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Advanced Solid Modeling

Ch 1 3D CAD의 개요

Department of Mechatronics EngineeRing

Prof. B. H. Kim

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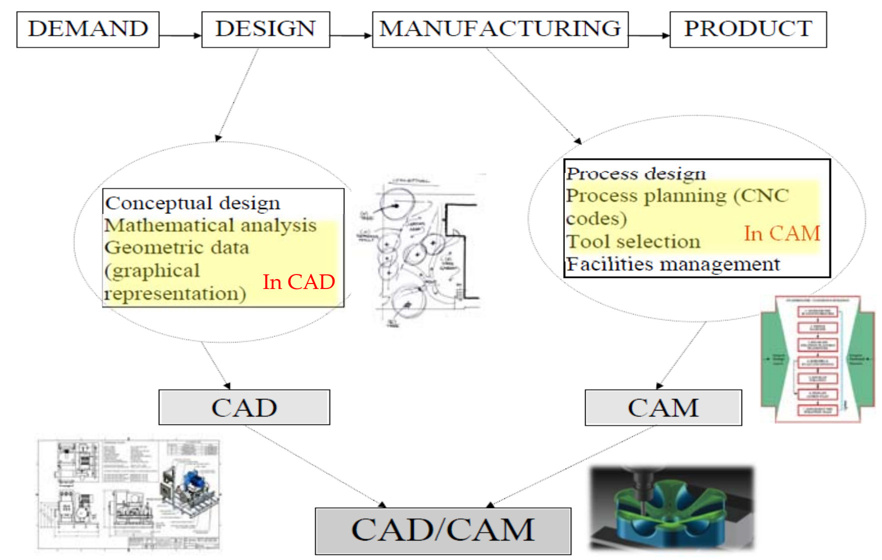
3D CAD & CAM



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3D CAD & CAE
Design (CAD)
Simulation (CAE)
Pre-processing
CAD/CAE Integration
Methods
Automating Tasks
Coupling software
Software development [VB, CAA, C + +]
Design
Calculation
Post Processing
from [Crash FE Simulation in the Design Process - Theory and Application, By S. Roth, et al.]
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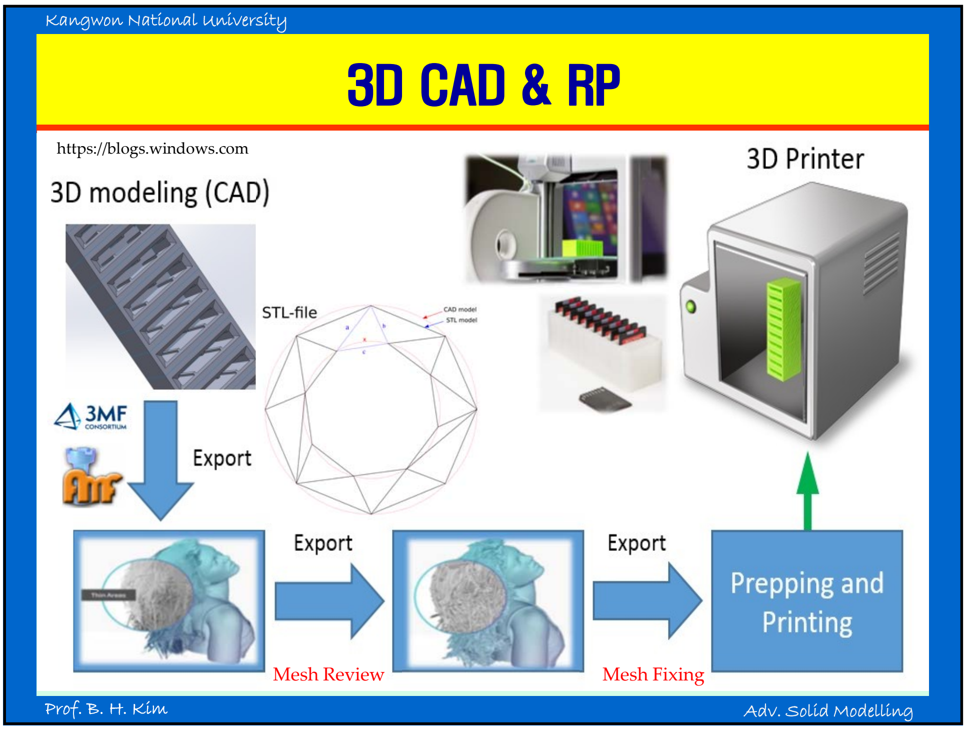
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3D CAD & RP
https://blogs.windows.com
3D modeling (CAD)
3D Printer
STL-file
3MF
Export
Export
Export
Prepping and Printing
Mesh Review
Mesh Fixing
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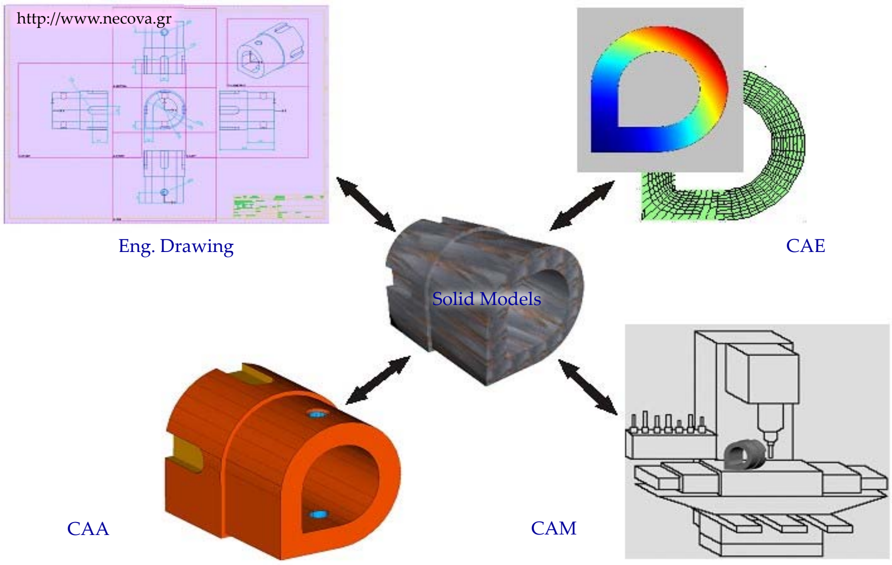
3D CAD & Concurrent Eng.



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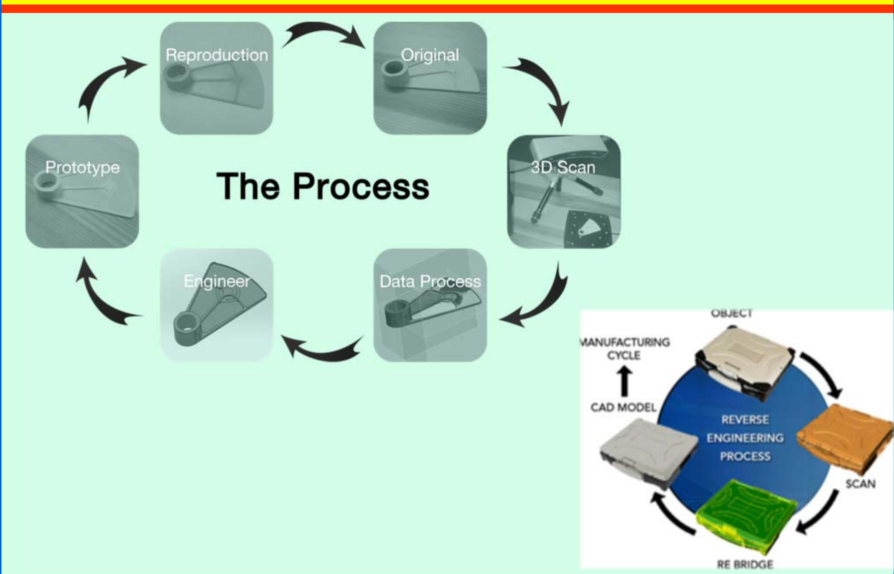
3D CAD & Reverse Eng.



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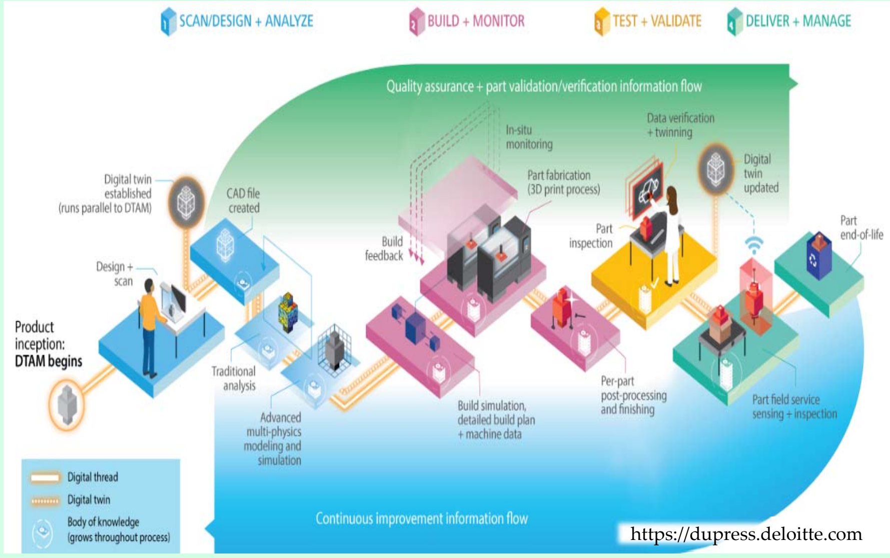
3D CAD & Digital Twins



https://dupress.deloitte.com

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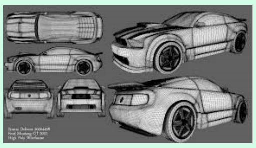
CAD basic

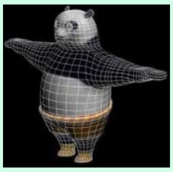
Wire Frame Model

Prof. B. H. Kim CAD/CAM

Wire Frame Model

- **Definition of wire frame model**
  - One of the visual presentations of a three-dimensional (3D) or physical object used in 3D computer graphics.
  - It is created by connecting an object's **constituent vertices** using straight lines or curves.





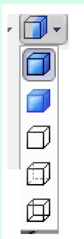
Vertex	X	Y	Z
1	1	1	1
2	1	-1	1
3	-1	-1	1
4	-1	1	1
5	1	1	-1
6	1	-1	-1
7	-1	-1	-1
8	-1	1	-1

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

Topology Example

Exercise

- See **Display style** on Head-up Tool bar in Graphic area of Solidworks



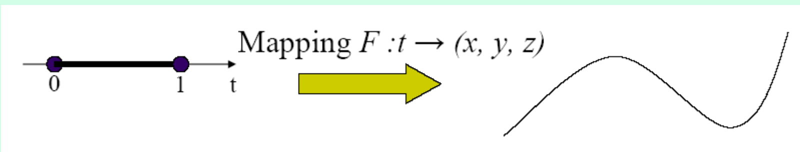
  - Shaded with edges (Solid model + Wireframe)
  - Shaded (Solid model)
  - Hidden Line Removed (Surface model or Wireframe model)
  - Hidden Line Visible (Wireframe model)
  - Wireframe Model

- Weldments Exercise (using 3D sketch)
  - At first Download Weldments Contents @ Design Library
    - Download (Control+Click) ISO files to Weldment profile folder.
  - Draw Simple table using 3D sketch (How to fully define the entities?)

CAD basic
Surface Model

What is parametric ?

- Define a parameter space
  - 1D for curves   ex) $0 \le t \le 1$, $-\pi \le t \le \pi$, $-\infty \le t \le \infty$
  - 2D for surfaces
- Define a mapping from parameter space to 3D points
  - A function that takes parameter values and gives back 3D points
  - The result is a parametric curve or surface



Parametric curves

- We have seen the parametric form for a line:

$$x = x_0 t + (1-t)x_1$$
$$y = y_0 t + (1-t)y_1$$
$$z = z_0 t + (1-t)z_1$$

- Note that x, y and z are each given by an equation that involves:
  - The parameter *t*
  - Some user specified control points, *x0* and *x1*
- This is an example of a parametric curve

Why parametric ?

- Problems of analytical or nonparametric representations of curves
  - unsuitable for use in CAD applications
  - Dependent on the choice of coordinate system
  - unsuitable for geometric transformations, such as rotations, translations, and scaling.
  - The implicit representation is awkward for generating points on a curve because x values may be chosen which do not actually lie on the curve.
  - ex) the circle fails the vertical line test

Mathematics

- **Derivative of Implicit f'n**
  - Circle: $x^2 + y^2 = 1$
  - Chain rule
  - $2xdx + 2ydy = 0$ ➔ $dy/dx = -x/y$
- **Derivative of parametric f'n**
  - Circle: $r(\theta) = [R\cos\theta \quad R\sin\theta]$ $(0 \le \theta \le 2\pi)$
  - $dr(\theta)/d\theta = [-R\sin\theta \quad R\cos\theta]$

∴ 1) free from coordinate,
2) free form x, y, z correlation (1 input ➔ 2 output)
3) easy to get derivtives

Parametric Curve Examples

Circle

i) $x = r\cos t + x_o, \quad y = r\sin t + y_o \,, \quad 0 \le t \le 2\pi$

P(t) = $[\, r\cos t + x_o, \quad r\sin t + y_o \,, \; 0 \,]$

ii) $x = r(1-t^2)/(1+t^2) + x_o, \quad y = 2rt/(1+t^2) + y_o, \; -\infty \le t \le \infty$

P(t) = $[\, r(1-t^2)/(1+t^2) + x_o, \; 2rt/(1+t^2) + y_o, \; 0]$

Ellipse

$x = a\cos t + x_o, \quad y = b\sin t + y_o \,, \quad 0 \le t \le 2\pi$

Hyperbola

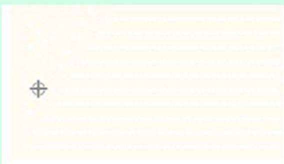
$x = a\cosh t + x_o, \quad y = a\sinh t + y_o \,, \quad 0 \le t \le 2\pi$

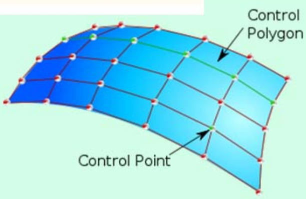
Parabola

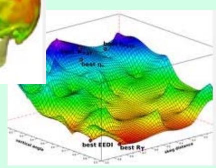
$x = t^2/4a + x_o, \quad y = t + y_o$

Surface model

- **(free form) Surface model**
  - It is used in CAD and other computer graphics software to describe the skin of a 3D geometric element.
  - They are used to describe forms such as turbine blades, car bodies and boat hulls.

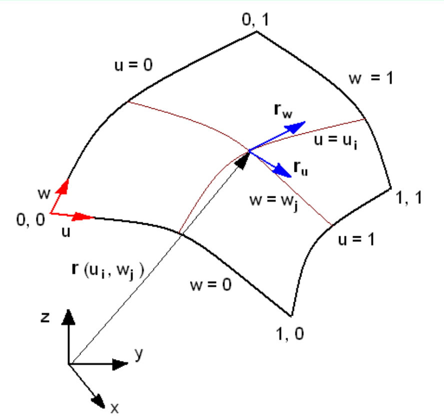






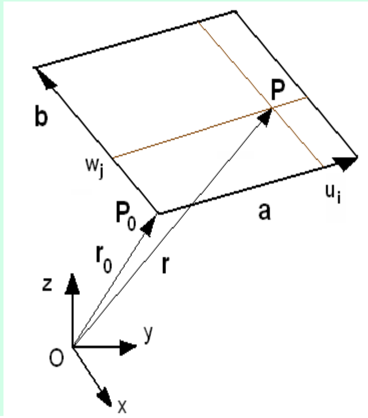
Surface model

- **Parametric description of a surface patch**



$r = r(u, w) = x(u, w)i + y(u, w)j + z(u, w)k$

- **plane**

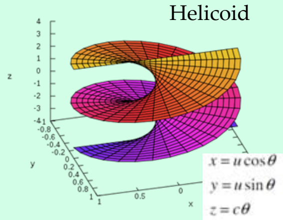


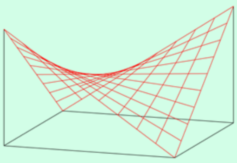
$r(u, w) = r_0 + ua + wb \quad 0 \leqq u, w \leqq 1$

Surface model

Hyperboloid

Helicoid



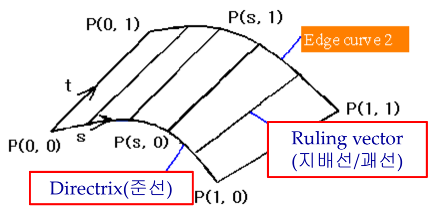


Hyperbolic-paraboloid

- **Ruled surfaces**
  - In geometry, a surface S is ruled (also called a scroll) if through every point of S there is a straight line that lies on S.
  - A ruled surface can always be described (at least locally) as the set of points swept by a moving straight line. (e.g.: a cone)
  - See examples
    - . TAB surfaces
    - . Developable surfaces: G. Curvature =0

Surface model

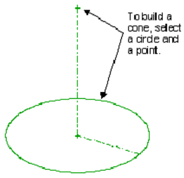
- Ruled surfaces

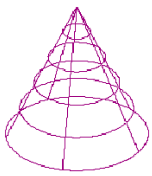


Linear interpolation between two edge curves

$$P(s,t) = P(s,0) + t\,[\,P(s,1) - P(s,0)]$$
$$= (1-t)\,P(s,0) + t\,P(s,1)$$

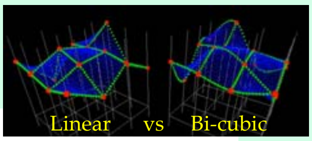
Create the cone by ruled surface

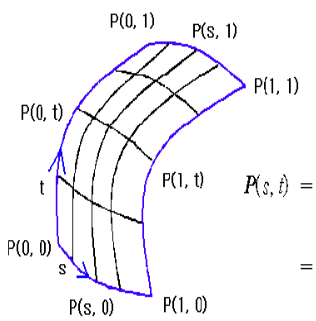




Ruled surfaces

- Bi-Cubic rule surfaces (Coons patch)
  - Addition of two ruled surfaces





$$P_1(s,t) = (1-s)\,P(0,t) + s\,P(1,t)$$
$$P_2(s,t) = (1-t)\,P(s,0) + t\,P(s,1)$$

$$P(s,t) = P_1(s,t) + P_2(s,t)$$
$$= \begin{bmatrix} 1-s & s & 1 \end{bmatrix} \begin{bmatrix} -P(0,0) & -P(0,1) & P(0,t) \\ -P(1,0) & -P(1,1) & P(1,t) \\ P(s,0) & P(s,1) & 0 \end{bmatrix} \begin{bmatrix} 1-t \\ t \\ 1 \end{bmatrix}$$

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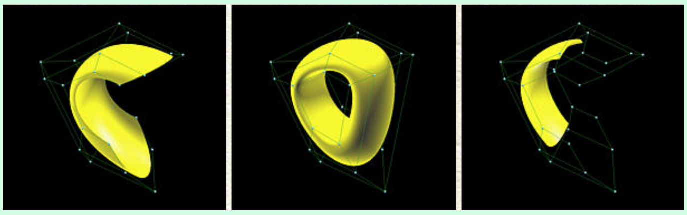
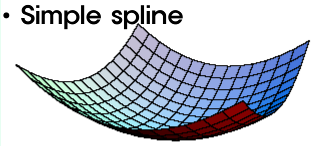
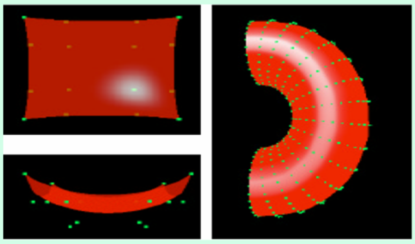
Surface model

- B-splines



- Simple spline





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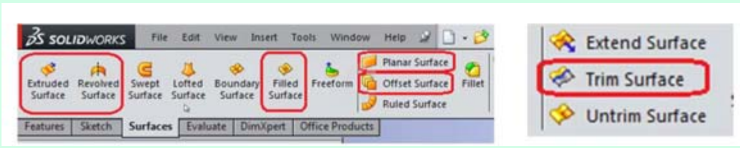
Exercise

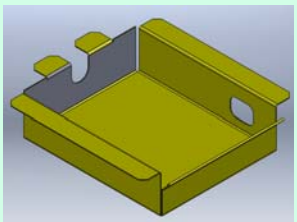
- Surface Modeling Exercise
  - Surface Tool Bar



  - Basic of surfacing in SWs

1. Every solid is actually a group of surfaces
2. Surfaces have no thickness/no volume
3. Surfaces are considered Reference Geometry
4. Surfaces allow you to create 1 face at a time

   Solids force you to create ALL FACES at once
5. Surfaces and curves are partners



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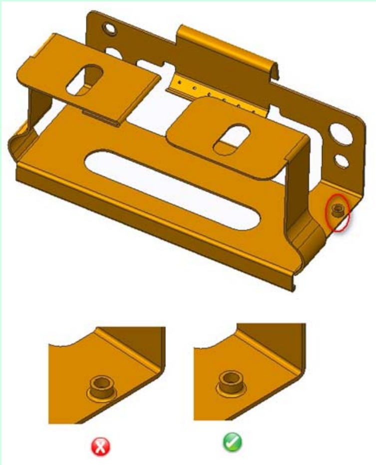
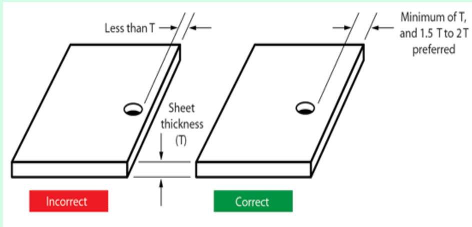
Ridiculous Design Examples



- Distance from Extruded Hole to Part Edge: If a(an) (extruded) hole is too close to the part edge, it can lead to deformation or tearing of the metal.



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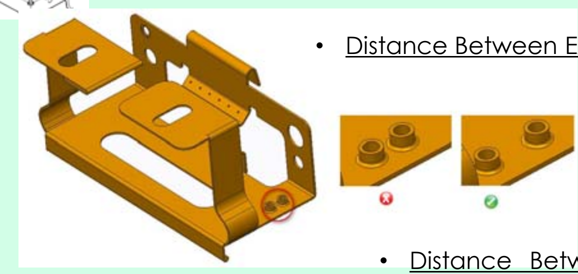
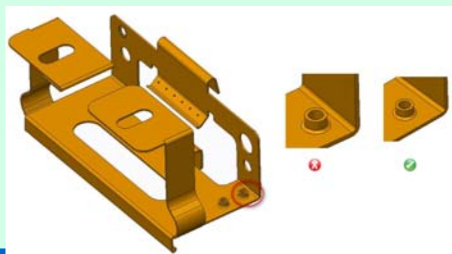
Ridiculous Design Examples



- Distance Between Extruded Holes
- Distance Between Extruded Hole to Bend



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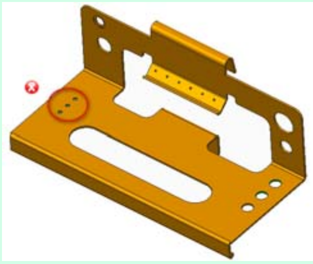
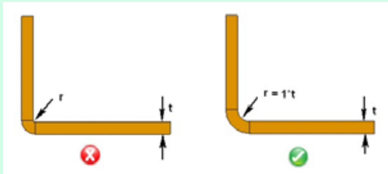
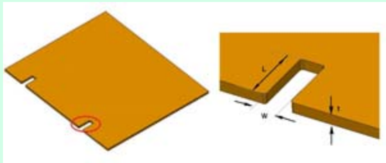
Ridiculous Design Examples



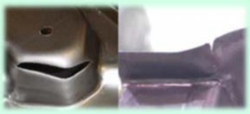
- Too small hole diameter
  - ✓ Hole ϕ ≥ Sheet metal *t*

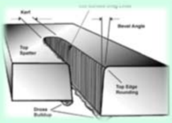


- Too small bend radius
  - ✓ Min. *R* ≥ Sheet metal *t*



- Improper notch feature
  - ✓ Width ≥ 1.5 times of *t*
  - ✓ Length ≥ 5 times of *t*
  - ✓ Corner R ≥ 0.5 times of *t*





CAD basic
Solid Model

What is Solid Modeling?

- **Definitions**
  - A consistent set of principles for mathematical and computer modeling of three-dimensional solids.
  - Solid modeling is distinguished from related areas of geometric modeling and computer graphics by its emphasis on **physical fidelity**.

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What is Solid Modeling?

- 'Solid Modeling' is a method used to design parts by combining various 'solid objects' into a single three-dimensional (3D) part design.
- Originally, solid modelers were based on solid objects being formed by primitive shapes such as a cube, rectangular prism, cone, torus, cylinder, sphere, wedge (rectangular prism) and so on.
- Because of their limited use, some solid modelers have abandoned the primitive shapes altogether in favor of predefined library solid objects. 'Stock' library objects provide the designer with a similar shape to begin the design with, eliminating some of the initial tedious design work. ☞ **Let's Check the Tool Box (Use read only)**
- The real power of a solid modeling application is how it can take the solid objects and combine them together by intersecting, joining, or subtracting the objects from one another to create the desired resulting shapes.
- Since the solid modeler's database knows so much about the entire part model, it can perform functions virtually impossible with surface modeling. For example you can 'fillet' all the adjacent edges of a face to other faces in a single command. Another popular example is the 'shell' function of solid modelers. This allows you to define a constant wall thickness for the entire model with a simple task with a single command.

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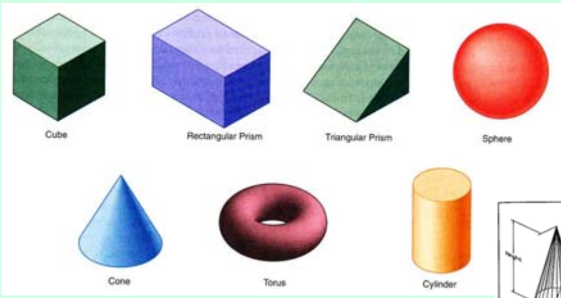
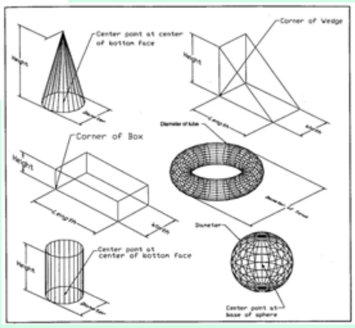
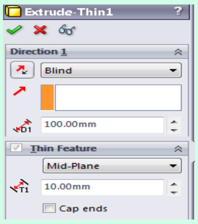
Primitives

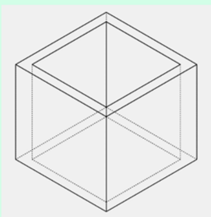


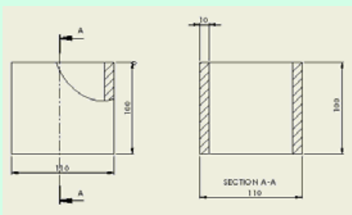


Exercise

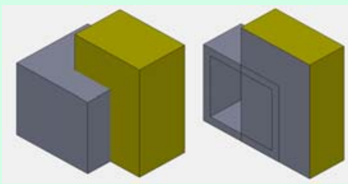
- **Cube & Thin Features**



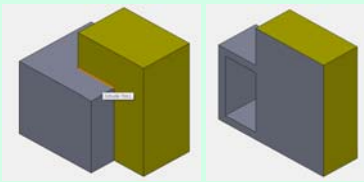




- **Merge**



Mass = 1612g



Mass = 1461g

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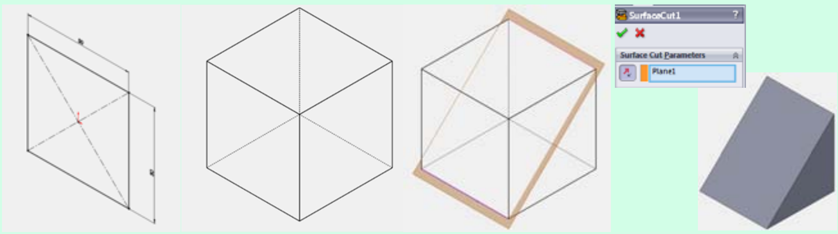
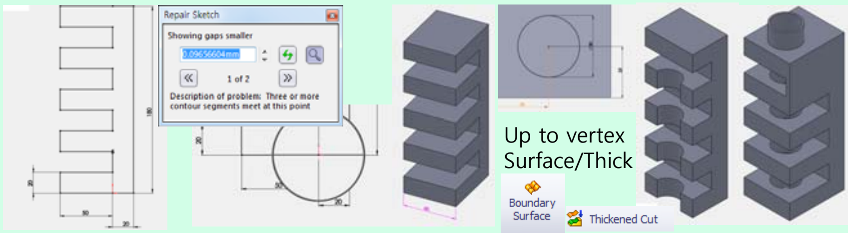
Exercise

- **Wedge by Cut with Surface**



- **Repairing sketch** (Tools > Sketch Tools > Repair Sketch)



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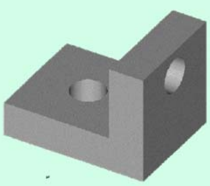
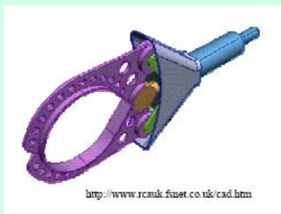
Solid modeling techniques

- **Parameterized Primitive Instancing**
- **Spatial Occupancy Enumeration (SOE)**
- **Cell Decomposition**
- **Constructive Solid Geometry (CSG)**
- **Boundary Representation (B-Rep)**





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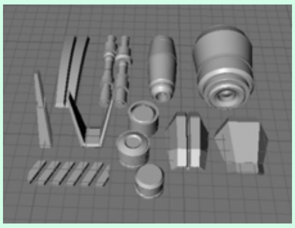
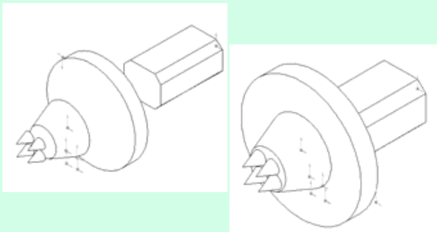
Parameterized primitive instancing

- Composite drawing with simple shapes (primitives)
- Representing families of objects (GT)
- Applying scaling transformation to the composite drawing/primitive
- A solid is specified by indicating the family to which it belongs and a limited set of parameter values
- Restricted range of objects (predefined families)





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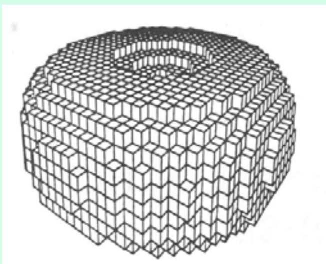
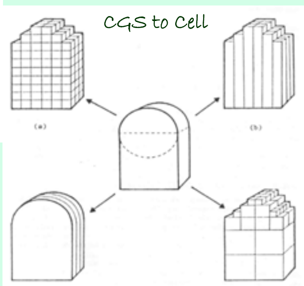
Spatial Occupancy Enumeration (SOE)

- Subdivides 3-D space into volumes (spatial cells) and classifies these volumes as empty, full, or partially full of the solid
- An object is specified by listing all the spatial cells it occupies
- Accuracy necessitates small cells
  ➔ enormous memory requirements
- These can be indexed using octrees



$$v_{ijk} = \begin{cases} 1 & \text{solid} \\ 0 & \text{otherwise} \end{cases}$$



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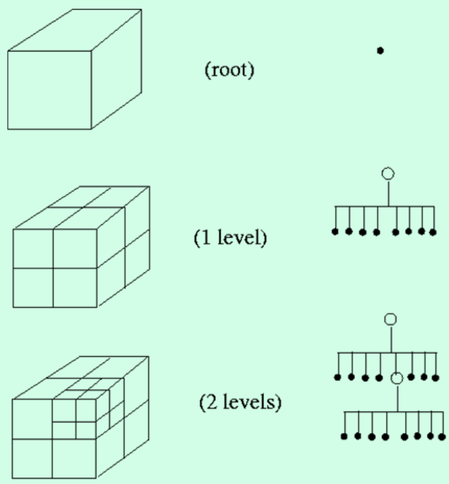
Octrees



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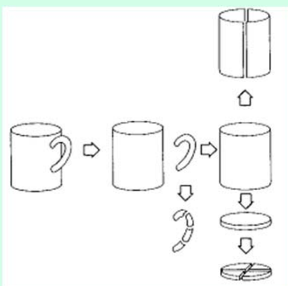
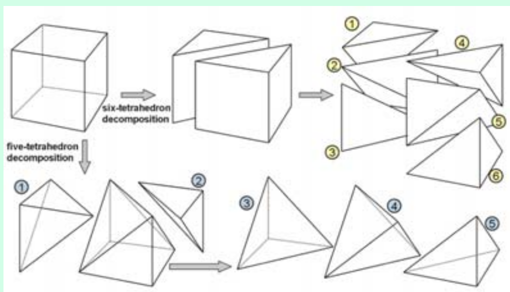
Cell decomposition

- A general class of SOE - similar to SOE but subdivides the object
- Solid is decomposed into simple solid cells with no holes and certain boundary matching conditions
- Much less memory than SOE





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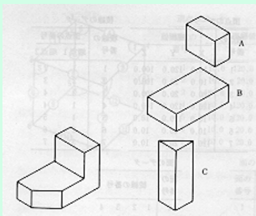
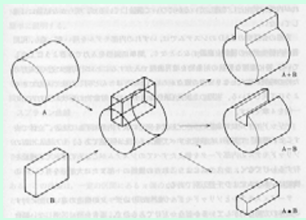
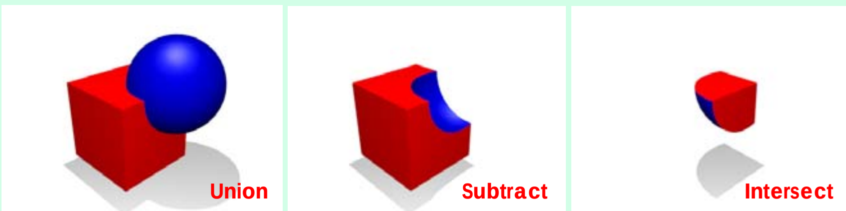
Constructive Solid Geometry (CSG)

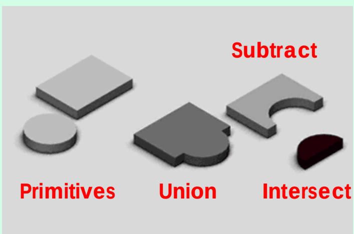
- Using unbounded half space and primitives
  - Unbounded half space: Using for generation solid primitive
  - Solid primitive: block, sphere, cone, cylinder, torus, wedge…
- Boolean operation
- Simple and obvious
- No unique solution ➔ lots of CSG tree
- Dangling Edges



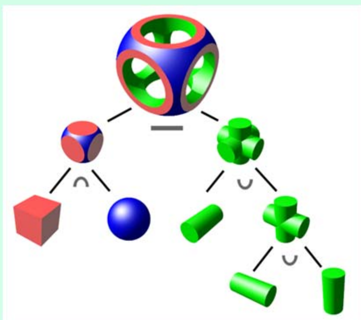


CSG Boolean operation (pp28~31)





http://www.youtube.com/watch?v=dCckl1gw8wo



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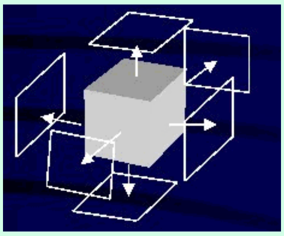
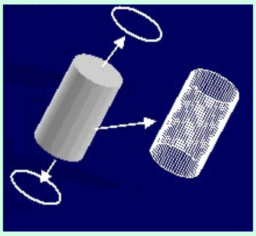
Boundary representation(pp31~33)

- Suitable to NC
- Unique solution
- Hard to construct data base
  - ➔ Generate the shape by CSG
  - ➔ Boundary evaluation
  - ➔ Construct B-rep database
- Euler's rule





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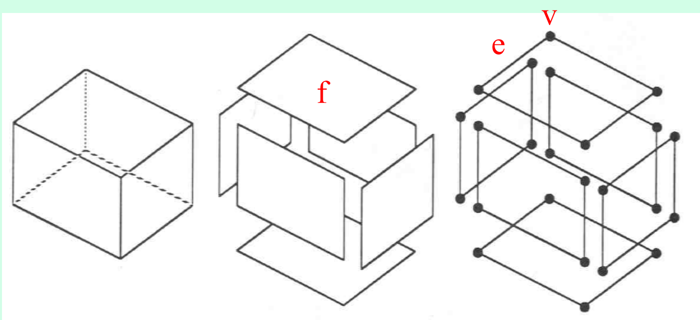
Boundary representation(pp31~33)



Face, Edge, Vertex

http://www.youtube.com/watch?v=sXbRT439vRI

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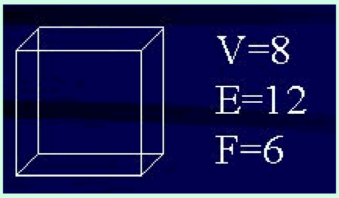
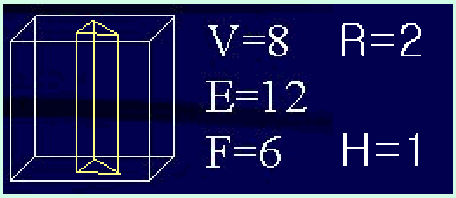
B-rep – Euler's rules (pp31~33)

- **No holes : F - E + V = 2**
- **With holes : F - E + V = 2 + R -2H (extended Euler rule)**
  - ✓ R : # of Internal edge rings
  - ✓ H : # of through holes





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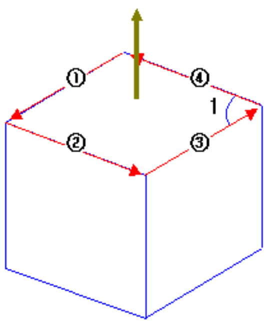
B-rep – data base (pp31~33)

. A hexahedron consists of eight (vertex) points, twelve linear edges and six plane surfaces.



topological data

Egde No.	end points start	end
①	1	2
②	2	3
③	3	4
④	4	1
⑤	1	5
⑥	2	6
⑦	3	7
⑧	4	8
⑨	5	6
⑩	6	7
⑪	7	8
⑫	8	5

Surface No.	Edges
①	1 2 3 4
②	1 5 9 6
③	9 10 11 12
④	3 7 8 11
⑤	2 6 7 10
⑥	4 5 8 12

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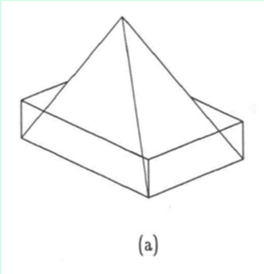
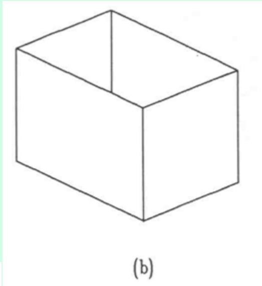
B-rep – Validity (pp31~33)

Self-intersecting

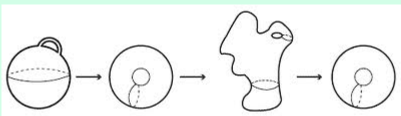


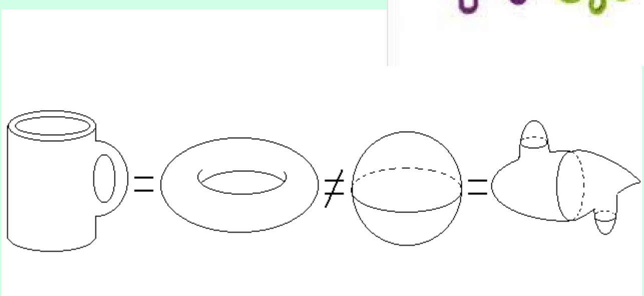
non-manifold (next page)



Elements of the model
- should not self-intersect
- should not intersect each other unless at their boundary.

B-rep – Topologically Equivalent





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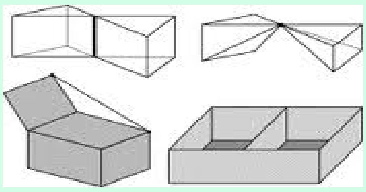
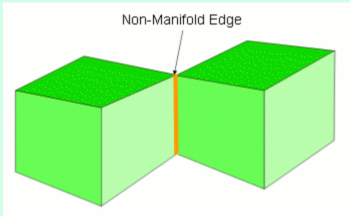
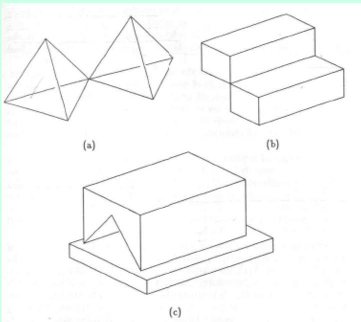
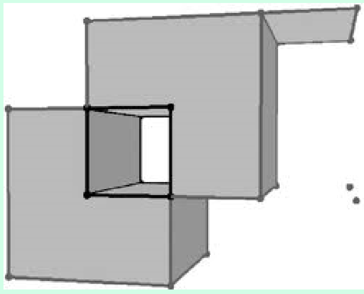
B-rep – Examples of Non-Manifold Models









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CSG vs. B-Rep

CSG	B-REP
• Simple representation • Limited to simple objects • Stored as binary tree • Difficult to calculate • Rarely used anymore	• Flexible and powerful representation • Stored explicitly • Can be generated from CSG representation • Used in current CAD systems

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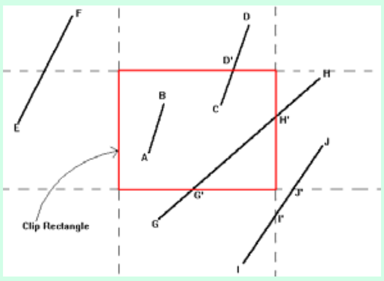
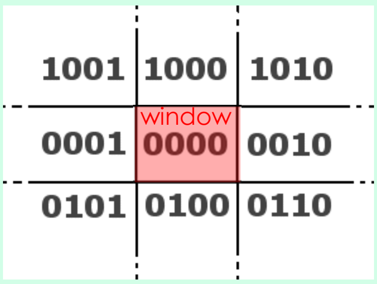
CAD basic
Basic Entities & Attributes

Viewing operation

- Clipping output primitives
  - Conventional way
    . Point: xmin ≤ x ≤ xmax,   ymin ≤ y ≤ ymin
    . Line: two point in(AB) ➔ no clipping,
        one point in(CD) ➔ intersection point cal.
        two point out(GH, IJ) ➔ intersection points cal.
  - Cohen-Sutherland clipping algorithm : using bits for simplicity
    . Top, Bottom, Right side, Left side ➔ discard line



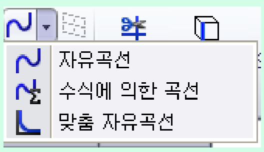


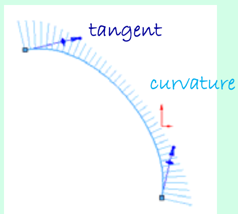
Curves and Lines – Editing and Creating

- A number of functions must be provided to allow editing of 2D geometrical entities, such as lines, circles, arcs.
- Basic editing functions
  - **Basic Entity Creation** (lines/ circles/ arcs/ etc)
    - . create using exact coordinates
      Ex) two screen points for line ends, circle radius/centre/diameter/etc
  - **Line Trimming**
    - . trim lines back to intersection/extend lines to intersection
    - . trim line to perpendicular point
    - . cut a circle/arc on one side of an intersection
  - **Point Creation**
    - . screen position (exact numerical coordinate)
    - . nearest tangent of line to an arc/nearest end of a line
    - . midpoint of nearest line/centre of nearest arc/nearest grid point
  - **Arc Creation**
    - . intersection of circle with another line
  - **Special Techniques**
    - . **offset** of a line
    - . extend lines to intersection
    - . delete entities

Basic Entity Creation

- Line & Curves Creation





- **Line (P_1, P_2)** :
  Select icon ➔ Move to graphic area ➔ Click left mouse button on start point ➔ Move to end point & click ➔ Move out & double click
  ☞ $L = sqrt((x_{p1}-x_{p2})^2+(y_{p1}-y_{p2})^2)$, $\theta = \tan^{-1}((y_{p1}-y_{p2})/(x_{p1}-x_{p2}))$
- **Curve(P_1, P_2, P_3, …)**
  Select icon ➔ Move to graphic area ➔ Click left mouse button on start point ➔ Move to 2nd point & click ➔ Move to 3rd point & double click ➔ revise curve by tangent
  ☞ *Tangent = r'(=dr/dt), Curvature =* $|r' \times r''| / |r'|^3$

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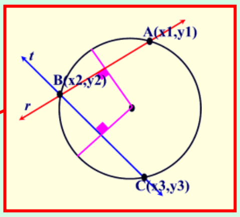
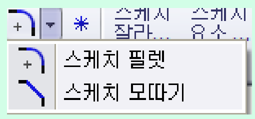
Basic Entity Creation Ex.1

- Line & Curves Creation





- **Circle (P_1, P_2 or P_3)**

Select icon ➔ Move to graphic area ➔ Click left mouse button on center point ➔ Move to end point & click

☞ $R = sqrt((x_{p1}-x_{p2})^2+(y_{p1}-y_{p2})^2)$, $P_c = P_1$

☞ 3 p. circle: Calculating $P_c = (x, y)$, $R = sqrt((x_{p1}-x)^2+(y_{p1}-y)^2)$

slope: $m_r = \frac{y_2-y_1}{x_2-x_1}$	$m_t = \frac{y_3-y_2}{x_3-x_2}$
equation: $y-y_1 = m_r(x-x_1)$	$y-y_2 = m_t(x-x_2)$
$y_r = m_r(x-x_1)+y_1$	$y_t = m_t(x-x_2)+y_2$

$$x = \frac{m_r m_t(y_3-y_1)+m_r(x_2+x_3)-m_t(x_1+x_2)}{2(m_r-m_t)}$$

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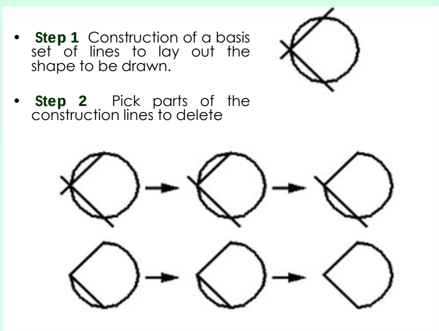
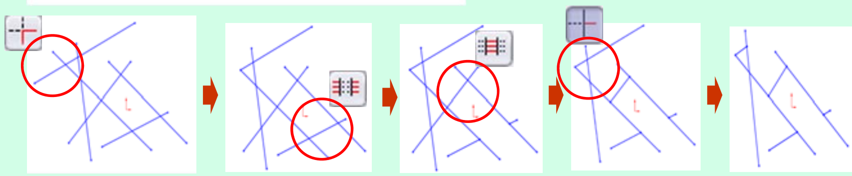
Basic Entity Creation Ex.2

- **Line Trimming**



At SolidWorks



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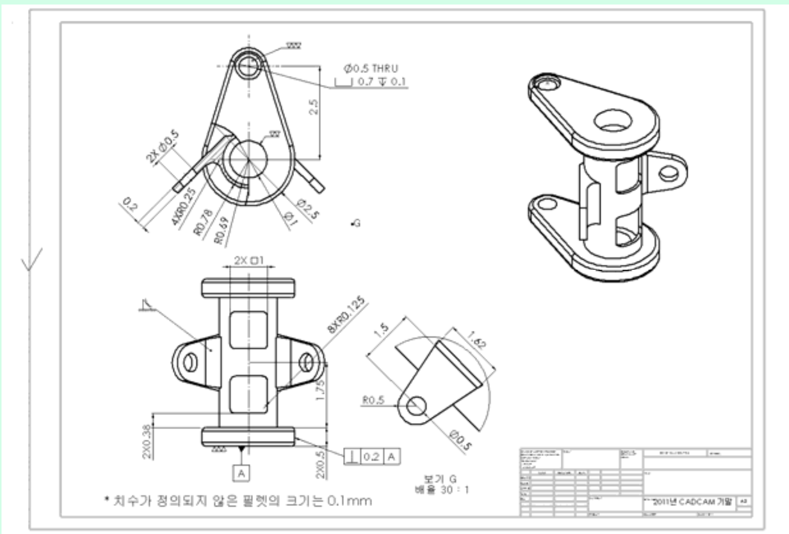
User Interpretation

- Every CAD system uses a graphical display for user interpretation of the final part.
- The display methods discussed in the computer graphics section are all used in CAD packages.
- There are many techniques possible with computer graphics that make on screen designs easier to understand.

- **Dimensioning**
  - Placed manually, but updates when dimensions change.
  - Annotation : the user may add comments to drawings
    - text with a leader pointing to something
    - text alone
    - tolerances
    - Drawing information

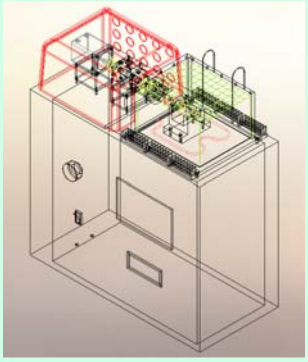
- **Graphics effects**
  - Wireframe model
  - Solid model
  - Rendering

Annotation

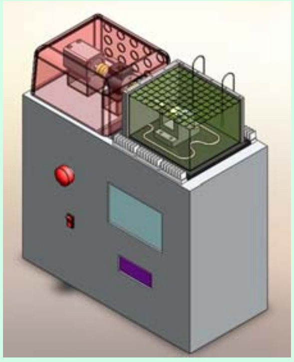


Graphics effects

Wire model view



Solid model view



Rendering view