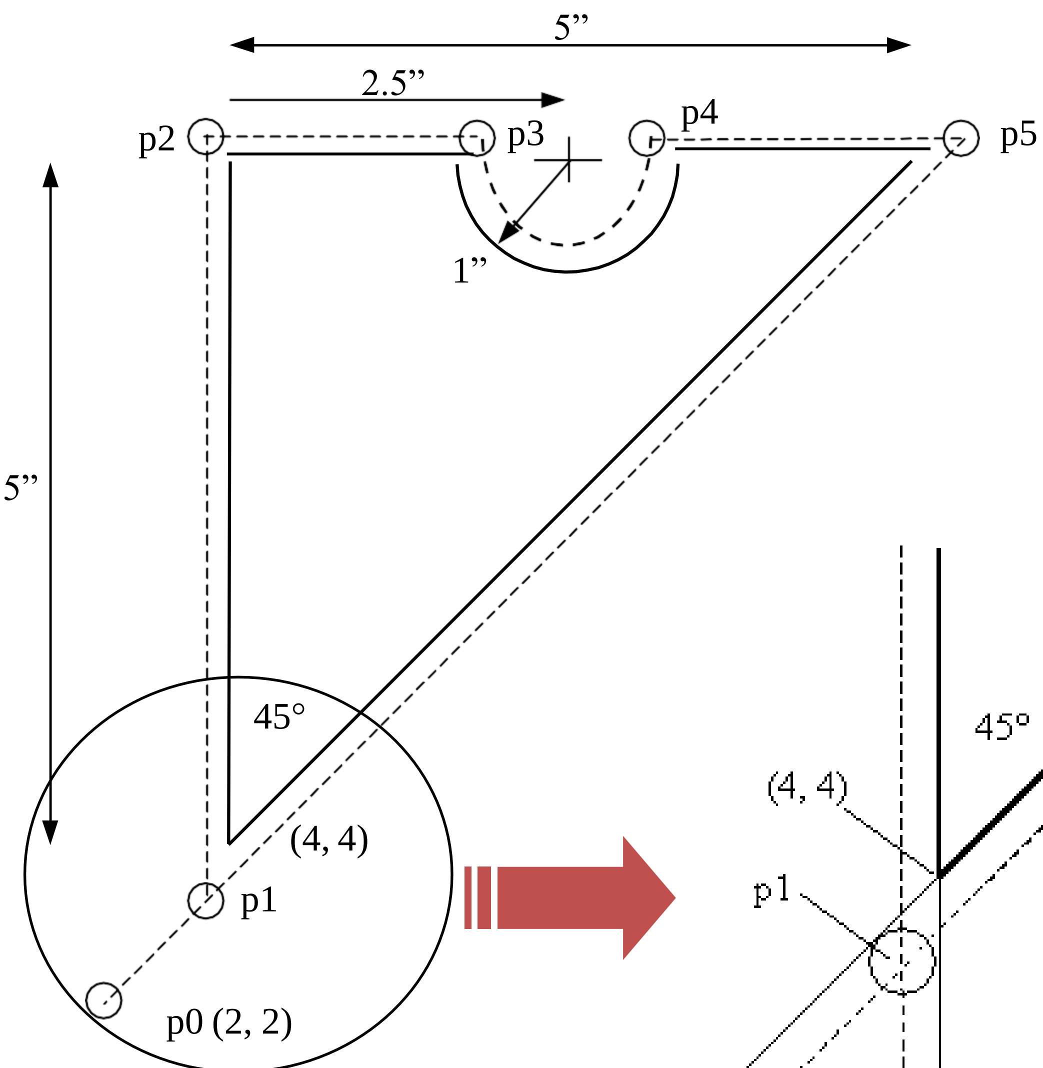
Spindle speed

N020 G17 G75 F6.0 S300 T1001 M08

Tool no.

Flood coolant ON

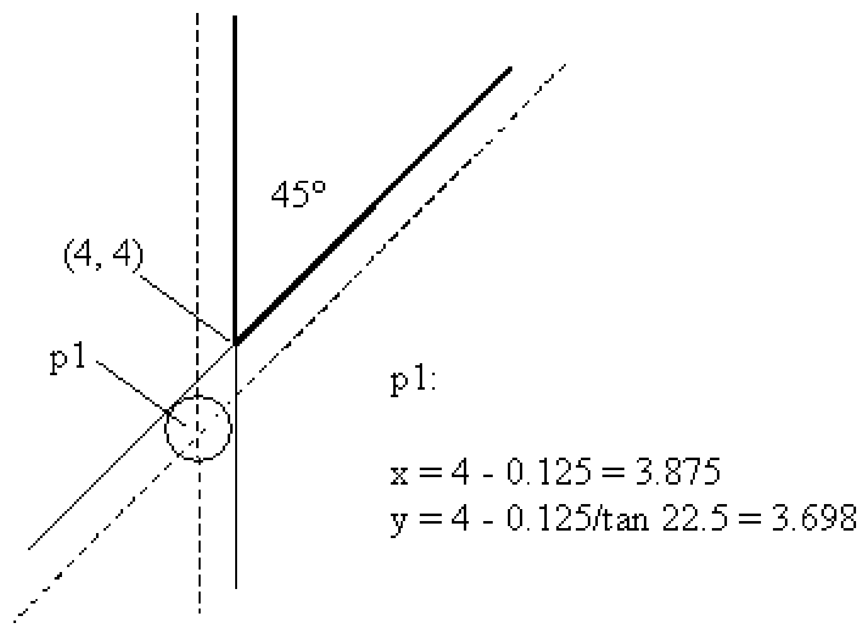
3. Move tool from p0 to p1 in straight line



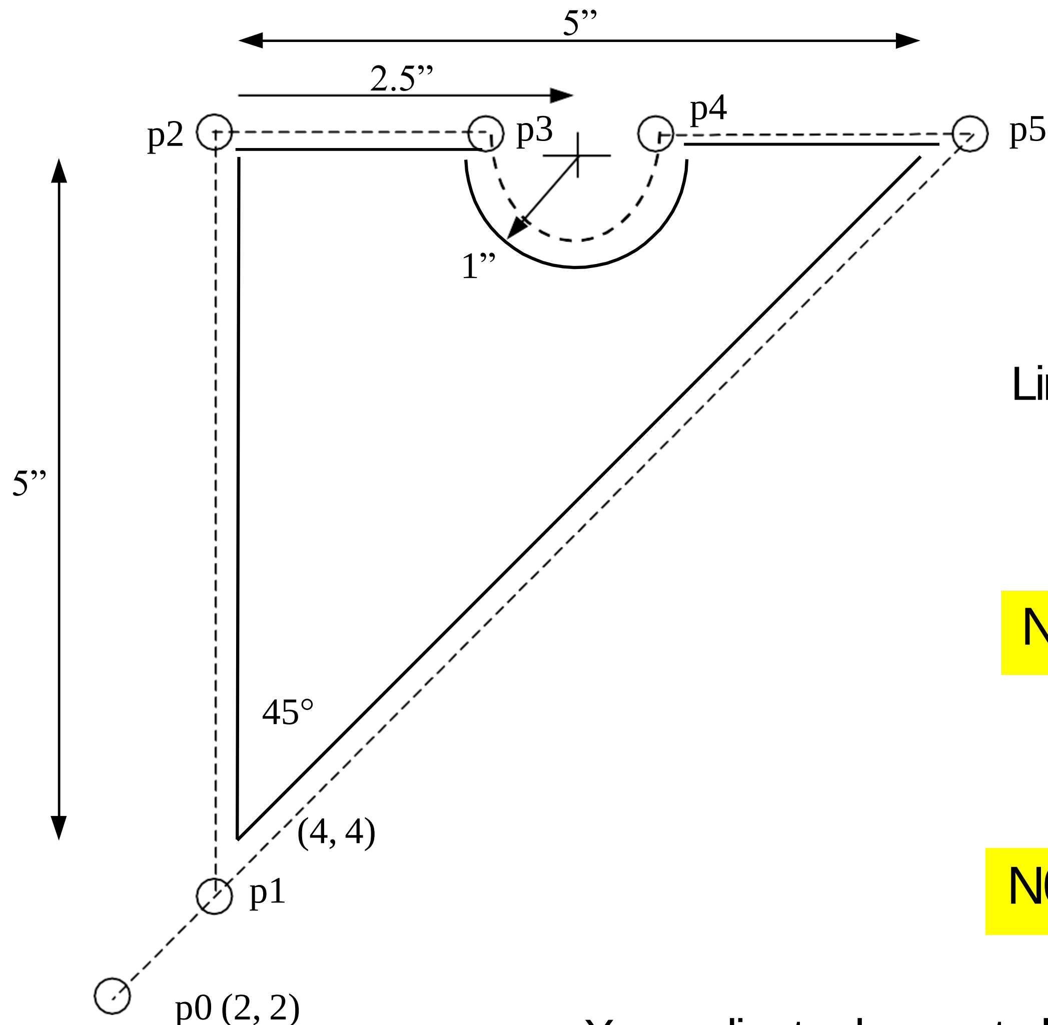
Linear interpolation

target coordinates

N030 G01 X3.875 Y3.698



4. Cut profile from p1 top2



Linear interpolation

target coordinates

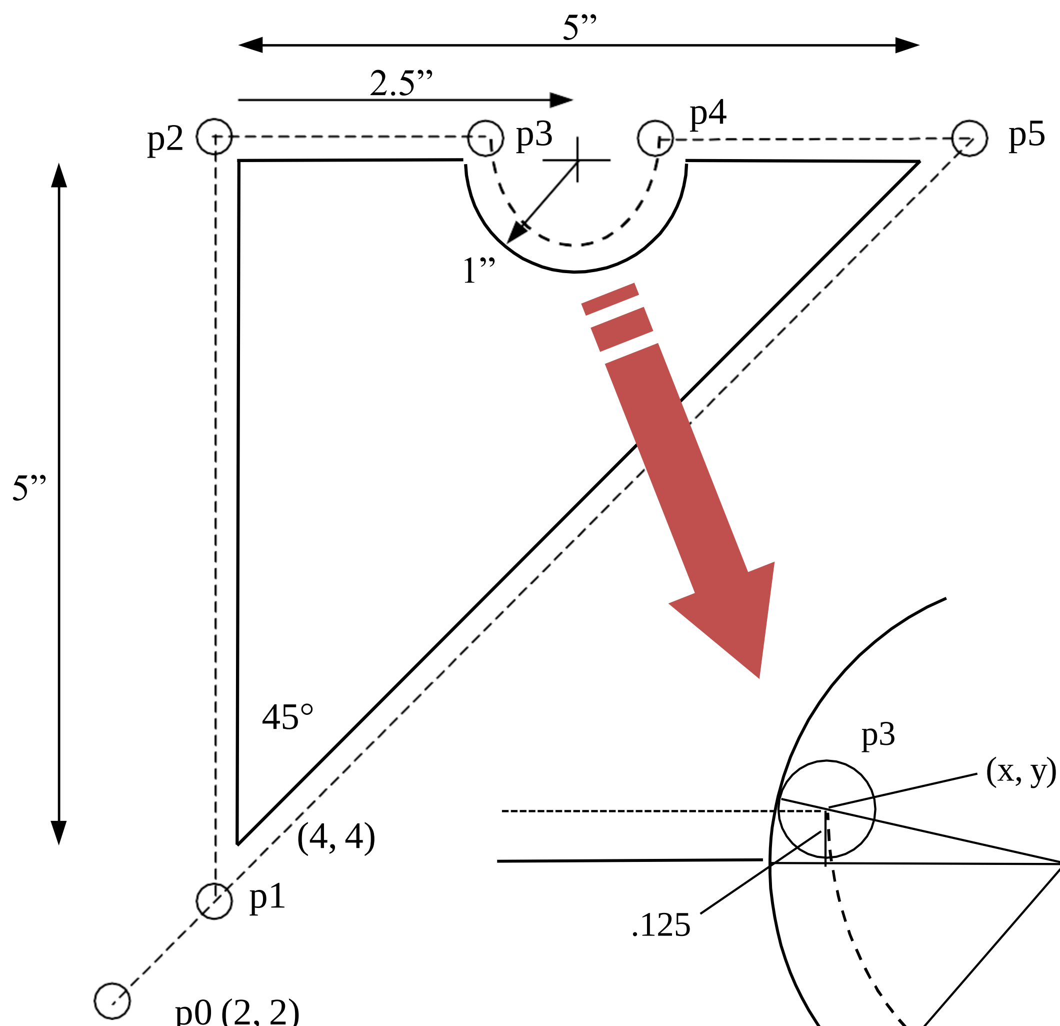
N040 **G01** **X**3.875 **Y**9.125

or

N040 **G01** **Y**9.125

X-coordinate does not change → no need to program it

5. Cut profile from p2 top3



Linear interpolation

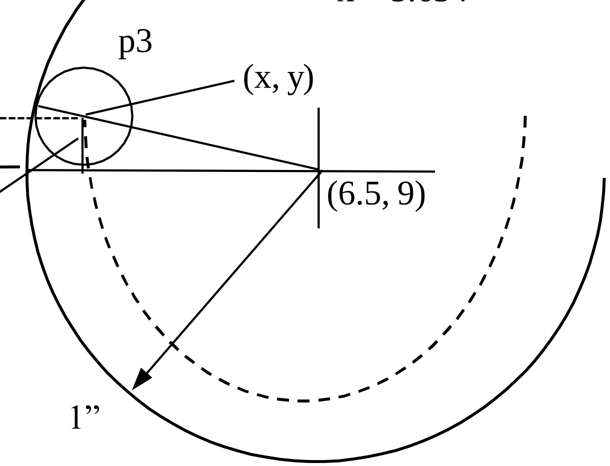
target coordinates

N050 G01 X5.634 Y9.125

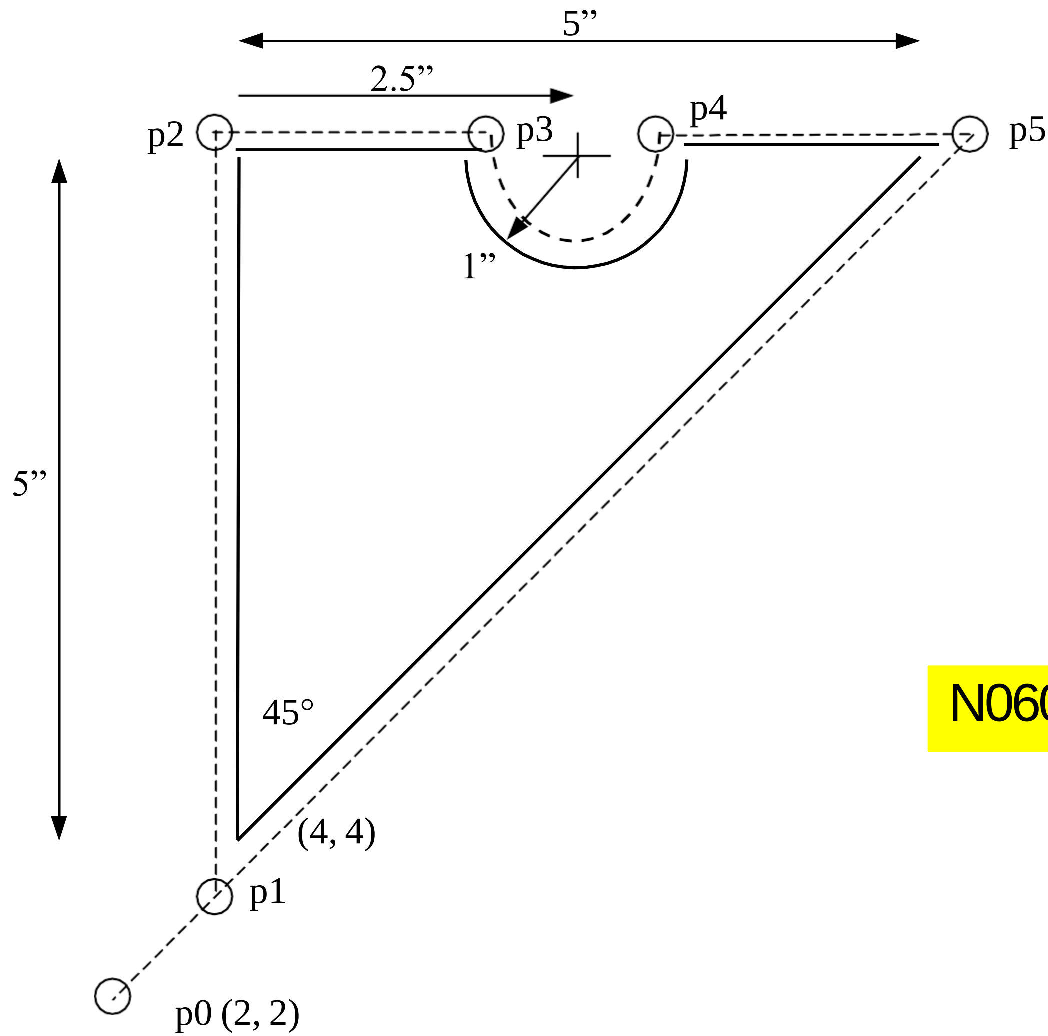
$y = 9 + 0.125 = 9.125$

$(6.5 - x)^2 + 0.125^2 = (1 - 0.125)^2$

$x = 5.634$



6. Cut along circle from p3 top4



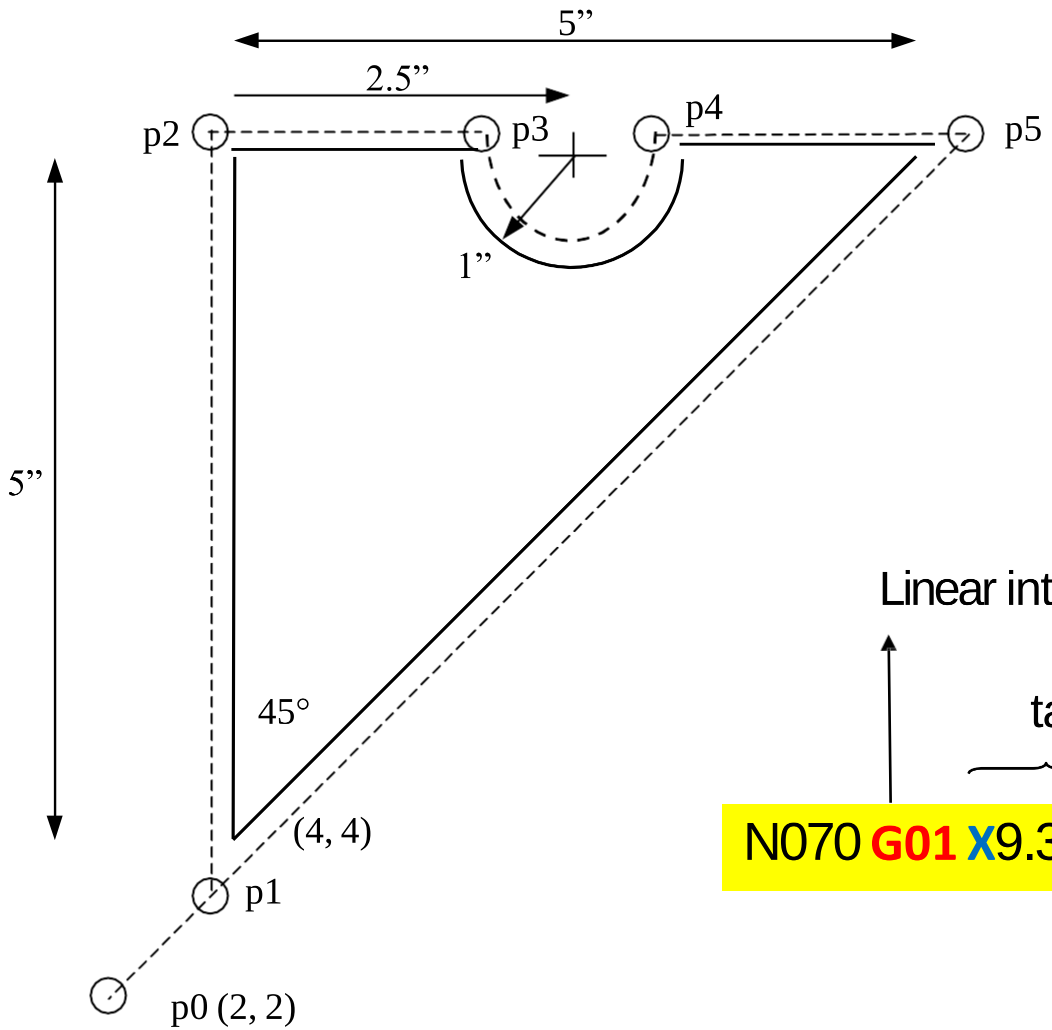
circular interpolation, CCWmotion

target coordinates

N060 **G03** **X**7.366 **Y**9.125 **I**6.5 **J**9.0

coordinates of center of circle

7. Cut from p4 to p5

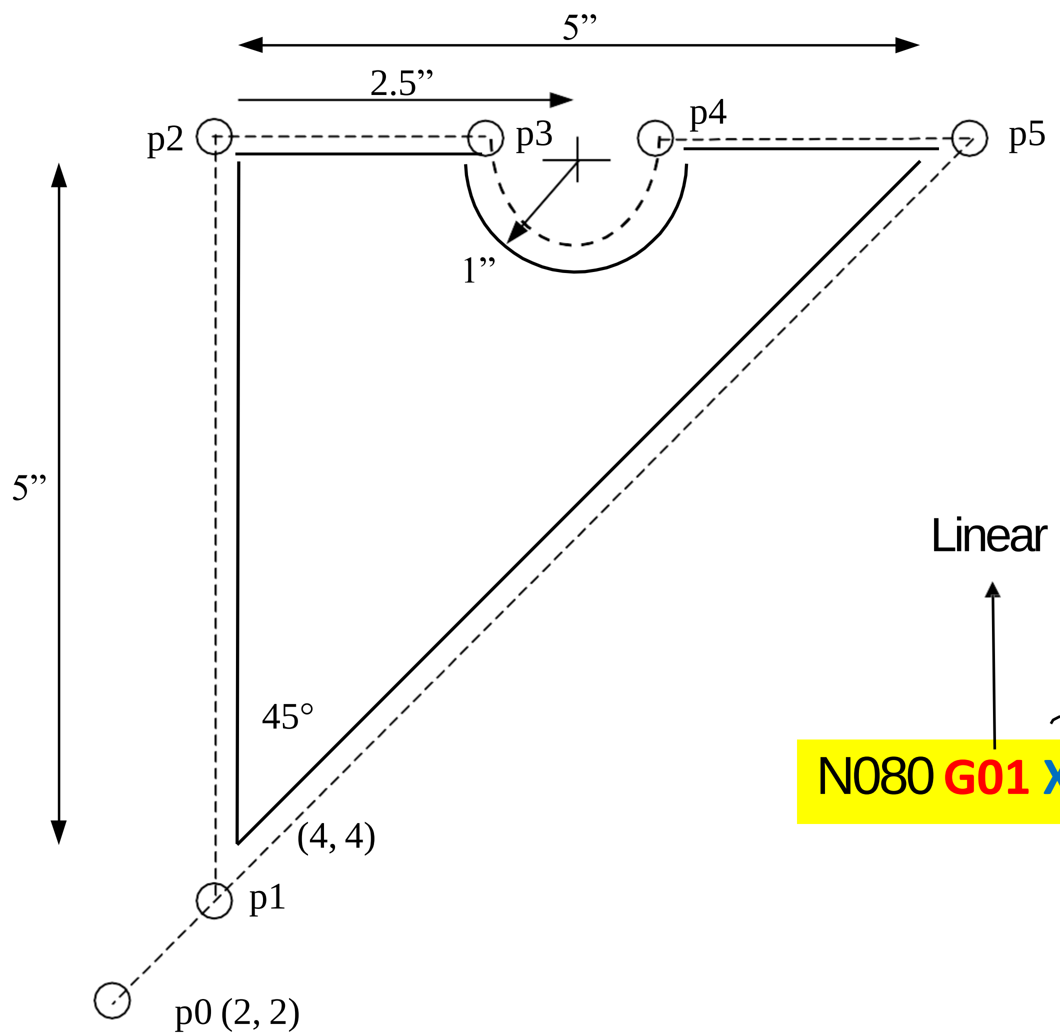


Linear interpolation

target coordinates (Y is unchanged)

N070 **G01** **X**9.302

8. Cut from p5 to p1

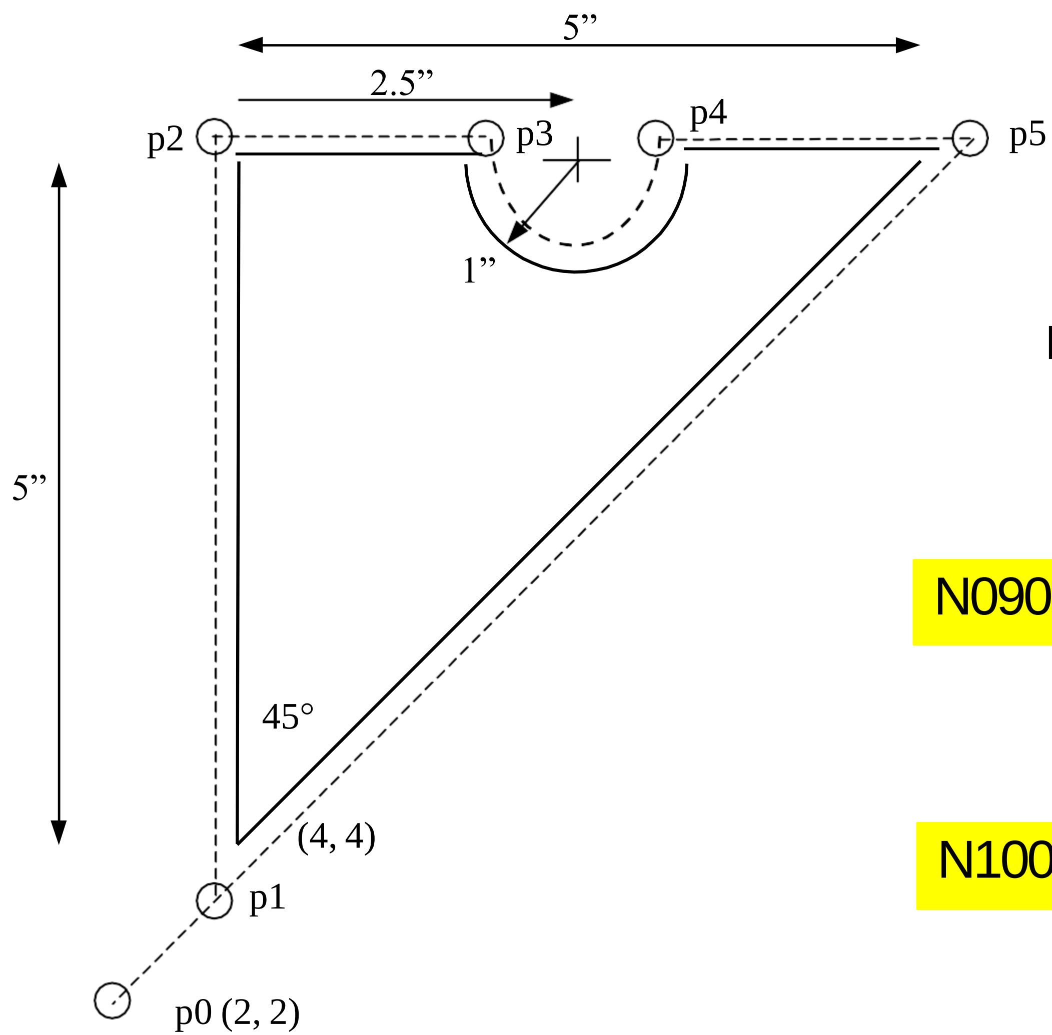


Linear interpolation

target coordinates (see step 3)

N080 G01 X3.875 Y3.698

9. Return to home position, stop program



Linear interpolation

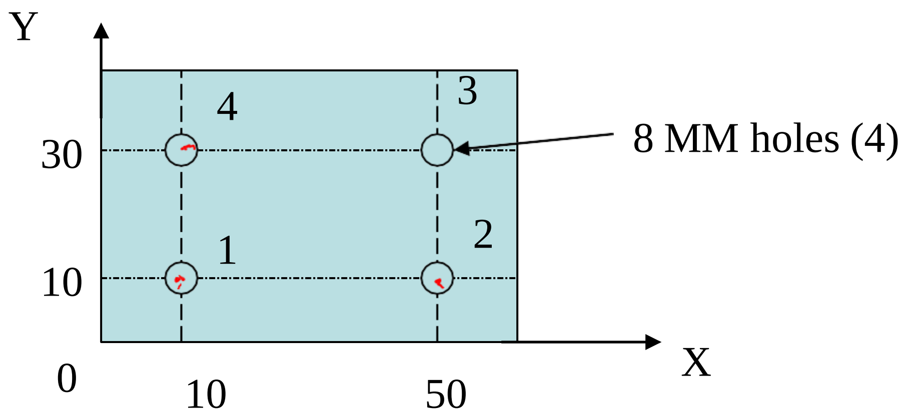
target coordinates (see step 3)

N090 G01 X2.0 Y2.0 M30

end of data

N100 M00

program stop

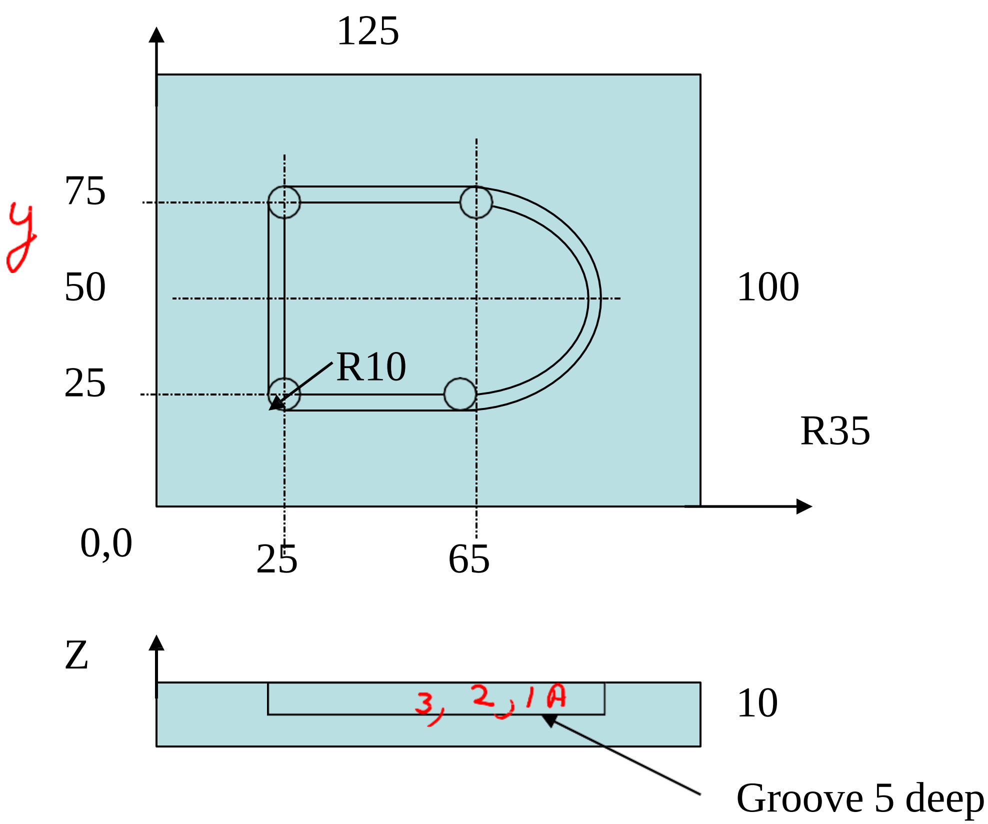


Let us look into making a program using Word Address Format to machine above part.

O0500 (Program no. 0500)

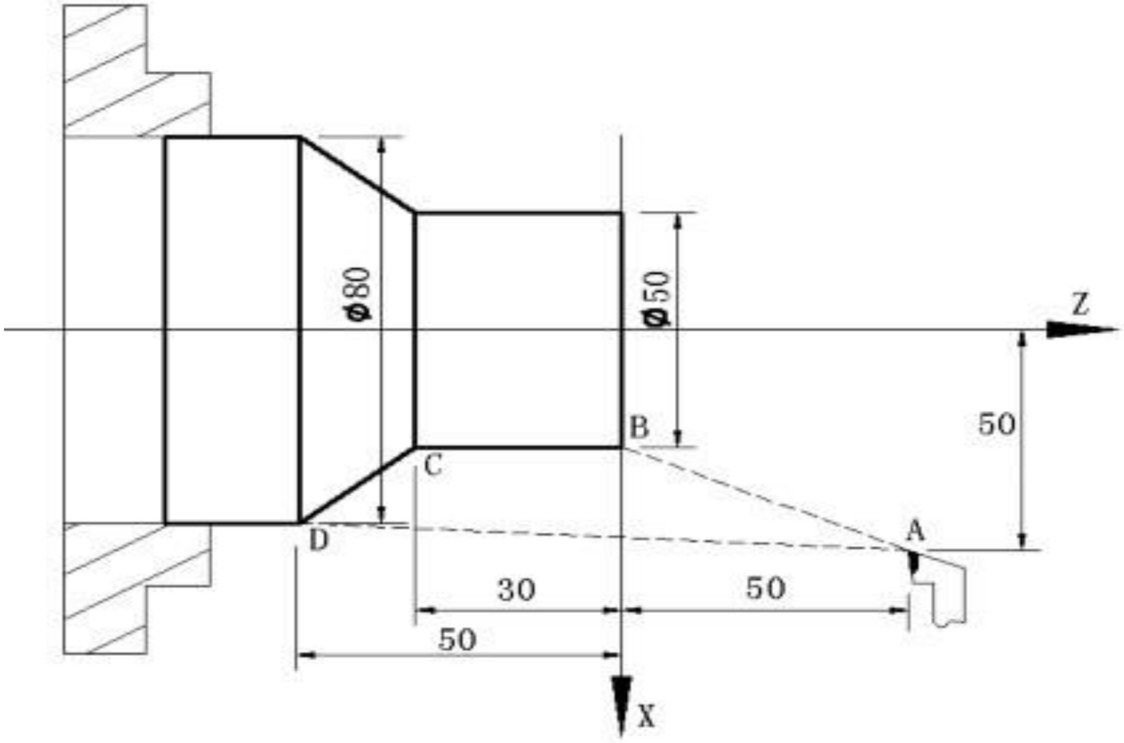
N005 G90 G01 T01 F200 S1500 M03 (Abs Prog, Lin Int, Tool 1, Feed 200mm/min, Sp RPM 1500, CW)

N010 X10 Y10	**(Go to Hole no. 1)**
N015 X50 Y10	**(Go to Hole no. 1)**
N020 X50 Y30	**(Go to Hole no. 1)**
N025 X10 Y30	**(Go to Hole no. 1)**
N030 M05 M30	**(Spindle off, End Prog)**

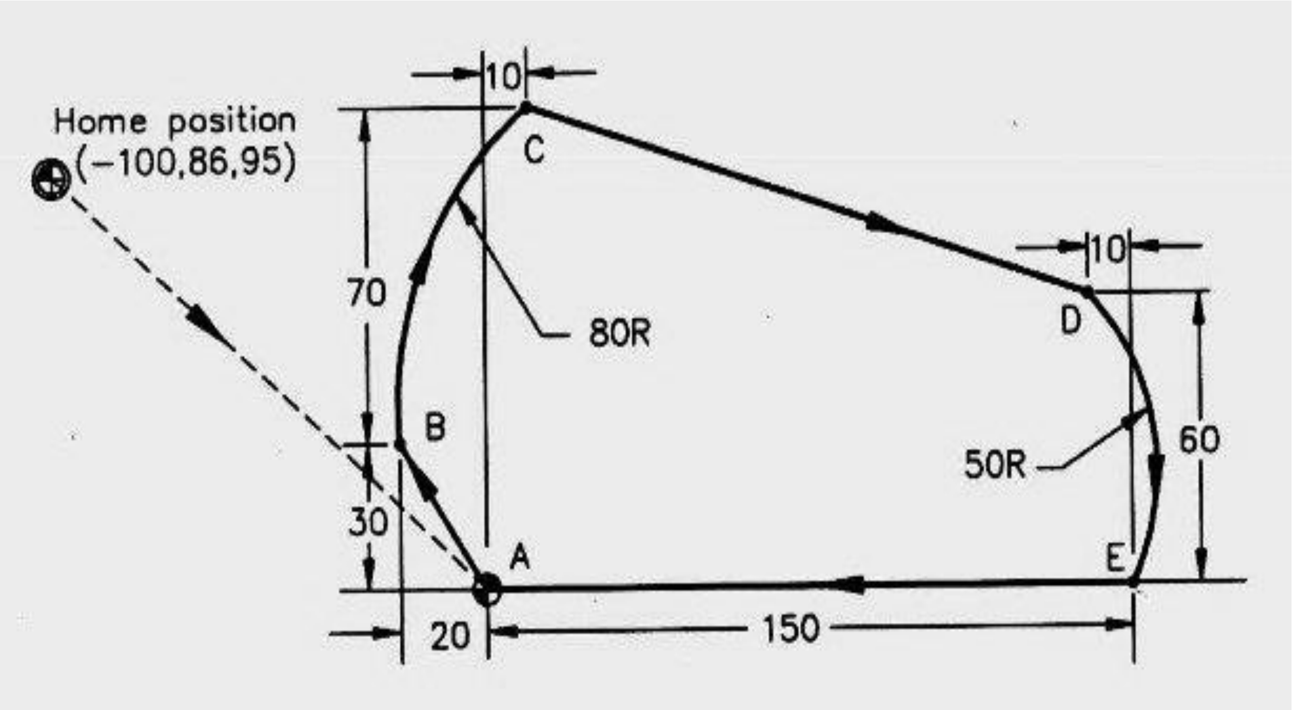



```
O0500
N005 G92 X0 Y0 Z0
N010 G90
N015 G00 X25 Y25 Z12 T01 S3000 M03
N020 G01 Z-5 F120
N025 Y75
N030 X65
N035 G02 Y25 I0 J-25
N040 G01 X25
N045 Z12.0
N050 G00 Z15 M05
N055 X0 Y0
N060 M30
```

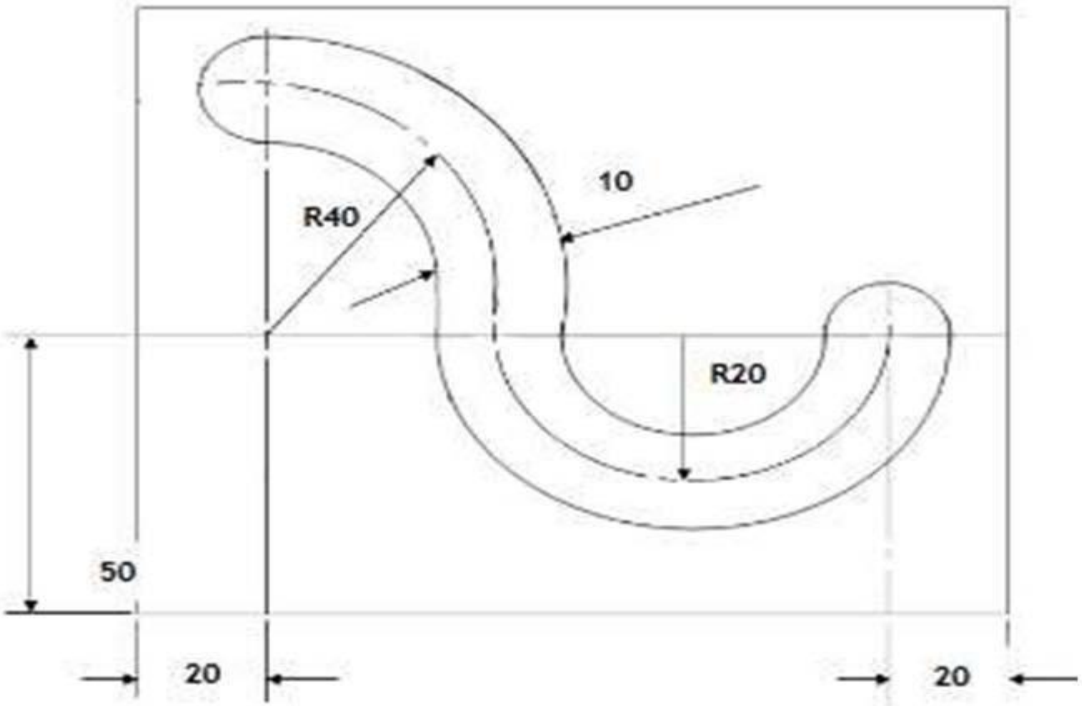
CNC Turning operation




```
N5 M12
N10 T0101
N15 G0 X100 Z50
N20 M3 S600
N25 M8
N30 G1 X50 Z0 F600
N40 Y-30 F200
N50 X80 Y-20 F150
N60 G0 X100 Z50
N70 T0100
N80 M5
N90 M9
N100 M13
N110 M30
```




```
N5 G90 G71
N10 T1 M6
N15 G92 X-100 Y86 Z95
N20 G0 X0 Y0 S2500 M3
N25 Z12.5
N30 G1 Z-12.5 F150
N35 X-20 Y30
N40 G2 X10 Y100 R80
N45 G1 X140 Y60
N50 G2 X150 Y0 R50
N55 G1 X0 Y0
N60 G0 Z12.5
N65 G91 G28 Z0 M5
N70 G91 G28 X0 Y0
N75 M30
```



Circular Interpolation

N2 G17 G71 G90 G94 G54

N4 T1 L90

N6 G00 Z5 D5 M3 S500 X20 Y90

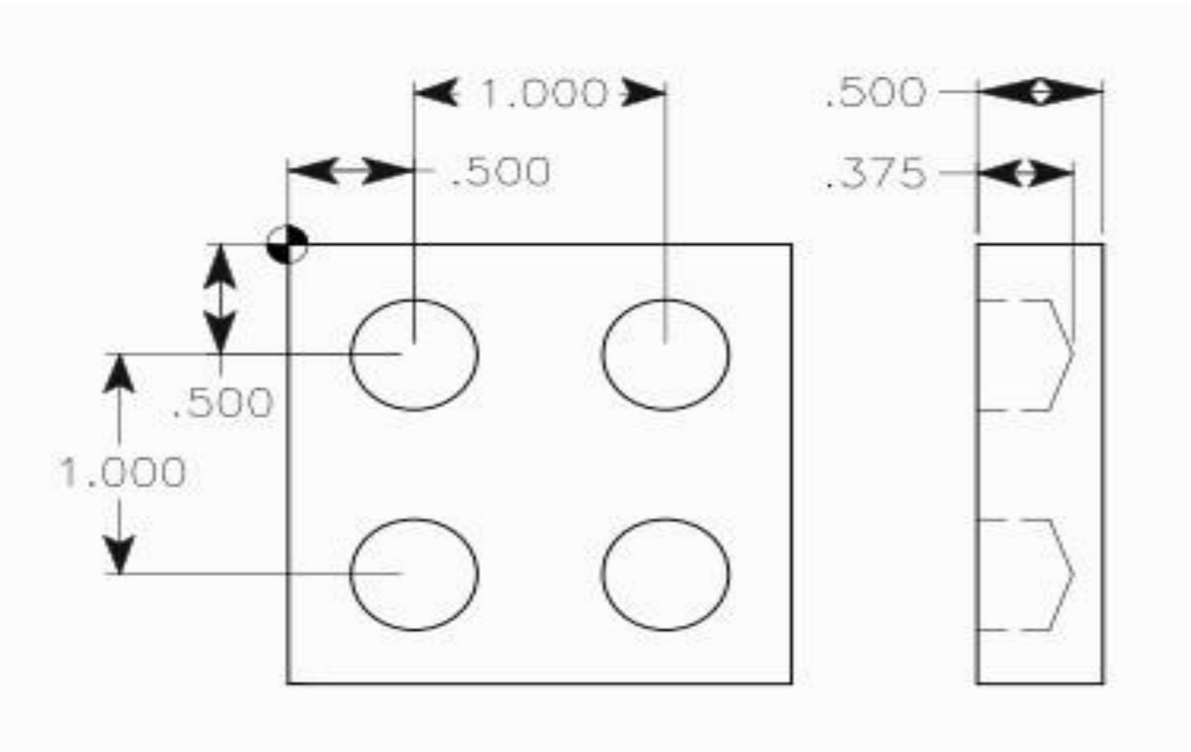
N8 G01 Z-2 F50

N10 G02 X60 Y50 I0 J-40

N12 G03 X80 Y50 I20 J0

N14 G00 Z100

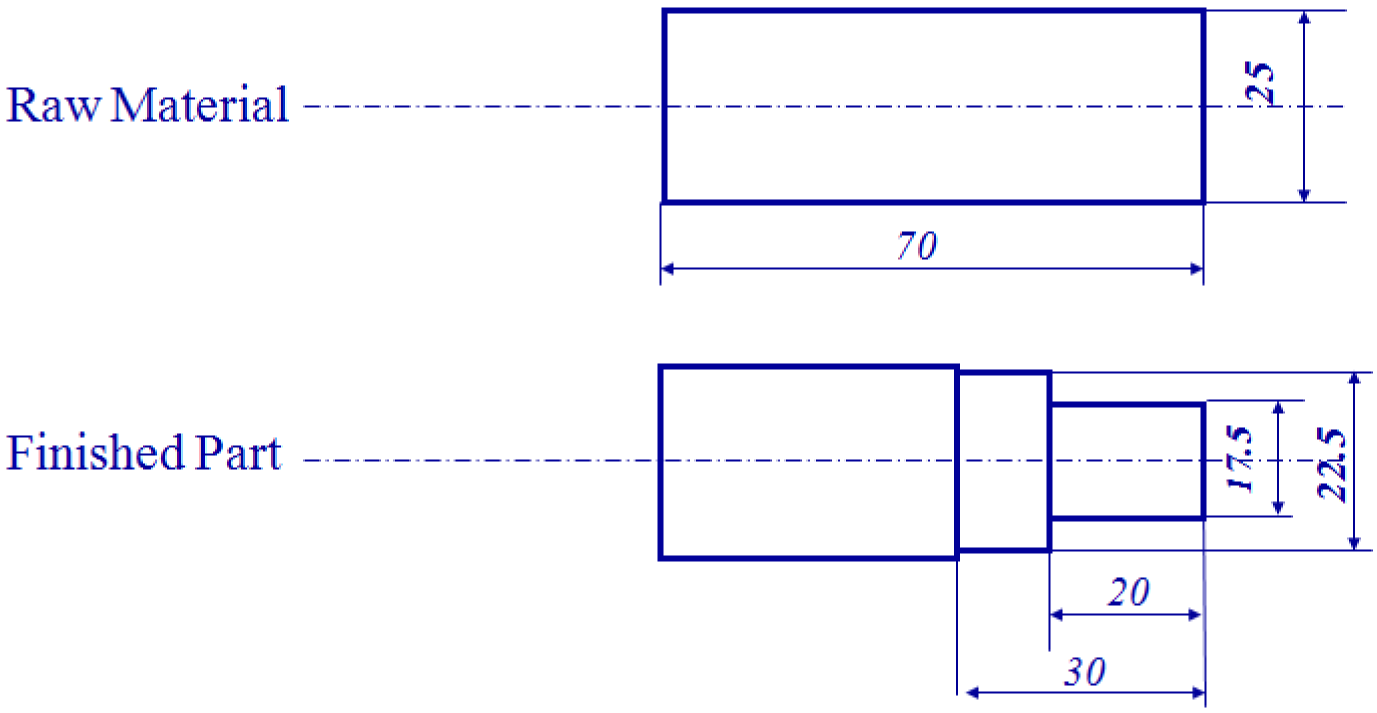
N16 M02



N1 T16 M06
N2 G90 G54 G00 X0.5 Y-0.5
N3 S1450 M03
N4 G43 H16 Z1. M08
N5 G81 G99 Z-0.375 R0.1 F9.
N6 X1.5
N7 Y-1.5
N8 X0.5
N9 G80 G00 Z1. M09
N10 G53 G49 Z0. M05
N11 M30

CNC Programming Example [2]

Cylindrical Part



N0005 G53

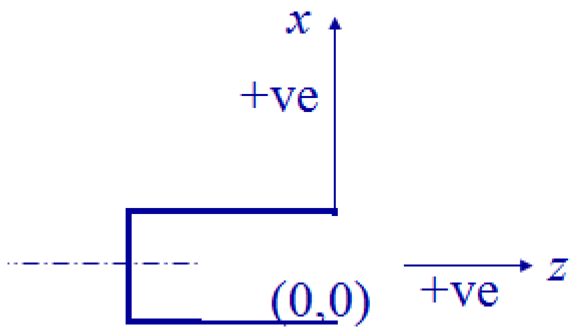
To cancel any previous working zero point

N0010 T0404

N0010 Sequence number
T0404 Select tool number 404

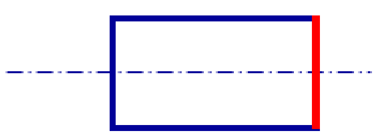
N0020 G57 G00 X26.0 Z0.0 S500 M04

G57 To set the working zero point as saved
G00 Rapid movement (no cutting)
X26.0 *X* location (as a diameter; 13 form zero)
Z0.0 *Z* location
S500 Spindle speed is 500 rpm
M04 Rotate spindle counterclockwise



N0030 G01 X-0.20 F100

G01 Linear interpolation (cutting)
X-0.20 Move only in x direction until you pass the center by 0.1 mm (facing)
F100 Set feed rate to 100 mm/min.



N0040 G00 Z2.0

G00 Move rapidly away from work piece (no cutting)
Z2.0 the movement is 2 mm away from the face.

N0050 X50.0 Z50.0

Go to a safe location away from the workpiece [x = 50 (25 from zero), z = 50] to change the tool.

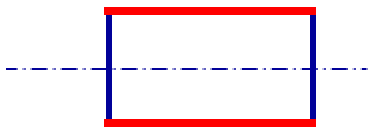
N0060 T0404

T0404 Select tool number 404

N0070 G57 G00 X22.50 Z2.0 S500

G57 PS0
G00 Rapid movement (no cutting)
X22.50 *X* location (as a diameter; 11.25 form zero)
Z2.0 *Z* location
S500 Spindle speed is 500 rpm

N0080 G01 Z-30.0 F100

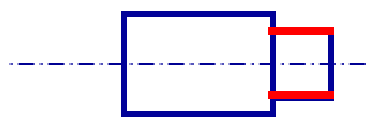


G01 Linear interpolation (cutting)
Z-30 Move only in z direction (external turning)
F100 Set feed rate to 100 mm/min.

N0090 G00 X23.0 Z2.0 S500

G00 Move rapidly away from work piece (no cutting) to location x= 23.0 (11.50 from zero) and z = 2.0.

N0100 G84 X17.5 Z-20.0 D0=200 D2=200D3=650



G84 Turning cycle for machining the step
X17.5 final diameter
Z-20 length of step is 20 mm
D0=200 Finish allowance in X direction (0.2 mm) D2=200 Finish allowance in Z direction (0.2 mm)
D3=650 Depth of cut in each pass (0.65 mm)

N0110 G00 Z2.0

G00 Move rapidly away from workpiece (no cutting)
Z2.0 the movement is 2 mm away from the face.

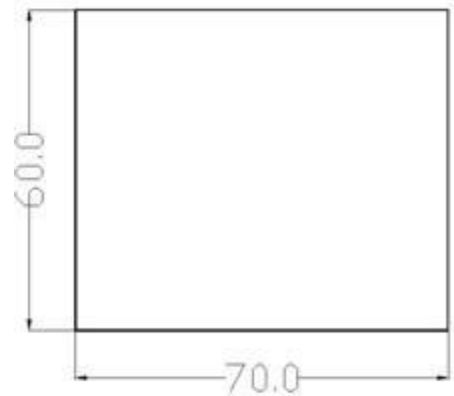
N0120 X50.0 Z50.0

X50.0 Z50.0 Move to the tool changing location

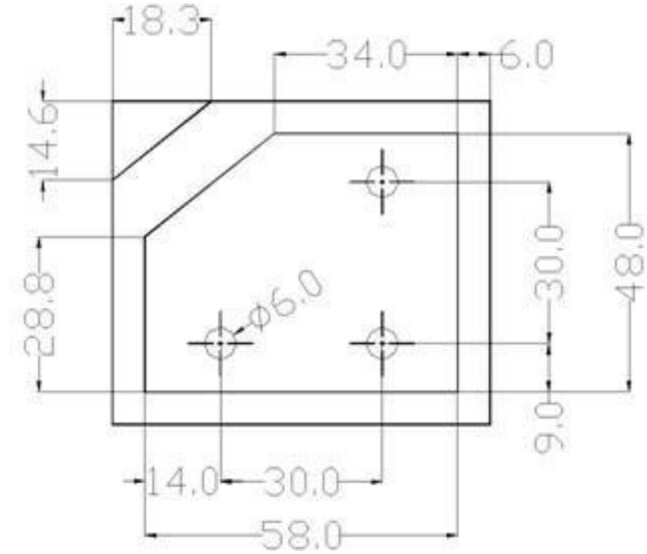
N0130 M30

M30 Program End

Example [3]



Row Material



Finished Part

Tool Change
G55 X200 Y80
Program 2
N001 M06 T2
N002 M03 rpm 400
N003 G01 X-8 Y0 Z0 XYFeed 150
N004 G01 X20 Y15 Z10 XYFeed 150 ZFeed 150
N005 G01 X20 Y15 Z-10 ZFeed 75
N006 G01 X20 Y15 Z10 ZFeed 150
N007 G01 X50 Y15 Z10 ZFeed 150
N008 G01 X50 Y15 Z-10 ZFeed 75
N009 G01 X50 Y15 Z10 ZFeed 150
N010 G01 X50 Y45 Z10 ZFeed 150
N011 G01 X50 Y45 Z-10 ZFeed 75
N012 G01 X50 Y45 Z10 ZFeed 150
N013 M05
N014 M02

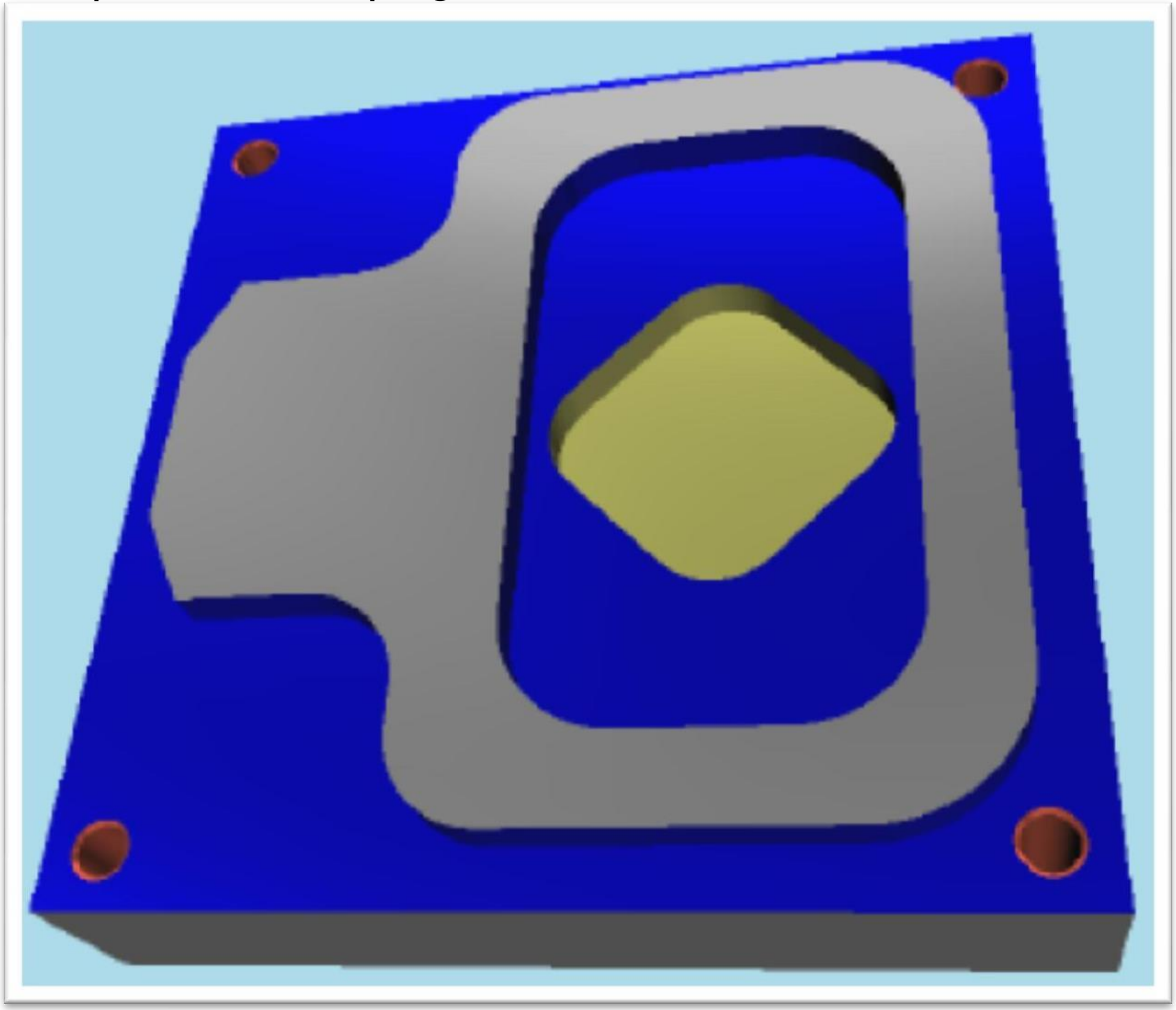
G55 X200 Y80
Program 1
N001 M06 T1
N002 M03 rpm 400
N003 G01 X-8 Y0 Z0 XYFeed 150
N004 G01 X-8 Y0 Z-0.5 ZFeed 150
N005 G01 X70 Y0 Z-0.5 XYFeed 75
N006 G01 X70 Y60 Z-0.5 XYFeed 75
N007 G01 X30 Y60 Z-0.5 XYFeed 75
N008 G01 X0 Y40 Z-0.5 XYFeed 75
N009 G01 X0 Y0 Z-0.5 XYFeed 75
N010 G81 R3 E9 N7 Z-0.5
N011 M05
N012 M02

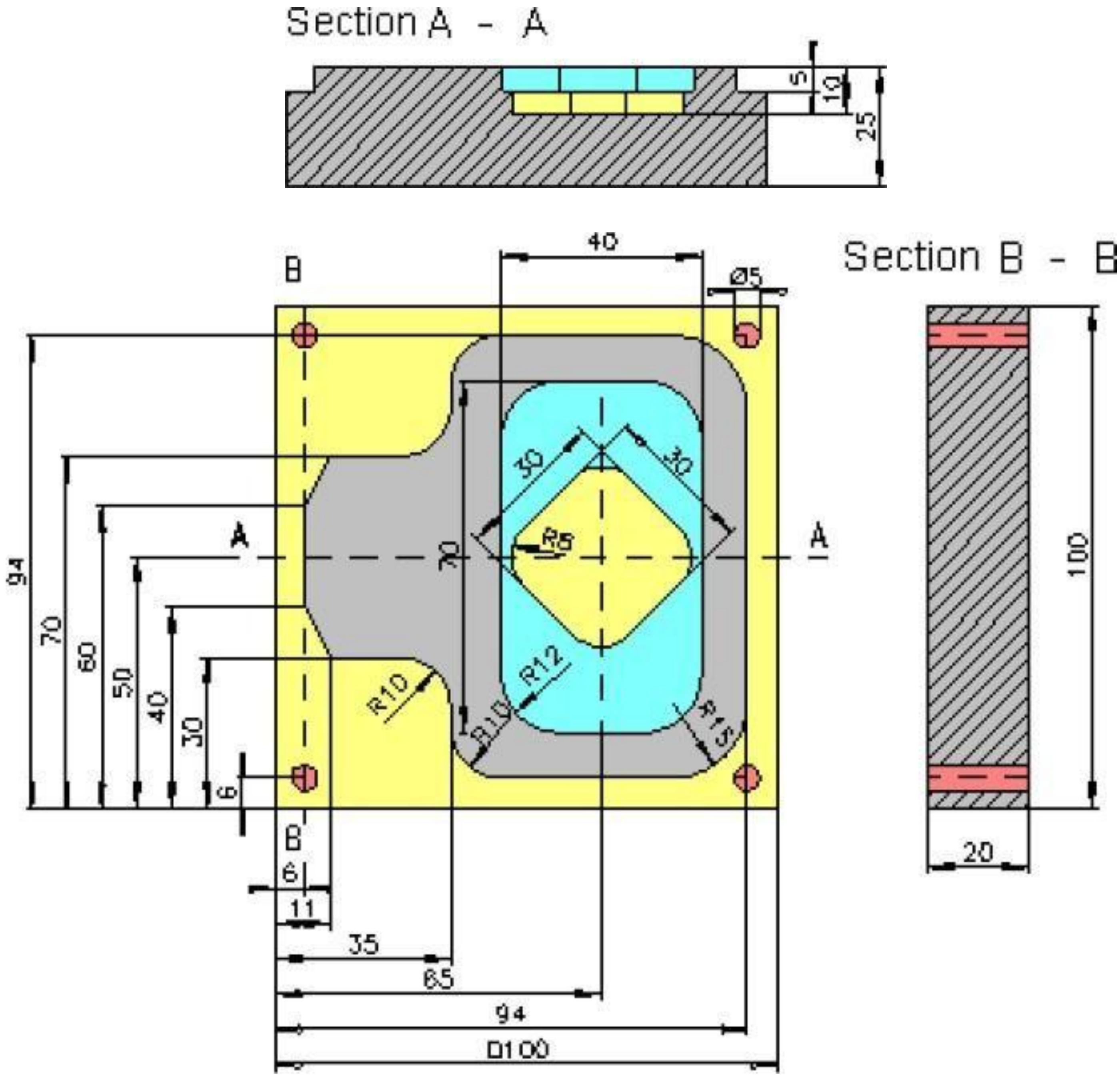
Flow of Computer-Aided CNC Processing

- Develop or obtain the 3D geometric model of the part, using CAD.
- Decide which machining operations and cutter-path directions are required (computer assisted).
- Choose the tooling required (computer assisted).
- Run CAM software to generate the CNC part program.
- Verify and edit program.
- Download the part program to the appropriate machine.
- Verify the program on the actual machine and edit if necessary.
- Run the program and produce the part.

Exercise CNC Milling Programming: Contact plate

The contact plate on the drawing is to be produced on a CNC vertical milling machine from a blank of AlMg1 dimensioned 100 x 100 x 25 mm. Prepare, test and correct the manufacturing process with the MasterCAM CNC Milling Simulator. Define the workpart zero, work out the process layout, set-up form and NCprogram.

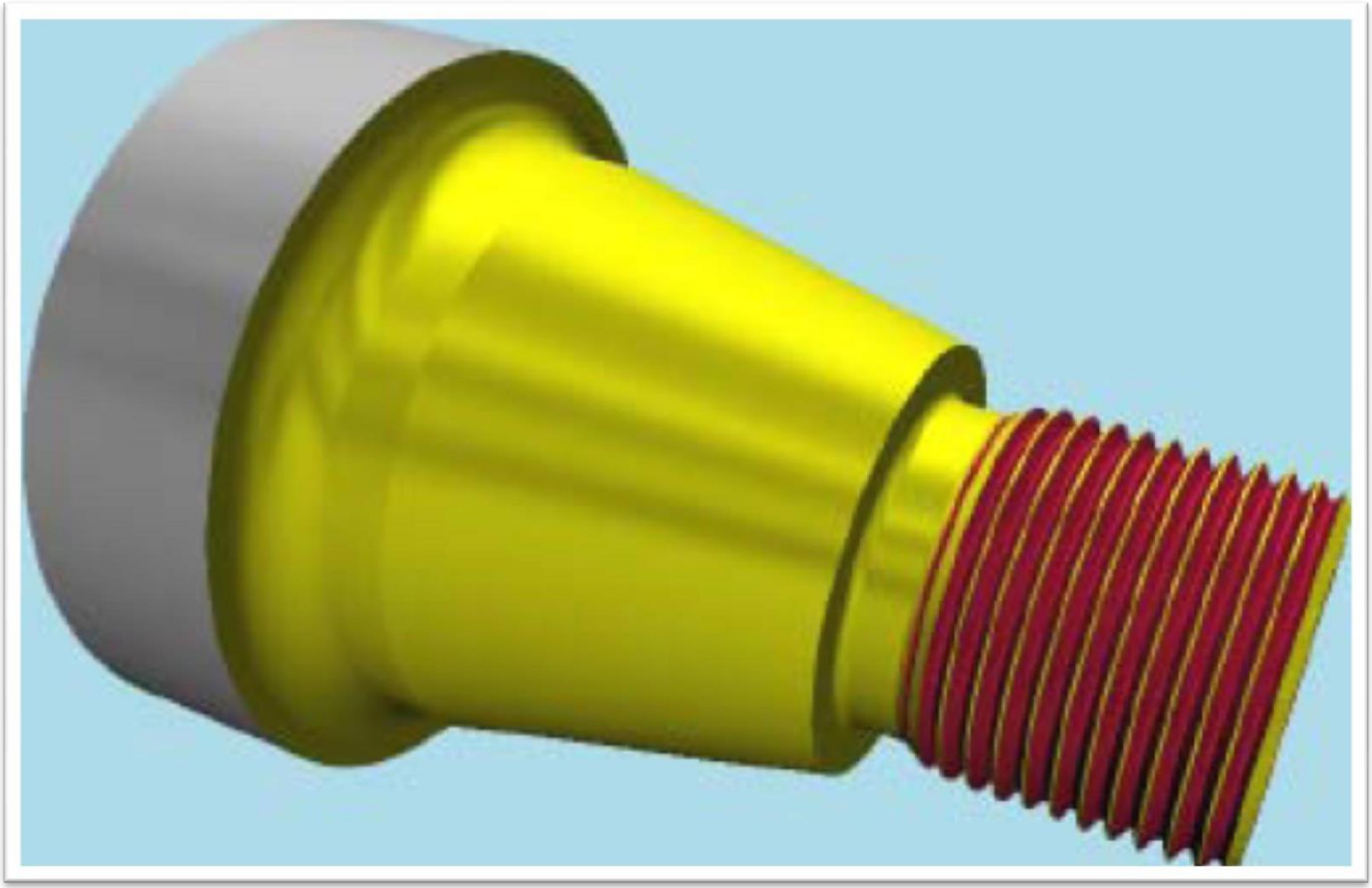


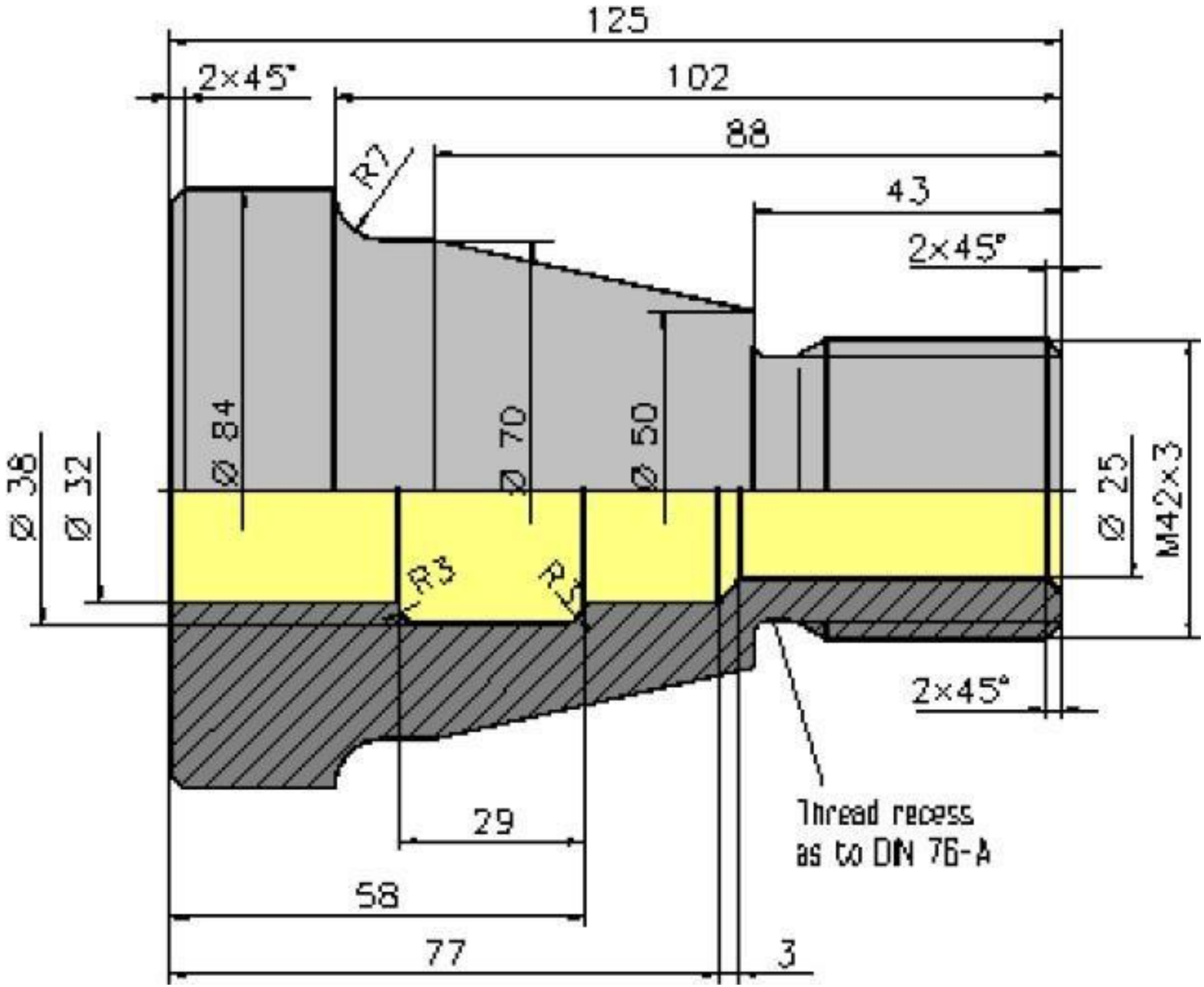


Section A - A
5
10
25
Section B - B
B
B
40
Ø5
A
A
94
70
60
50
40
30
6
70
30
30
R8
R12
R10
R10
R15
100
20
6
11
35
65
94
D100

Exercise CNC Turning Programming: Drill sleeve

The drill sleeve is to be produced on a CNC lathe as to the drawing from a blank made of AlMg1 dimensioned Ø90 x 128 mm. The manufacturing process is to be prepared with the MasterCAM CNC Simulator including all planning documentation. Use the compound fixed cycle G71. Test, correct and print the NC program.




125
2×45°
102
88
R7
43
2×45°
Ø 84
Ø 70
Ø 50
Ø 38
Ø 32
Ø 25
M42×3
R3
R5
2×45°
29
58
77
3
Thread recess
as to DIN 76-A

Lecture 30-32

CNC Programming

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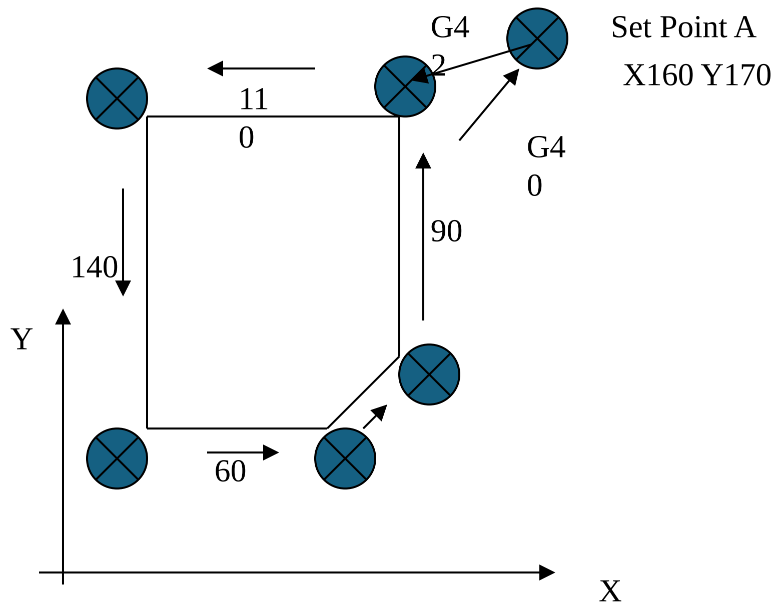
Sant Longowal Institute of Engineering and Technology, Longowal

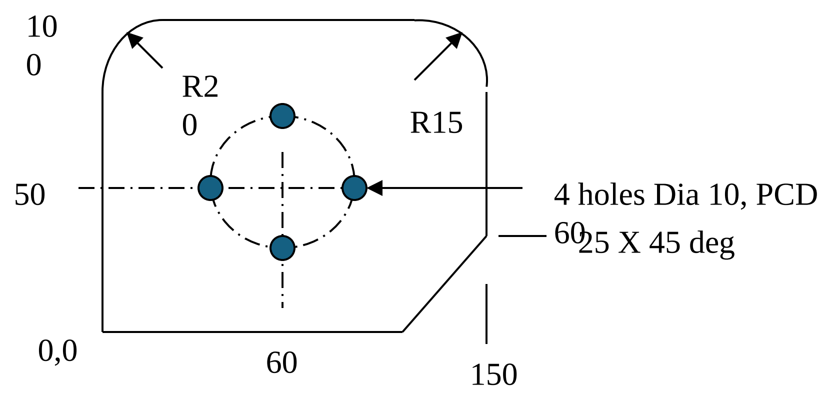
Tool Radius Compensation

- G41 Used when the cutter is on the left of the part OR the part to be machined is on the right of the tool looking in the direction of the tool Motion.
- G42 Used when the cutter is the right of the programmed part OR the part to be machined is on the left of the tool looking in the direction of tool motion.

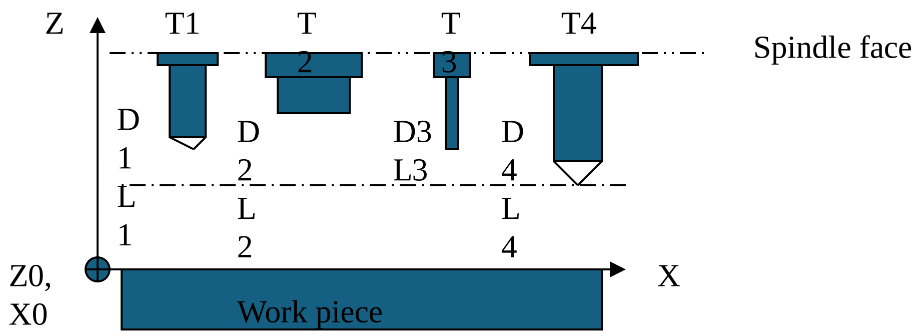
Example 1



Example 2



Tool Length Compensation



N001 M06 T01

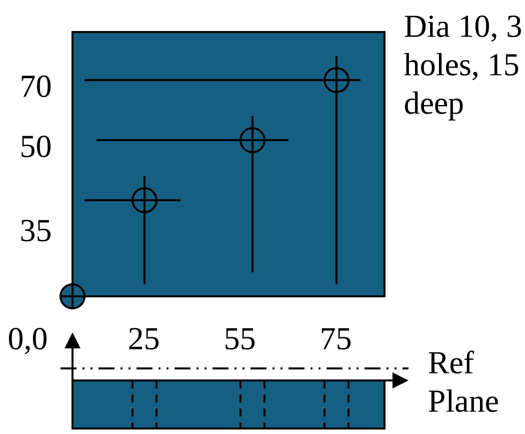
N002 M06 T02

M06 refers to the tool change function and T01 and T02.. refer to the tool to be loaded. Whenever a tool is changed or ground or replaced, the new value for the height and diameter have to be entered into the appropriate tool registry to effectively machine parts of correct dimensions

Canned Cycles

Sometimes a series of motions are to be repeated a number of times. Example, a hole of same size to be drilled in 4 different places having the same Z dimensions. This operation involves, positioning the drill at the proper X and Y co-ordinates. Moving tool at rapid to a safe reference Z plane. Drilling at a feed rate to a depth indicated in the drawing. Finally the drill has to retract back to the safe reference plane.

Canned Cycles



The typical program would look like this,

N010 G00 X25 Y35 Z2.0

N015 G01 Z-18 F125

N020 G00 Z2.0

N025 X55 Y50

N030 G01 Z-18 F125

N035 G00 Z2.0

N040 Z75 Y70

N045 G01 Z-2.0 F125

N050 G00 Z2.0

N060 X0 Y0 Z50

Canned Cycles

The same program, using canned cycle function can be written as below,

N010 G81 X25 Y35 Z-18.0 R2.0 F125

N020 X55 Y50

N030 X75 Y70

N040 G80 X0Y0 Z50

Here, X, Y refer to the center co-ordinates

Z refers to the final depth of the hole

R refers to the clearance plane

G81 canned drill cycle (Modal)

Standard Canned Cycles

G80 Canned cycle off

G81 Drilling and center drilling

G82 Counter boring/ Counter sinking (has dwell)

G83 Deep hole drilling (Intermittent drill)

G84 Tapping (Has built in reverse motion)

G85 Reaming (Return at feed rate)

G86 Boring (Has spindle stop and rapid retract)

G87 Multiple Boring (Has manual return motion)

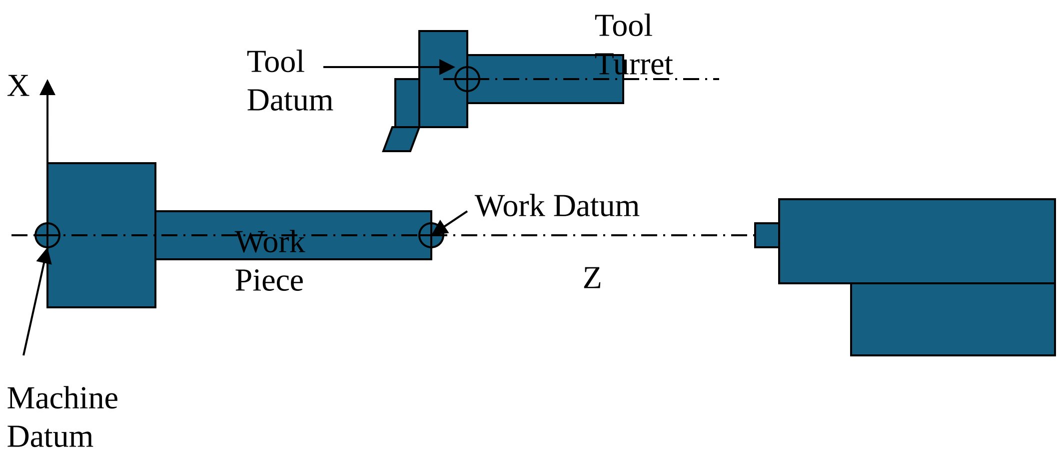
G88 Boring (has swell, spindle stop and manual retract)

G89 Boring (Has dwell, retract at feed rate)

Turning Center Programming

Characteristics of turning centers

1. Axes System: Mainly X and Z axes are used in a turning center.



Characteristics of turning centers

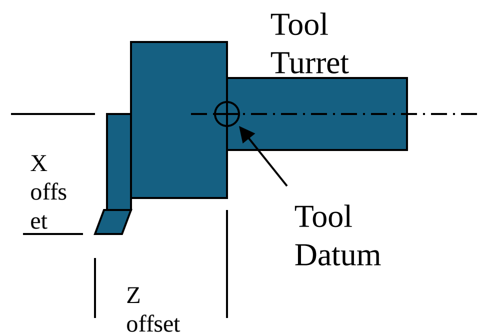
2. Tool Used: Usually single point tools are used. Typical operations are turning and boring. Some times milling and drilling tools can be used based on the machine type and turret type.
3. Cut Planning: Typically, turning centers need to cut out heavy material from blanks which often calls for many rough cutting cycles. The planning for such is called cut- planning.

Characteristics of turning centers

4. G and M codes: In turning center programming also, Preparatory (G) and Miscellaneous (M) codes are used. However their numbering could be different compared to machining centers.
5. 2D programming: As the work rotates, typical programming is 2D in nature. Thus simplifies programming as there are only 2 axes involved.
6. Tool changing: Tool Indexing (turning center) involves rotation of the turret to facilitate tool change.

Characteristics of turning centers

7. Tool Nose Radius: In turning centers programming is to be done with the center of the tool nose radius and compensation for the tool nose radius has to be done.

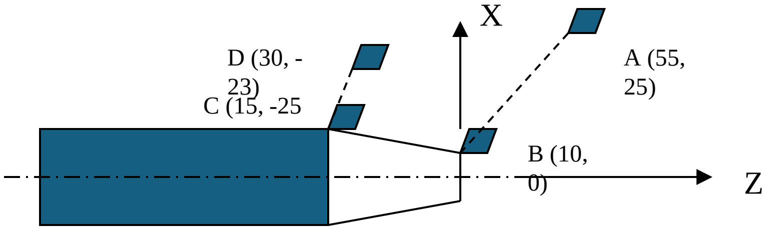


Characteristics of turning centers

8. Ease of Programming: Most of the turning center systems allow programming using radius and diameter values.

   Also many systems would let the programme be done in absolute and incremental and/or mixed mode.

Sample part



Absolute Programming:

O0300

N010 G00 X10, Z0

N020 G01 X15 Z –25 F120

N030 G00 X30 Z -23

Incremental Programming:

O0300

N010 G00 U-45, W-25

N020 G01 U5 W –25 F120

N030 G00 U15 W2

Mixed Mode:

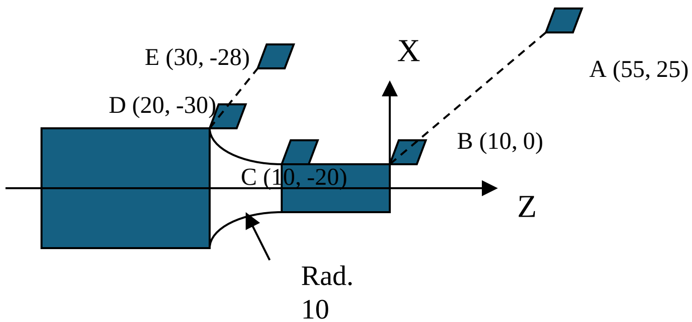
O0300

G00 U-45 Z0

G01 U5 Z-25 F120

G00 U15 Z-23

Sample Part



Programming from A-B-C-D-E

O0301

N010 G00 X10 Z0

N020 G01 X10 Z-20 F100

N030 G02 X20 Z-30 R10 F80

N040 G00 X30 Z-28

N050 M30