2.008 Design & Manufacturing II

Spring 2004

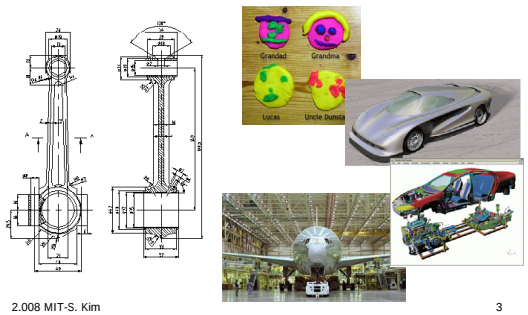
Process Planning
CAD/CAM

Ref 1: CAD/CAM/CAE systems, by K.W. Lee, Addison-Wesley, 1999
Ref. 2: Computer Aided Manufacturing, 2nd ed. by T.C. Chang, R. A. Wysk, and H-P Wang, Prentice Hall 1998
Ref.3: Manufacturing: Design, Production, Automation and Integration, by B. Benhabib, Marcel Dekker, New York, 2003

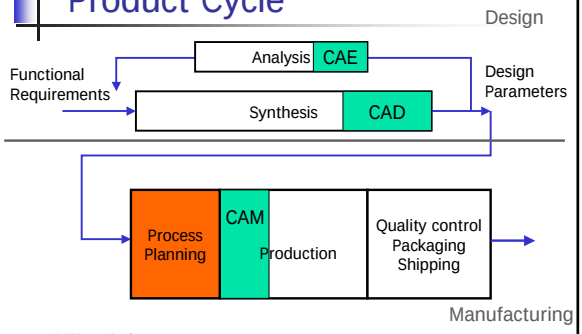
1

- Lab starts today.
- Monday 2/16, President's day, a Holiday
- Tuesday 2/17, Monday's lecture & lab group A
- HW#1 due 2/11 (W)

2D drafting v.s. digital Playdo



Product Cycle



3 day prototyping by CAD/CAM/CAE

-Catia, Euclid, AutoCAD, ProEngineer Solidworks
- MasterCAM, PowerMill
- Moldflow, C-Flow, ANSYS, I-DEAS

Geometric Modeling – Historical Development

- 1960-1962: The first Graphical User Interface (GUI), Sketchpad, developed at MIT.
- 1964-1965: DAC-1 by GM and CADAM by Lockheed.
- 1970-1980: Various systems that ran on proprietary hardware – only a handful survived beyond the 1990s.
- 1990-2000: Pro/Engineer, Solid Works and I-DEAS run on PC platforms.

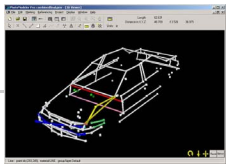
3D object geometric modeling

Wireframe

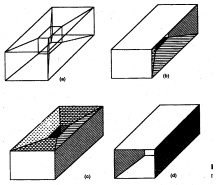
Surface modeling

Solid modeling ?

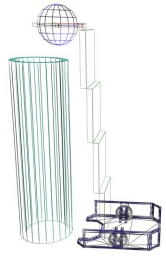
Wire frame



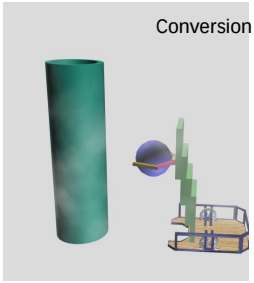
- List of
  - Curve equations
  - Coordinates of points
- Connectivity
- Easy method
- Ambiguity
- No mass, no surface



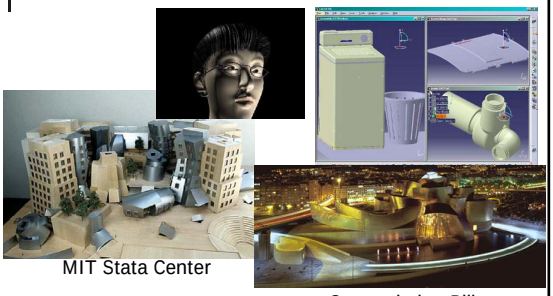
Wireframe



Conversion to surface



Surface Modeler



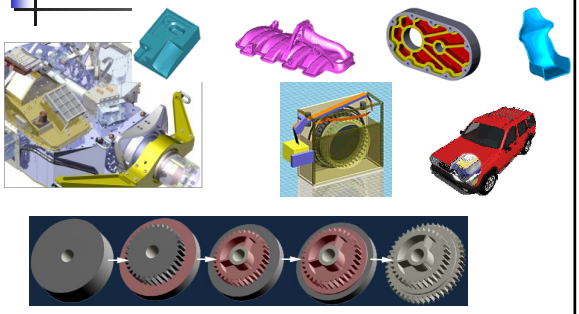
MIT Stata Center

Guggenheim, Bilbao[10]

Surface Modeler

- Wireframe data +
- Surfaces
  - Connectivity, Adjacency
  - Interpolation of points, curve nets
  - Translation or sweeping of curves
- Fits to complex free formed surfaces
  - Visual, aesthetic design
  - NC code generation

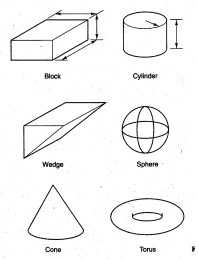
Solid Modeler



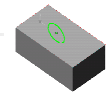
Solid modeler

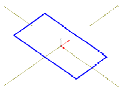
- Has a closed volume.
  - Knows “in” or “out”
- Has a mass and inertia.
- Huge input data, maths.
- User friendliness is a must.
  - Primitives
  - +/- by Boolean operations
  - Sweeping, rounding, lifting
- Hybrid (solid + Surface, CSG + BREP, Parametric + explicit)

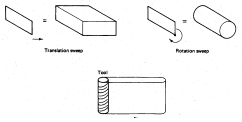
Primitives



Then
- Add/subtract
- Move
- Modify

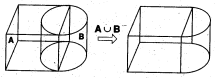




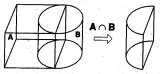


Boolean operations

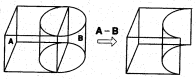
union

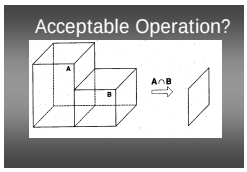


intersection

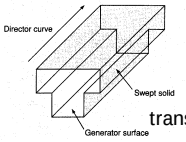


difference

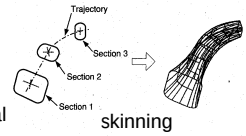




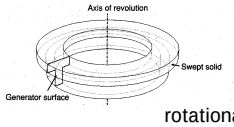
By sweeping, skinning surfaces



translational

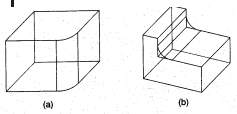


skinning

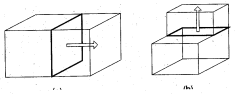


rotational

By modifying existing shapes



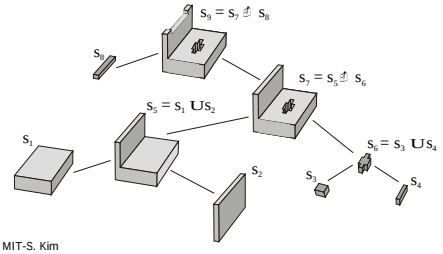
Edge rounding Filleting



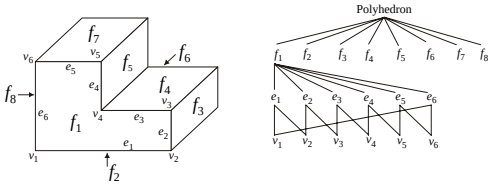
Lifting

Constructive Solid Geometry

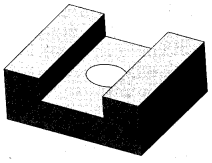
- CSG modelers allow designers to combine a set of primitives through Boolean operations:



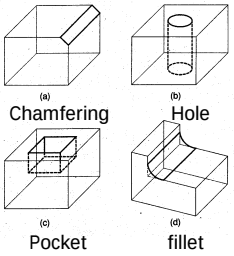
Boundary Representation



Feature-based Design

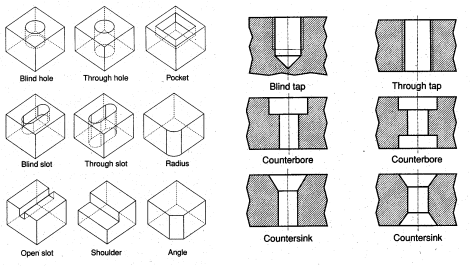


Open slot
Through hole



Chamfering
Hole
Pocket
fillet

Machining Features



Parametric modeling

- Feature-based
- Dimension data
- Geometric constraints

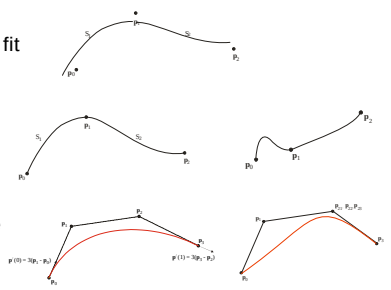
- Assembly modeling
- No standard of data exchange
- IGES (Initial Graphic Exchnage Standards)

Geometric Modeling - Curves

Least-square fit

spline fit

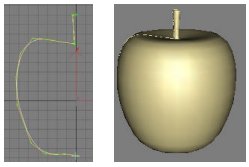
Bezier Curve



Geometric Modeling - Curves

B-spline : more flexibility than Bezier

NURB (non-uniform rational B-spline): Combine all



Geometric Modeling – Free form Surface

NURB (non-uniform rational B-spline): Combine all

Process Planning (CAPP)

- "Act of preparing detailed work instructions to machine or assemble a part or parts" –Chang, Wysk, Wang
- Sequence of manufacturing processes and/or assembly operations
- Operation sheet

Restaurant Owner

- Have customers eat well
- Customers serviced well
  - speed
  - customization
- Affordable tab
- $$$ - profit

What's the difference between McDonald v.s. Maison Robert?

Super bowl 2004

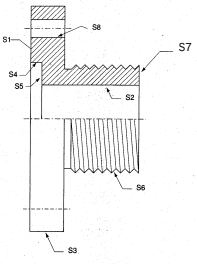
Play book
Play number

Image removed due to copyright considerations.

Process Planning

- Manual Approach
- Comupter Aided Process Planning (CAPP)
  - Variant Approach: Group Technology
  - Generative Approach: features, tolerances

Example 1 by manual approach

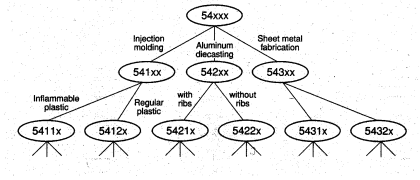


Setup 1
Chuck the workpiece
Turn S3 to a 100mm diameter
Face S1
Core drill S2
Counter bore S4, S5

Setup 2
Chuck the workpiece on S3
Turn S6 to 50 mm diameter
Undercut the neck
Thread S6
Face S7

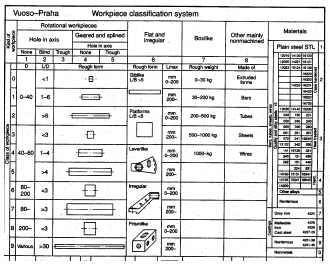
Group Technology

Zip code: 02139
Product Classification

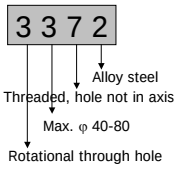


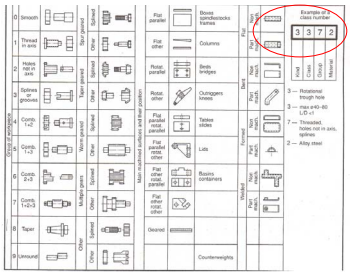
Vuoso-Praha coding system

4 digit system
-Kind
-Class
-Group
-Material

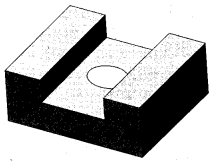


Coding system (continued)

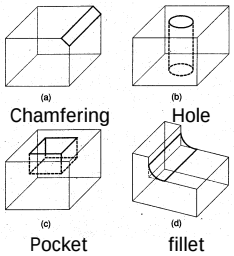




Feature-based CAPP

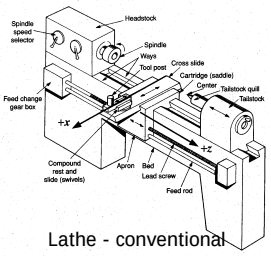


Open slot
Through hole

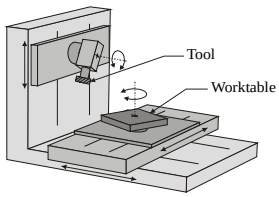


Chamfering
Hole
Pocket
fillet

Numerical Control



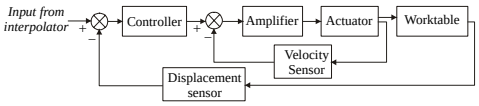
Lathe - conventional



5-axis milling

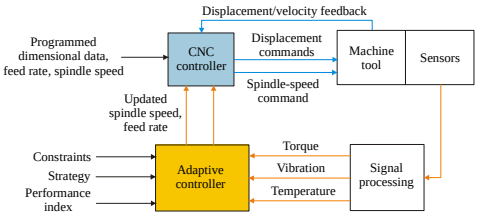
Motion Control

- Point to point, Continuous
- Interpolation
- Encoders, tachometers and interferometers provide high-precision displacement and velocity feedback:

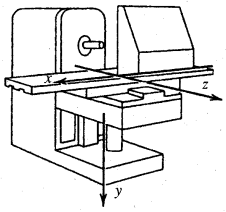


Adaptable Control

- sense cutting force, torque, temperature, etc.
- tool wear, tool breakage



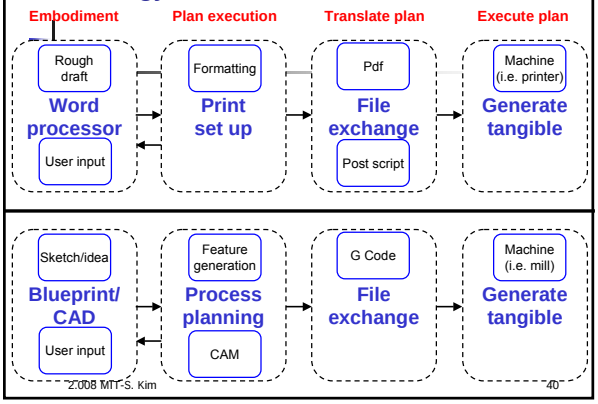
NC milling machine



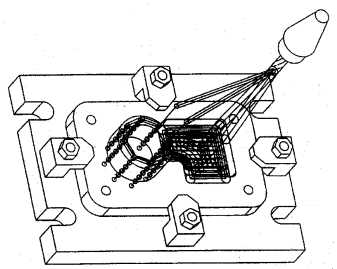
Code	Function	Explanation
g00	Point to point, positioning	Use with combination point-to-point/contouring systems for indicating positioning operation.
g01	Linear interpolation (normal dimensions)	A mode of contouring control used for generating a slope or straight cut, where the incremental dimensions are normal (i.e., input resolution is as specified).
g02	Circular interpolation arc CW (normal dimensions)	A mode of contouring control that produces an arc of a circle by the coordinated motion of two axes. The curvature of the path (clockwise = g02, or counterclockwise = g03) is determined when viewing the plane of motion in the negative direction of the perpendicular axis. The distances to the arc center (i, j, k) are "normal dimensions."
g03	Circular interpolation arc CCW (normal dimensions)	
g04	Dwell	A programmed (or established) time delay, during which there is no machine motion. Its duration is adjusted elsewhere, usually by the f word. In this case dimension words should be set at zero.
g05	Hold	Machine motion stopped until terminated by an operator or interlock action.
g06	Parabolic interpolation (normal dimensions)	A mode of contouring control that uses the information contained in successive blocks to produce a segment of a parabola.
g08	Acceleration	The feed rate (axes' velocity) increases smoothly (usually exponentially) to the programmed rate, which is noted later in the same block.
g09	Deceleration	The feed rate decreases (usually exponentially) to a fixed percent of the programmed feed rate in the deceleration block.
g10	Linear interpolation (long dimensions = LD)	Similar to g01, except that all dimensions are multiplied by 10. For example, a programmed dimension of 9874 will produce a travel of 98740 basic lenth-units. (Used only with incremental programming.)
g11	Linear interpolation (short dimensions = SD)	As g01, but dividing all dimensions by 10 (e.g., 987 units for the example above).

Source: Y. Koren, *Computer Control of Manufacturing Systems*. McGraw-Hill, 1983.

Analogy: Word document ⟷ Part



Tool path generation



g-code

- **N0027 G01 X175.25 Y325.00 Z136.50 F125 S800 T1712 M03 M08**

  Statement Number 27 (N0027) a linear-interpolation motion (G01) to a position defined by (X175.25 Y325.00 Z136.50), with a feed rate of 125 mm/min (F125), and a spindle speed of 800 rpm (S800), using a tool Number 1712 (T1712), performing a c/w turn of the spindle (M03), and having the coolant on (M08).

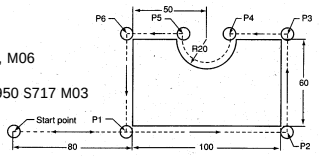
Manual Programming

N001 G91
N002 G71
N003 G00 X0.0 Y0.0 Z40.0 T01, M06

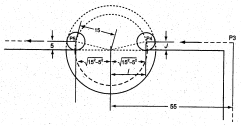
N004 G01 X75.0 Y0.0 Z-40.0 F950 S717 M03
N005 G01 Z10.0 F350 M08

N006 G01 X110.0
N007 G01 Y70.0

N008 G01 X-40.86
N009 G02 X-28.28 Y0.0 I14.14 J5.0



Cutter Location, P4



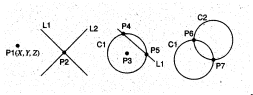
$$X_4 - X_3 = -\left(55 - \sqrt{15^2 - 5^2}\right) = -40.86$$
$$Y_4 - Y_3 = 0$$
$$X_5 - X_4 = -2\sqrt{15^2 - 5^2} = -28.28$$
$$Y_5 - Y_4 = 0$$
$$I = \sqrt{15^2 - 5^2} = 14.14$$
$$J = 5$$

APT –Automatic Programming Tool

- APT developed at MIT in 1956.
- APT II, APT III
  - Identification statement
  - Geometric Statements
  - Motion statement
  - Post-processor statement
  - Auxiliary statement

Geometry statements

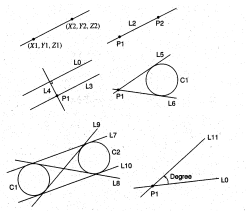
Points



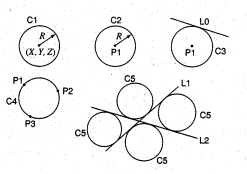

```
P1 = POINT/X, Y, Z
P2 = POINT/L1, L2          ; intersection of two lines already defined
P3 = POINT/CENTER, C1      ; center of a circle
P4 = POINT/YLARGE, INTOF, L1, C1
                           ; intersection of a line and a circle, one with a
                           larger y coordinate
P5 = POINT/XLARGE, INTOF, L1, C1
                           ; intersection of a line and a circle, one with a
                           larger x coordinate
P6 = POINT/YLARGE, INTOF, C1, C2
                           ; intersection of two circles, one with a larger y
                           coordinate
P7 = POINT/XLARGE, INTOF, C1, C2
                           ; intersection of two circles, one with a larger x
                           coordinate
```


APT statements (cont.)

Lines



Circles



Motion statement

- P to P-motion:

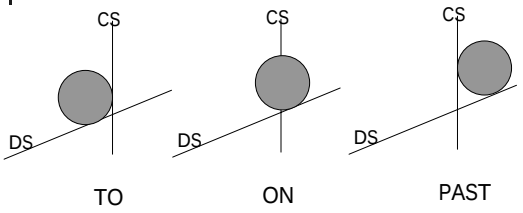
  GOTO/Point_Name; *Go to Point* Point_Name.

  GODLTA/ΔX, ΔY, ΔZ; *Move incrementally.*

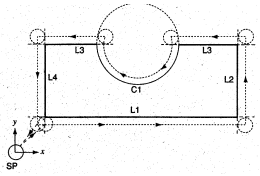
- CP-motion:

$$\begin{bmatrix} \text{GOFWD} \\ \text{GOBACK} \\ \text{GOLFT} \\ \text{GORGT} \\ \text{GOUP} \\ \text{GODOWN} \end{bmatrix} / \text{ Drive\_Surface, } \begin{bmatrix} \text{TO} \\ \text{ON} \\ \text{PAST} \\ \text{TANTO} \end{bmatrix}, \text{ Part Surface Check\_}$$

Ending locations



Example

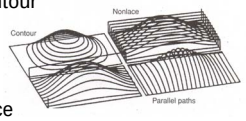


FROM/SP
GO/TO, L1, TO, PS, ON, L4
GORGT/L1, PAST, L2
GOLFT/L2, PAST, L3
GOLFT/L3, PAST, C1
GOLFT/C1, PAST, L3
GOLFT/L3, PAST, L4
GOLFT/L4, PAST, L1
GOTO/SP

Tool path interval and Cusp

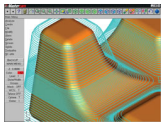
Contour

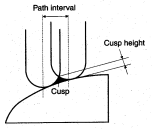
Non-lace



Lace

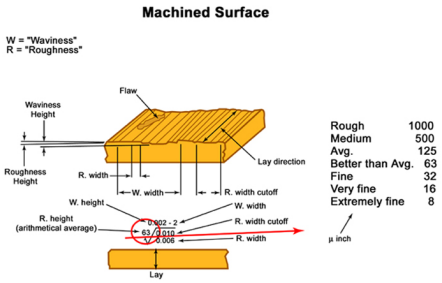
Parallel



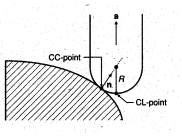


CUSP

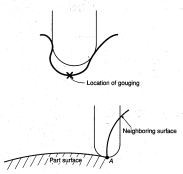
Machined Surface



Cutter Contact, Gouge



Contact Point



Gouging