# Real-time Parametric Surface Modeling for Free-form Conceptual Design


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# Motivation

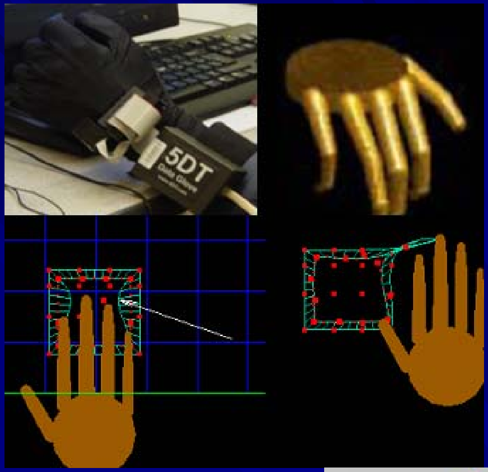
- Conceptual design is the initial stage of the product design cycle
- The aesthetic features are added into the design by the means of the creative inspiration and imagination
- Design is a collaborative effort, requires several iteration
- Detailed design is realized in CAD systems
- Hence, there is a need for systems where
  - Designers can freely convey their thoughts and imaginations into geometric shapes
  - Without any constraint: without dealing with the technical details
  - Directly into 3D space so:
    - Sketches are better perceived by the third parties
    - Easier to convert them in to CAD formats
    - Easier to perform engineering analysis

# Objectives

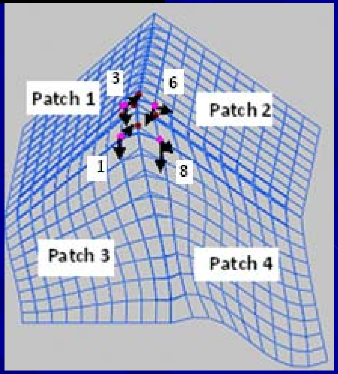
- Introduce a free-form conceptual design toolkit
- Enables designers to display their ideas instantaneously and inspirationally
- Directly in 3D space
- Using immersive or non-immersive VR systems

# Contributions of the Thesis

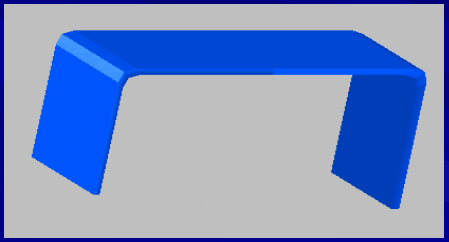
- Free-form sketching system
  - Inputs are received from the user's hand
  - Data is converted into parametric surfaces
  - Real-time modification is enabled



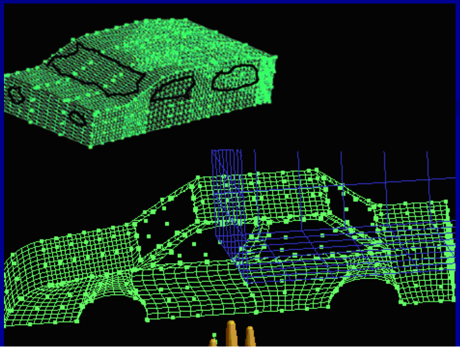

- Connecting surface patches while the continuity is ensured




- Adding a thickness to the arbitrary designed objects

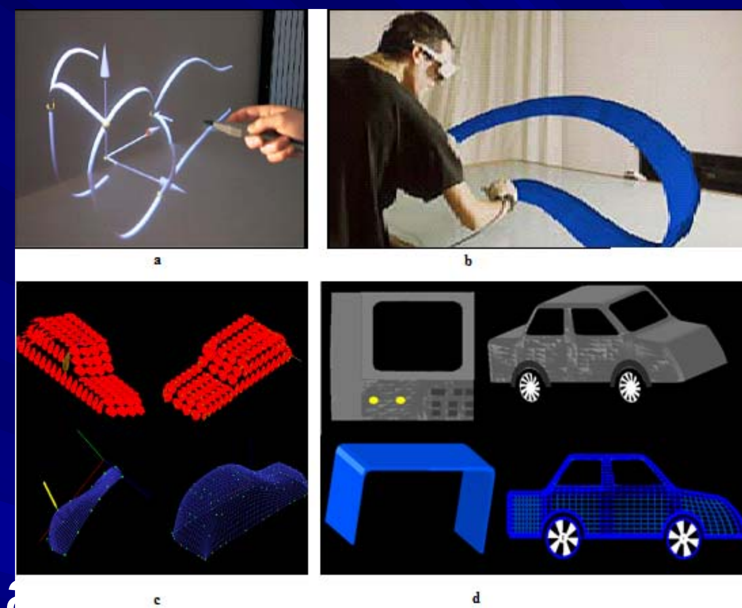


- Surface trimming is possible



# Literature Review

- Freeform design methods
  - Wesche, 2001
  - Schkolne, 2006
  - Akgunduz, 2005




- Literature on continuity and surface thickness
  - Hongwei Lin and Hujun Bao, 2007
  - Jana Pilnikova et al., 1998
  - Barian A. Barsky, 1990

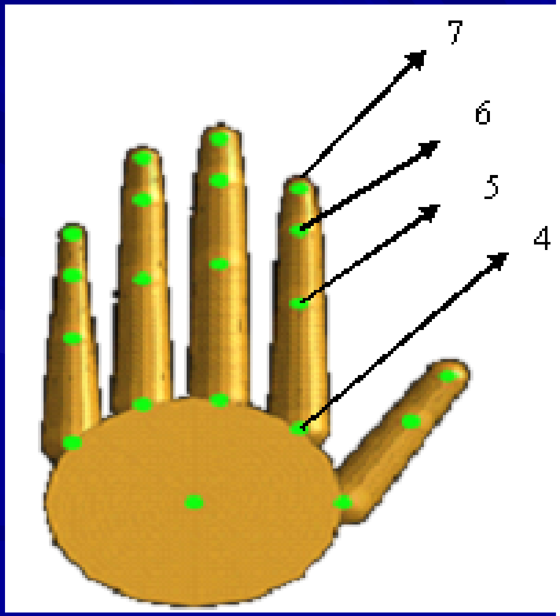
# Methodology

# Real-time parametric surface modeling (NURB)

- Data sources
- Independent motion control
- Data generation and process
- Least-square method to obtain the NURB surface modeling.

# Data sources

- Numbers 4, 5, 6, 7 are the index of the green color points which are adhered on the joints of the index finger of the right hand
- We use these points as the shape generation source

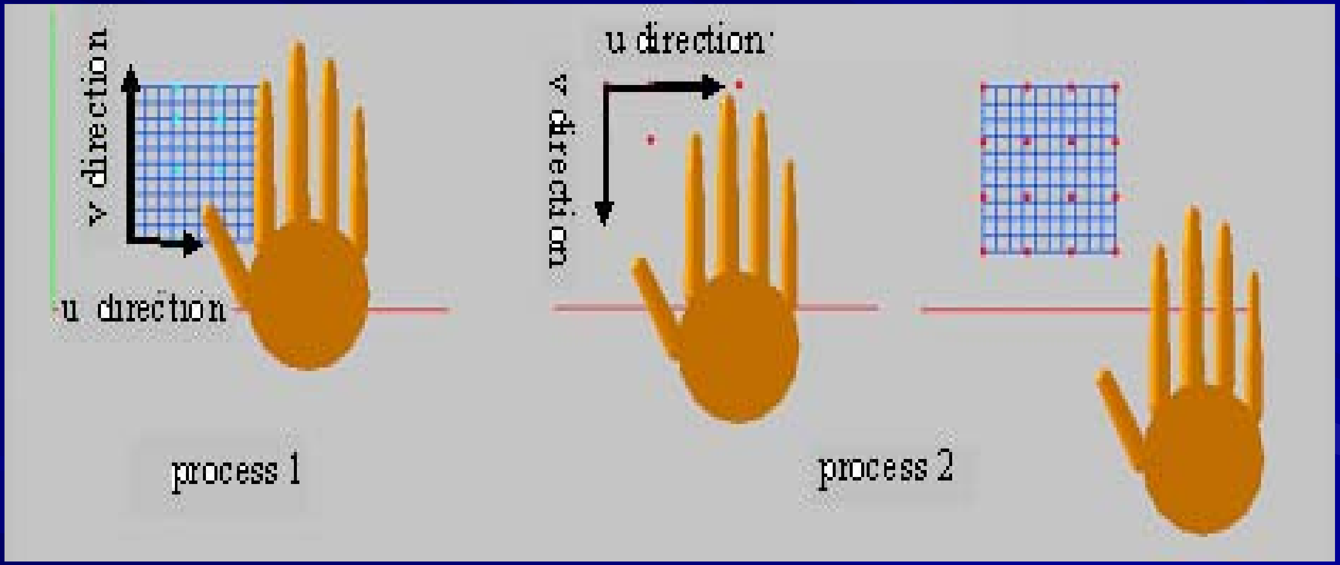



# Independent motion control

- In our sketching system, the user motion (user's hand) virtual space and the designed object are subject to independent motion
- The relative motion among the virtual objects are sustained by applying the corresponding reverse matrix of objects motion to separate the its motion relation between them

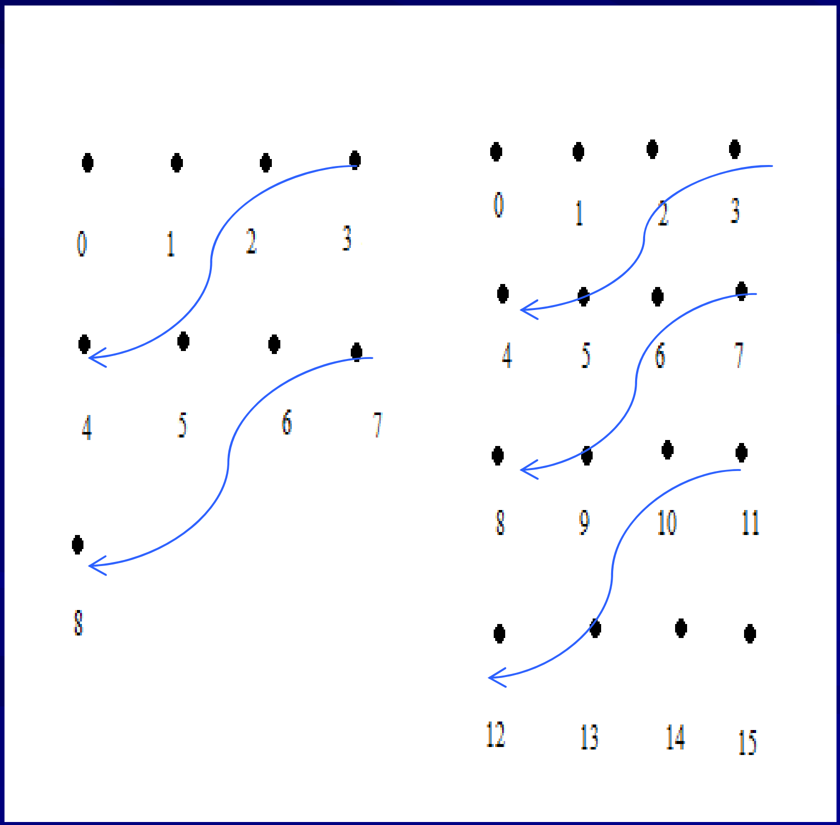
# Data generation methods and process

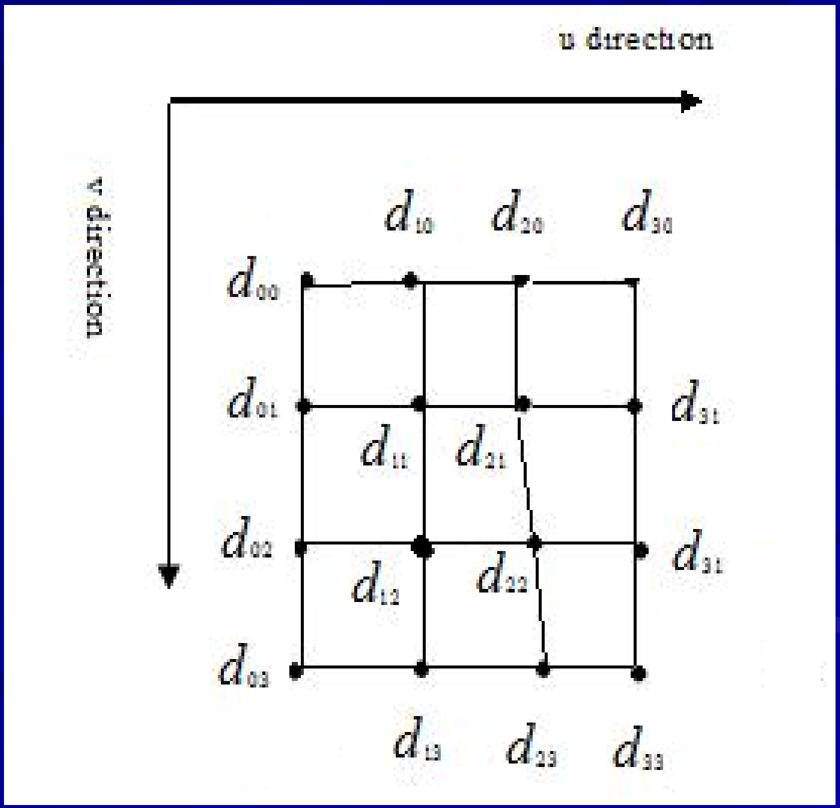
- single-point-generation and process
- multi-point-generation and process



# Single-point-generation and process

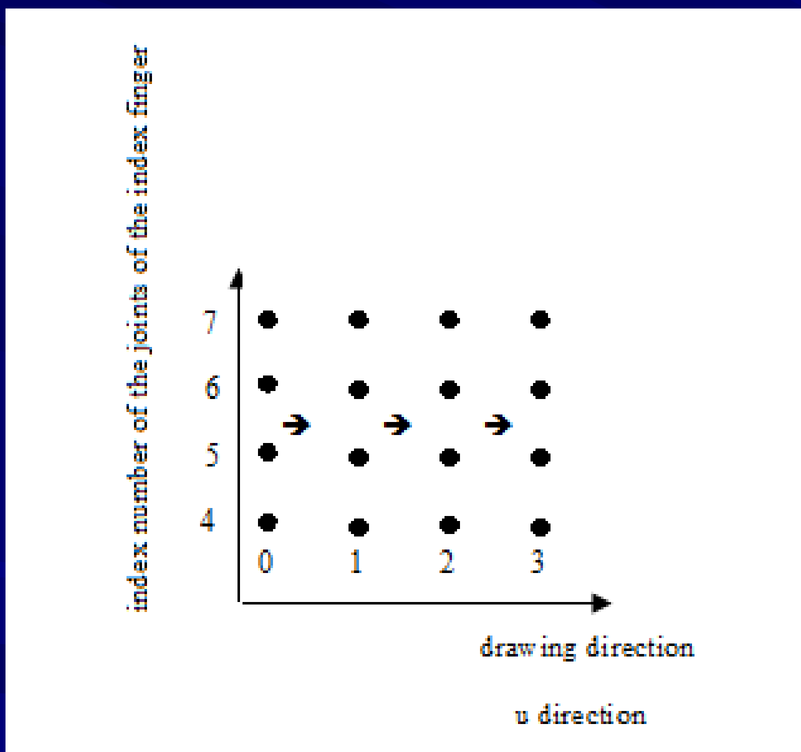
- Data drawing sequence
- Editing the acquired data matrix



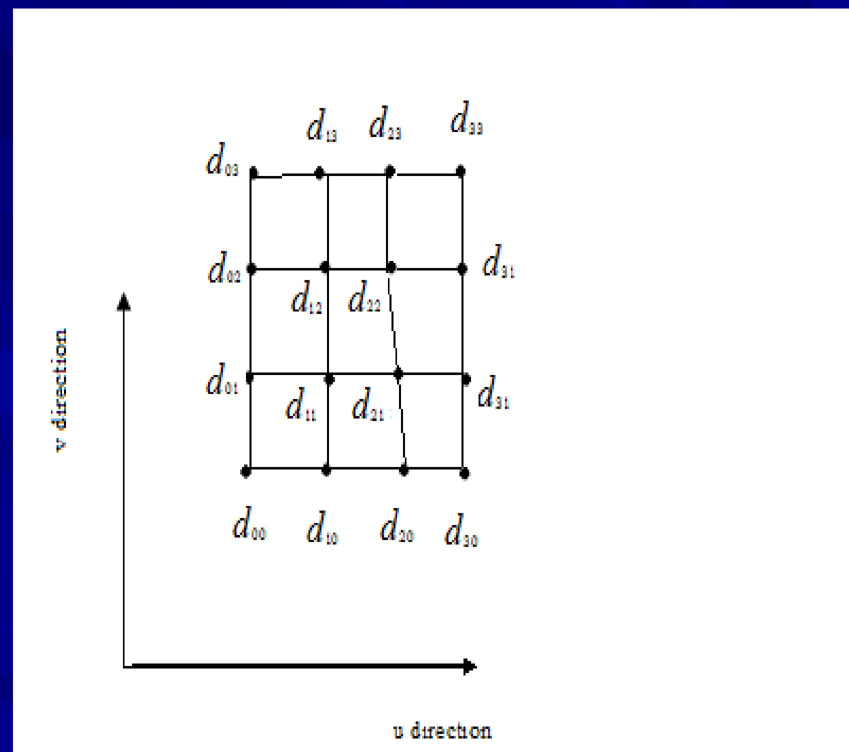



# Multi-point-generation and process

- Data drawing sequence




- Editing the acquired data matrix



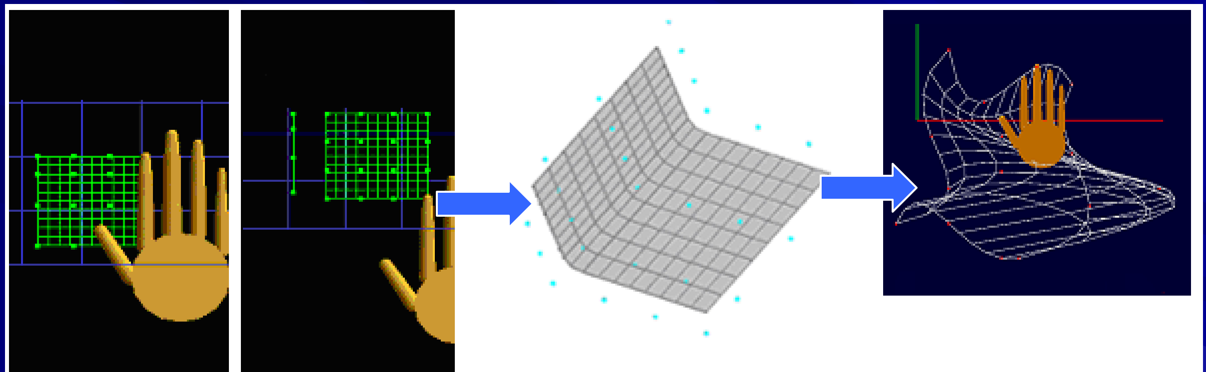
# From virtual hand to Parametric Surfaces

**Input Sources**

Single-point-generation

Multi-point generation

→ Finding Control Points → Generating NURB Surface Patches



Multi and single point generations — Control Points — NURB Surfaces

# From Surface Patches to Complete Design

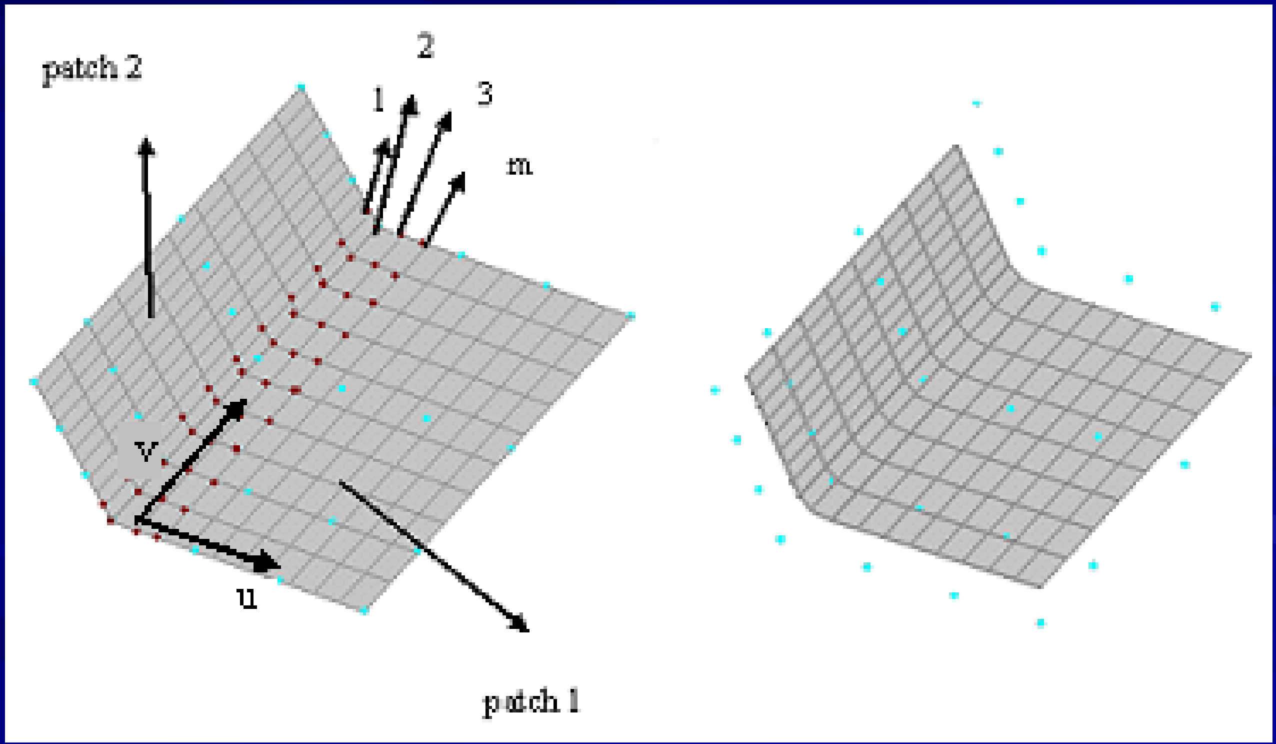
- Single NURB surface is not suitable to generate all complex geometries
- Final products usually require number of surface patches to be connected to each other
- Using surface patches and stitching them together
  - Flexible
  - Surface patches better fit to the desired geometry
  - Enables generating complex geometries
  - Local modifications possible
  - Assembly/disassembly is possible
  - Local modifications eliminate redundant calculations

# C1 smooth connection

1. Construct fillet surface to achieve C1 smooth connection between two stitched NURB patches.
2. Build-up NURB patches to fill in the holes to achieve the C1 smooth transition along their common boundaries as more than two patches are stitched together surrounding at their common joint point.

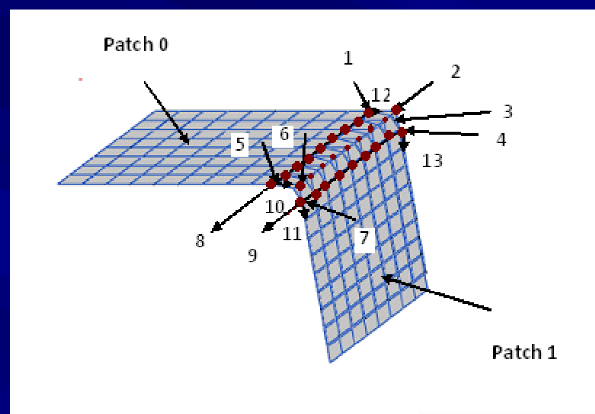
# Construct fillet surface

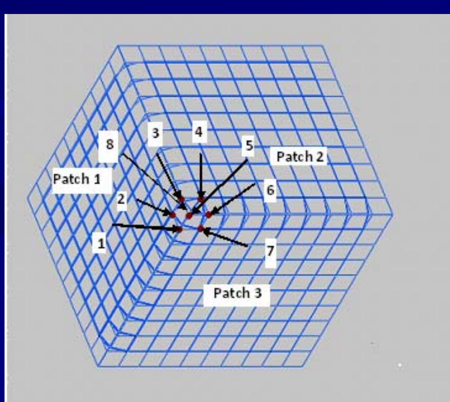
Method used to construct the fillet surface

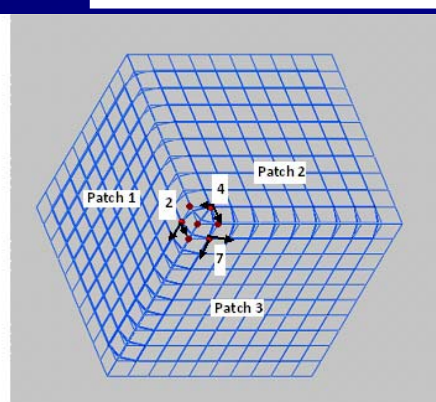


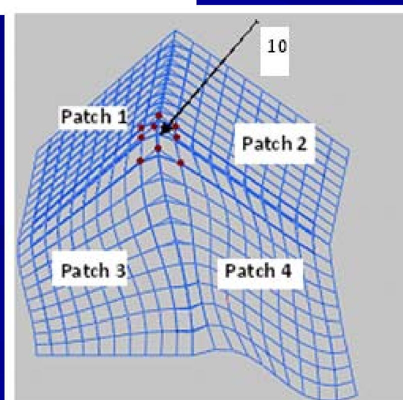
- Using the proposed Stitching technique we obtain fillet NURB surfaces which hold the following properties:
  - If the full multiplicity properties can be held by the end knots, the control polygons of the parametric surface boundary curves will be the boundary polygons of the control polygon mesh
  - When the order *k* of the B-spline is equal to 2, the parametric mesh will be its control polygon mesh itself
  - The boundary polygons of the parametric mesh pass through the four corner points of the control polygon mesh and tangent to the boundary polygon of control polygon at these four points if the end knots have full multiplicity.

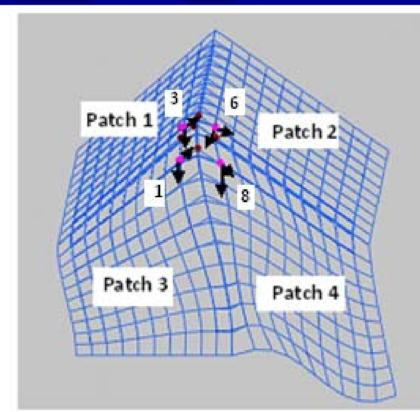
- These three properties guarantee to maintain the C1 continuity for the fillet NURB surface due to:
  - Boundaries being overlapped along the *v* direction;
  - At the four end points of the control polygon, the boundary conditions for C1 continuity being held



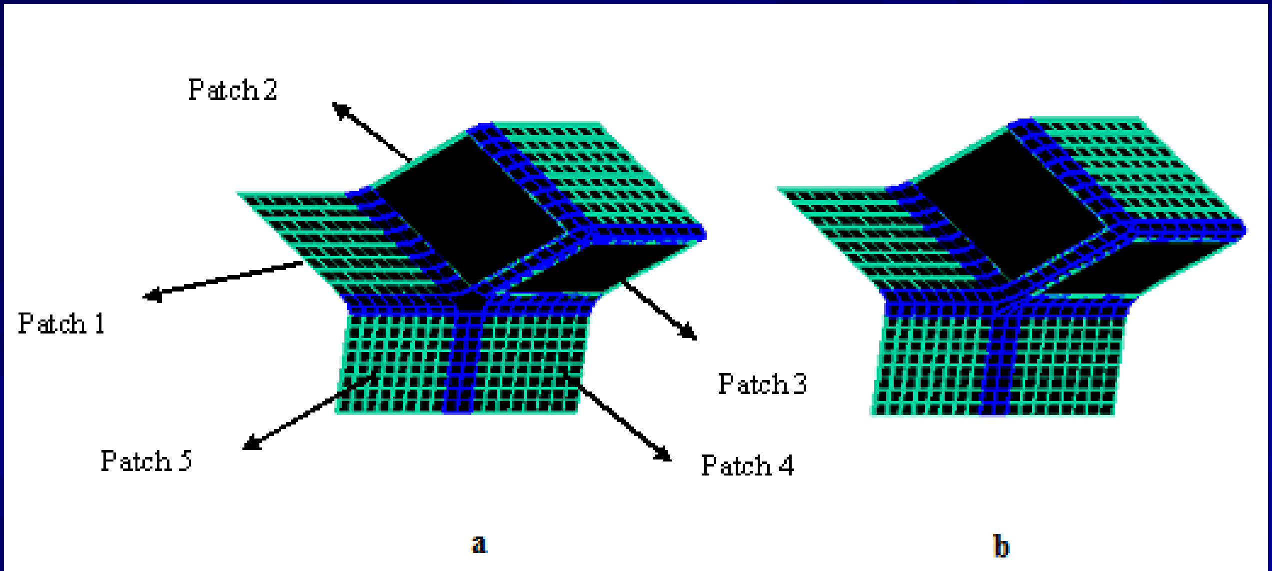



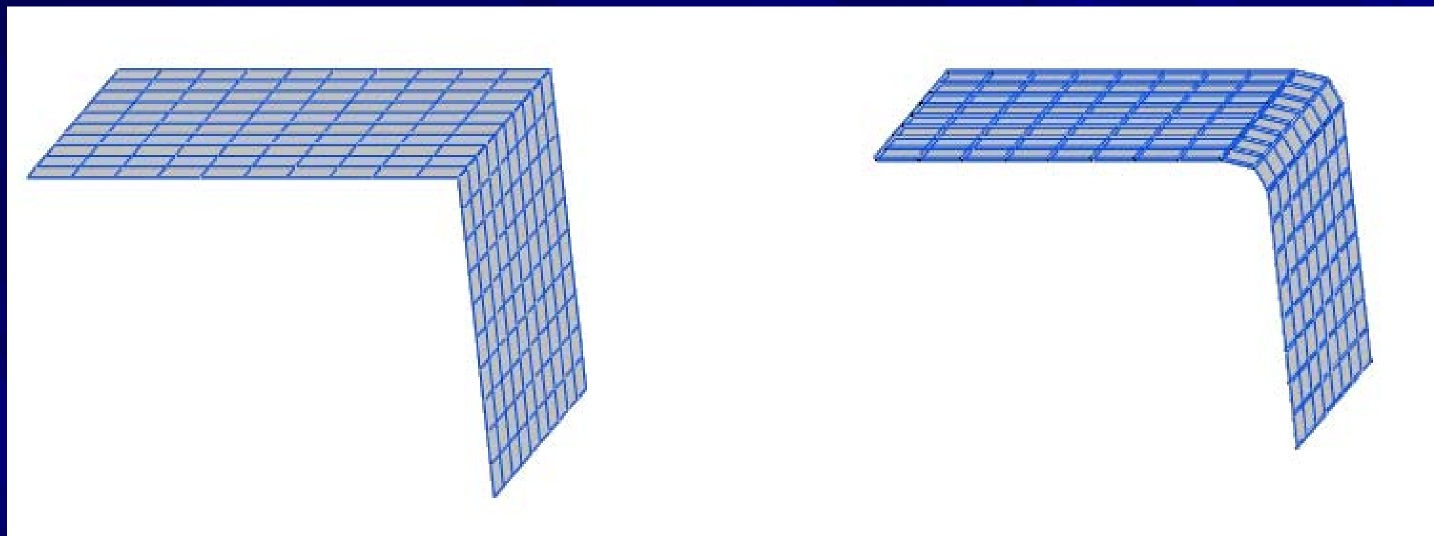



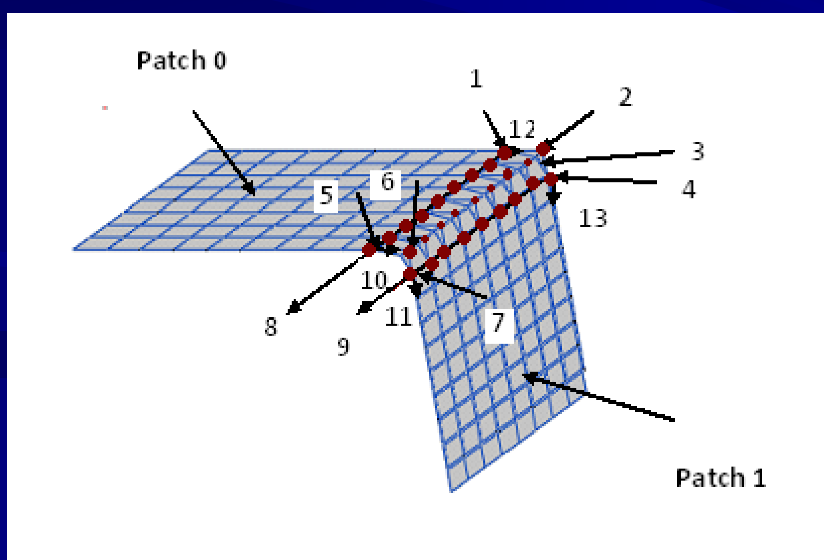



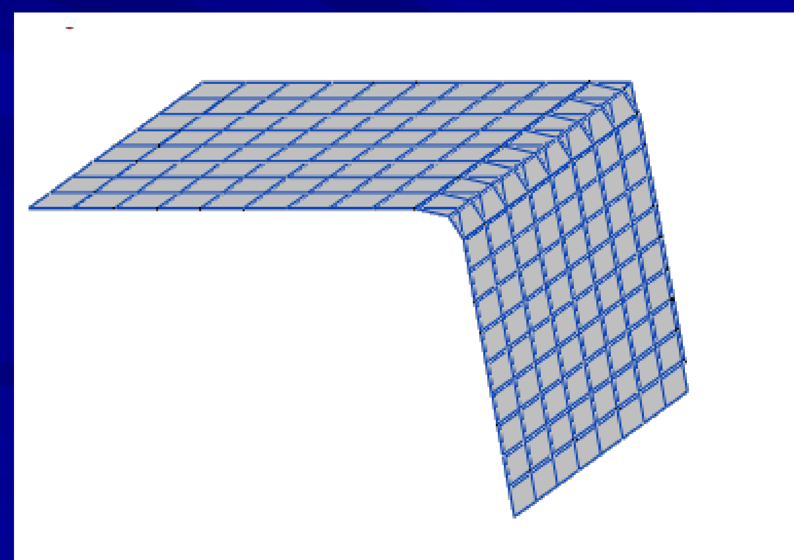
# Fill in the holes



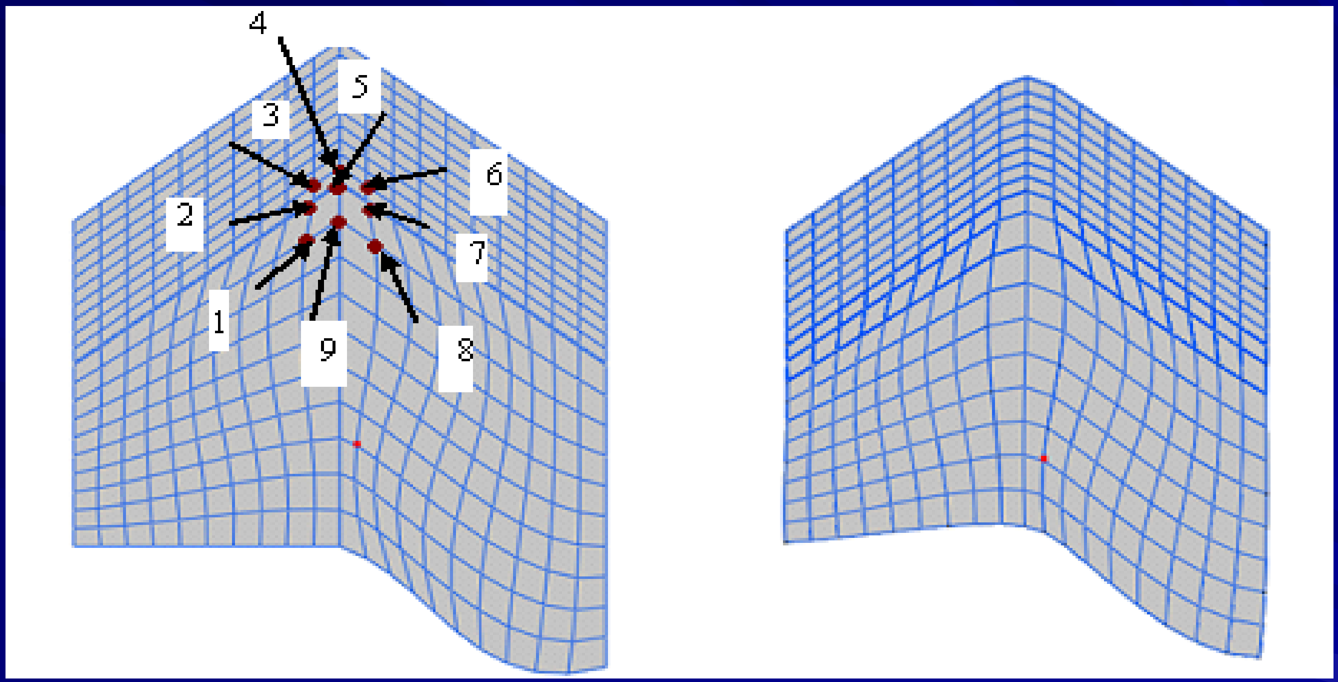
# Case 1: Two stitched patches



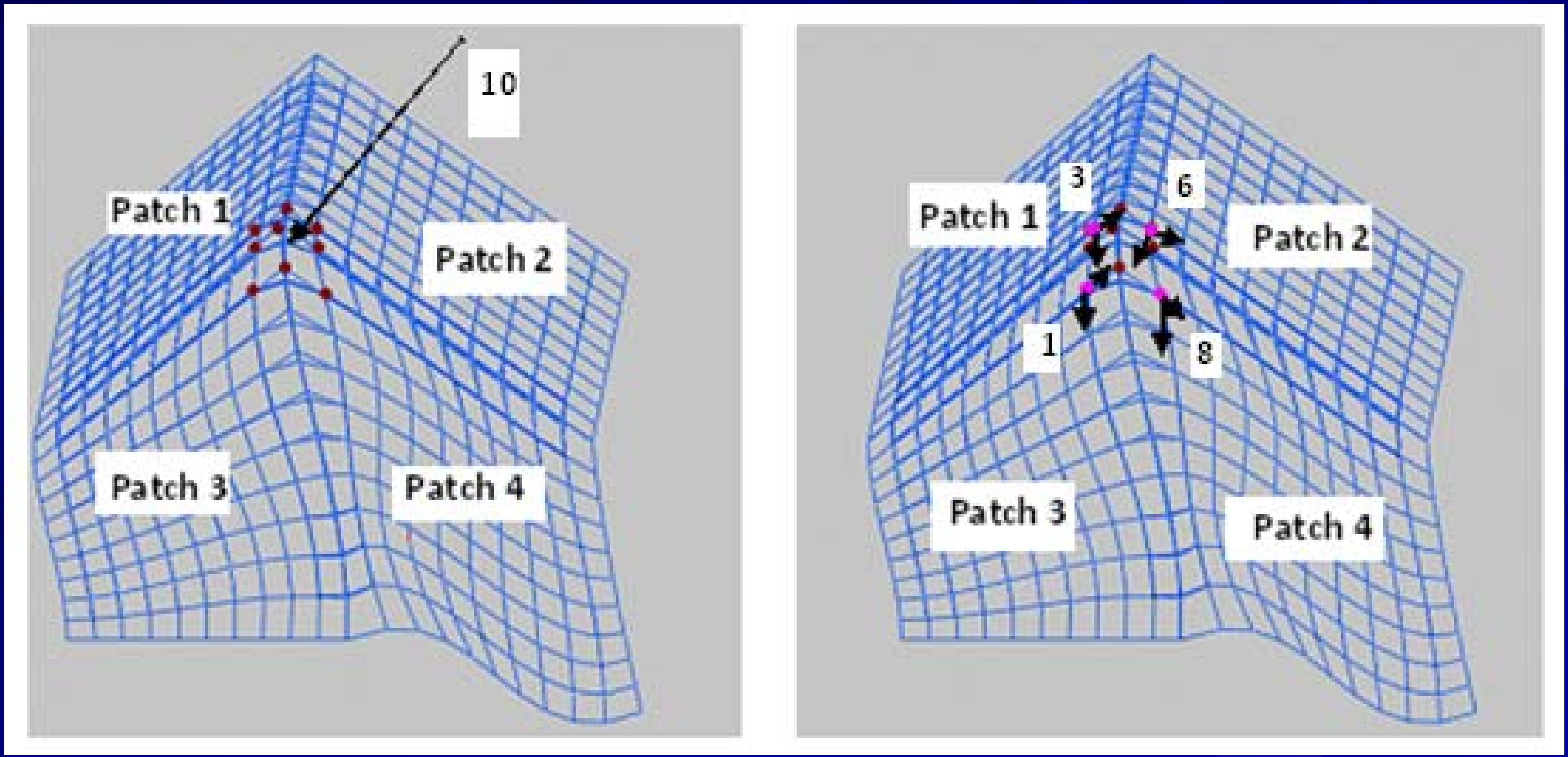


# Case 2:Four stitched NURB patches.

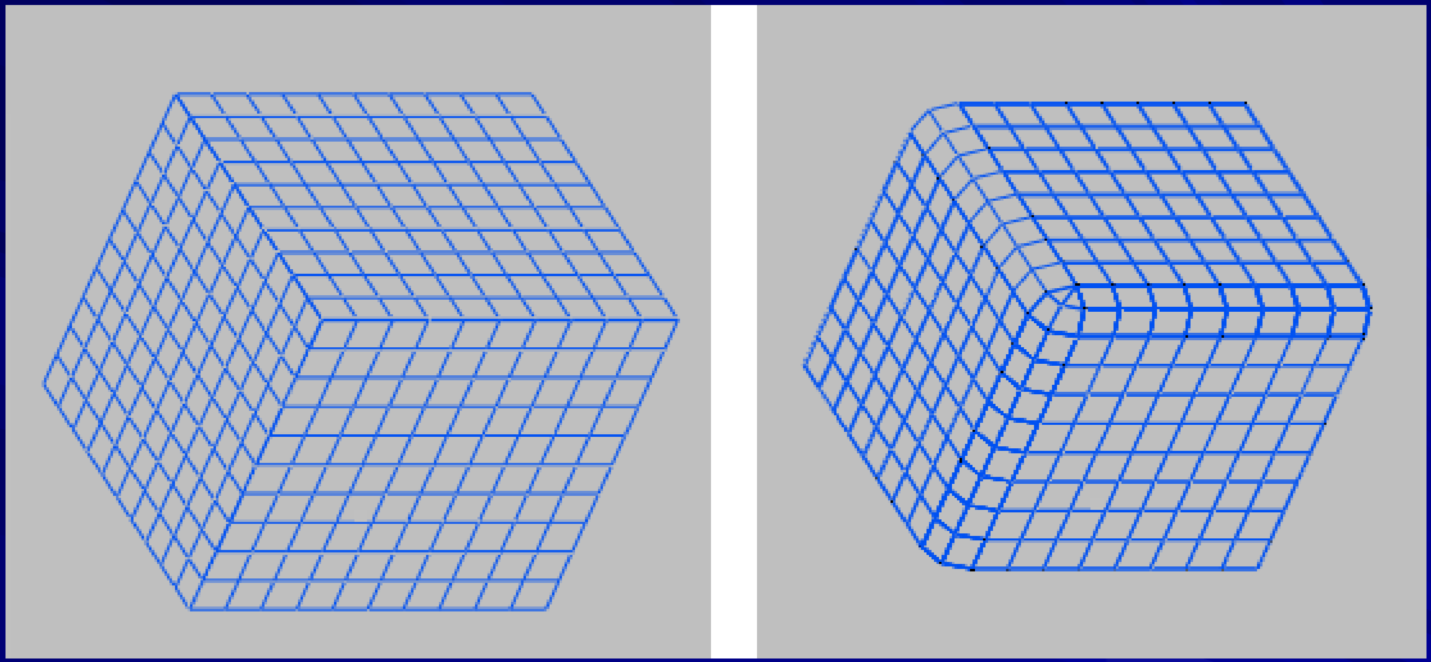



Four stitched patches before C1 and after C1connection.

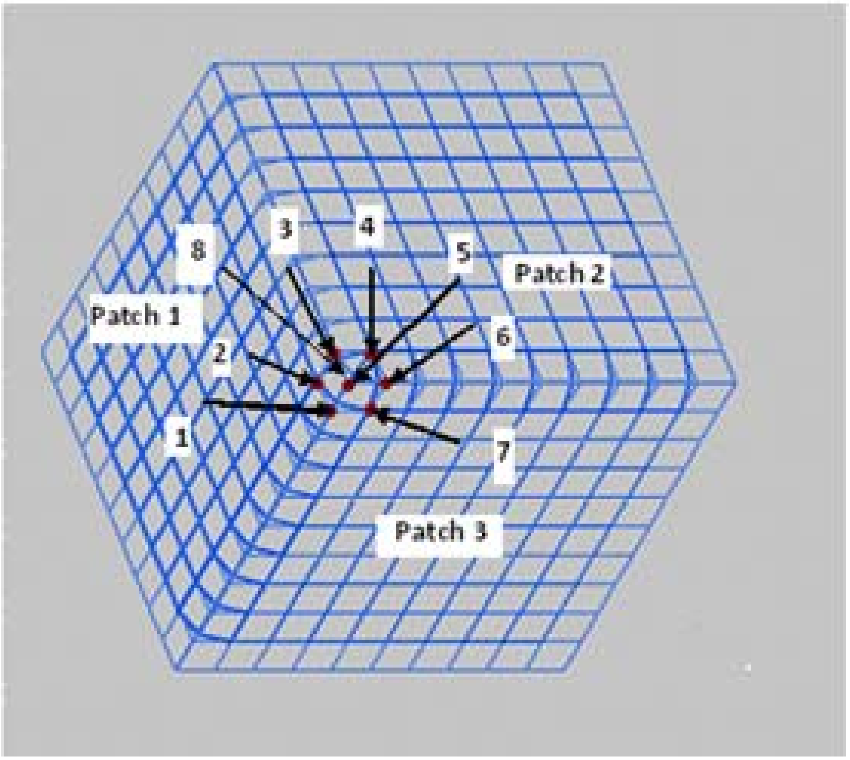



The construction of the NURB patch used to fill in the hole between four stitched patches with C1 continuity smooth transition

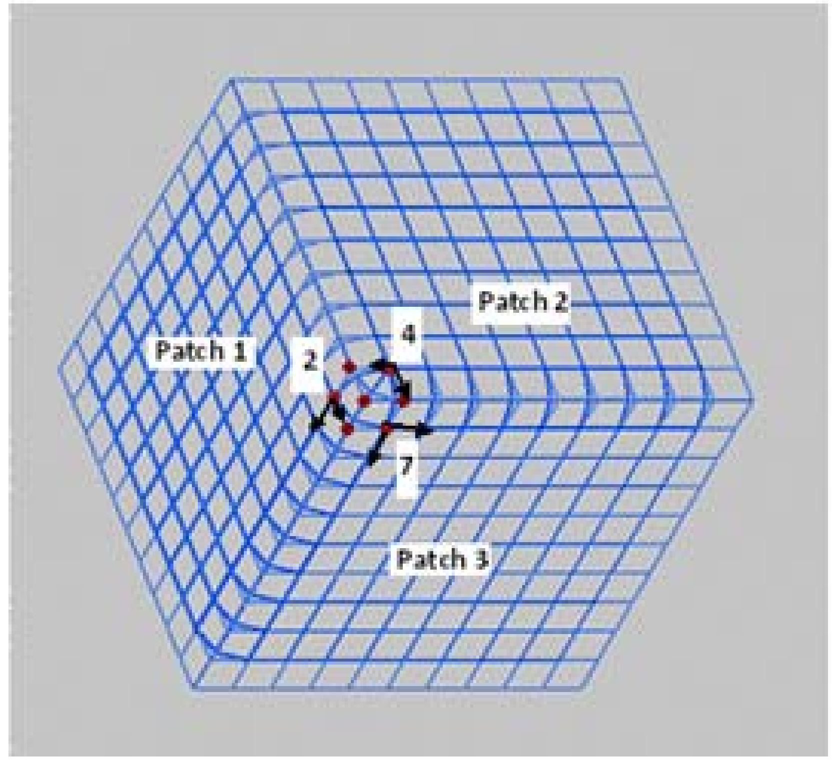
# Case 3:Three stitched NURB patches.



Three stitched patches before C1 and after C1connection.

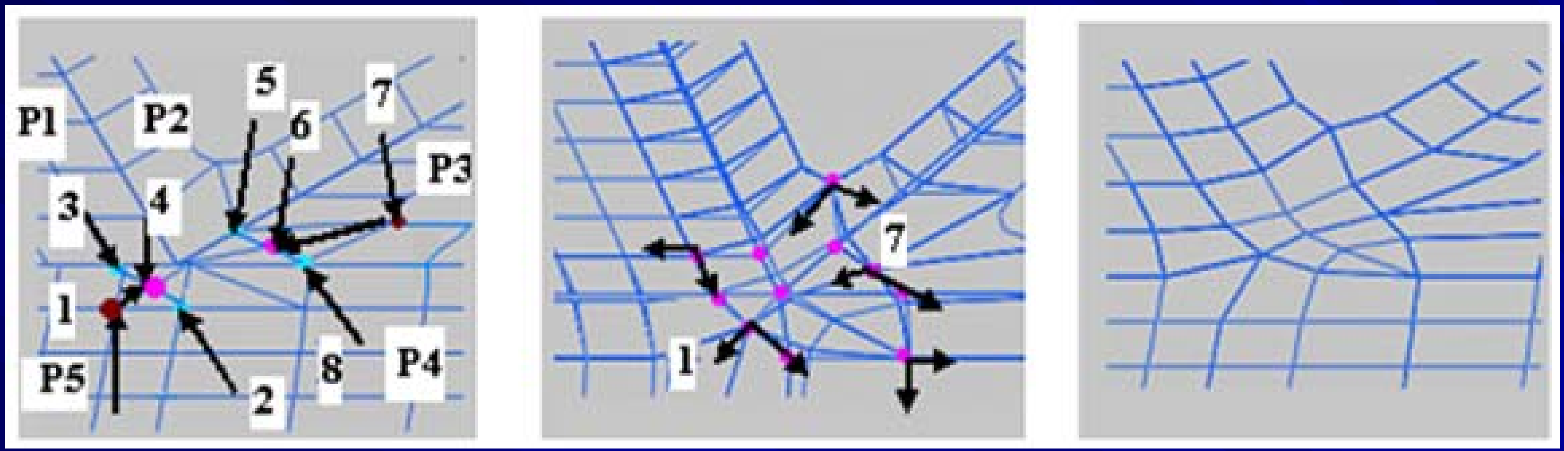


8
3
4
5
Patch 2
Patch 1
6
2
1
7
Patch 3

Patch 2
4
Patch 1
2
7
Patch 3

# Case 4: Five stitched NURB patches



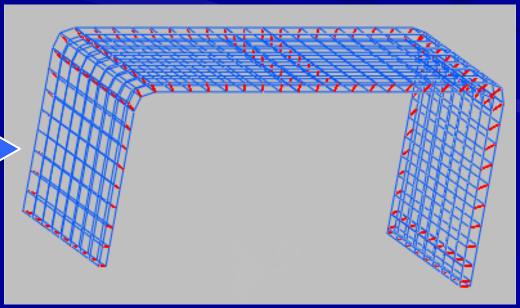
# Adding the thickness to the arbitrary designed objects

- Methodology
  - Calculate the geometric center for the designed objects
  - Pull the geometric center of the designed objects to the original point set up in our system
  - Given amplification coefficient for x, y and z directions
  - Connect the corresponding points on two images

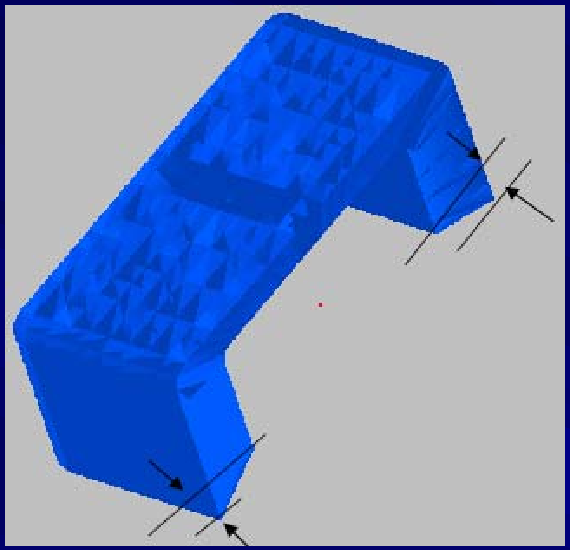
$$GC_i = \frac{\sum_{i=0}^{n} SM_i}{n+1}$$

$$T = \begin{bmatrix} -GC_{i,x} & 0 & 0 \\ 0 & -GC_{i,y} & 0 \\ 0 & 0 & -GC_{i,z} \end{bmatrix}$$

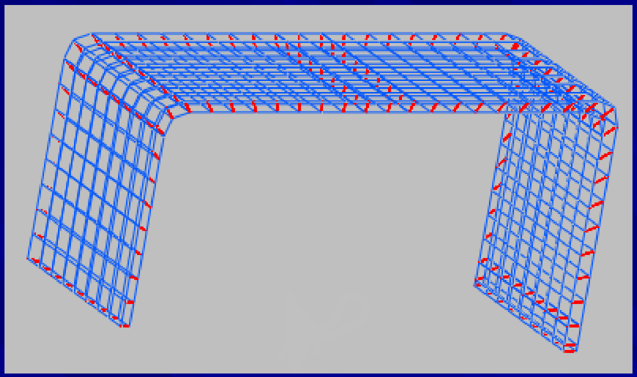
$$S = \begin{bmatrix} t_x & 0 & 0 \\ 0 & t_y & 0 \\ 0 & 0 & t_z \end{bmatrix}$$



# Outstanding Issues



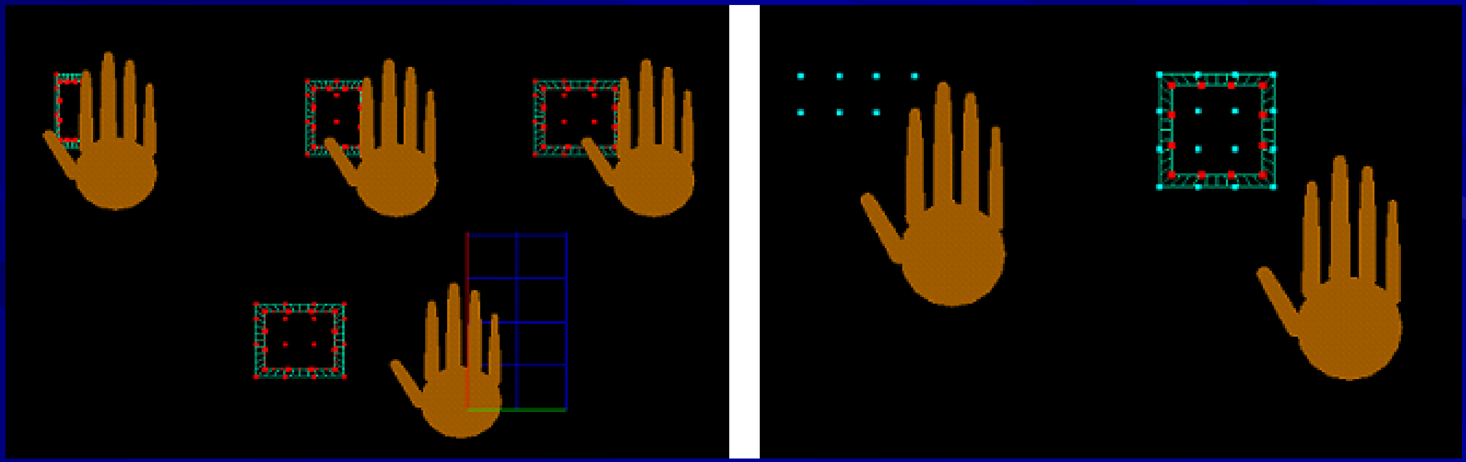
Problem is corrected using a scaling factor S



**The issues such as above may not be resolved easily by employing a scaling factor to the geometry.**

# Trimming the NURB surface

- First using the local points of the NURB surface reconstruct the inside frame
- Next, by redrawing the image we display the desired segment (suppose for car windows)



# Trimming the NURB surface

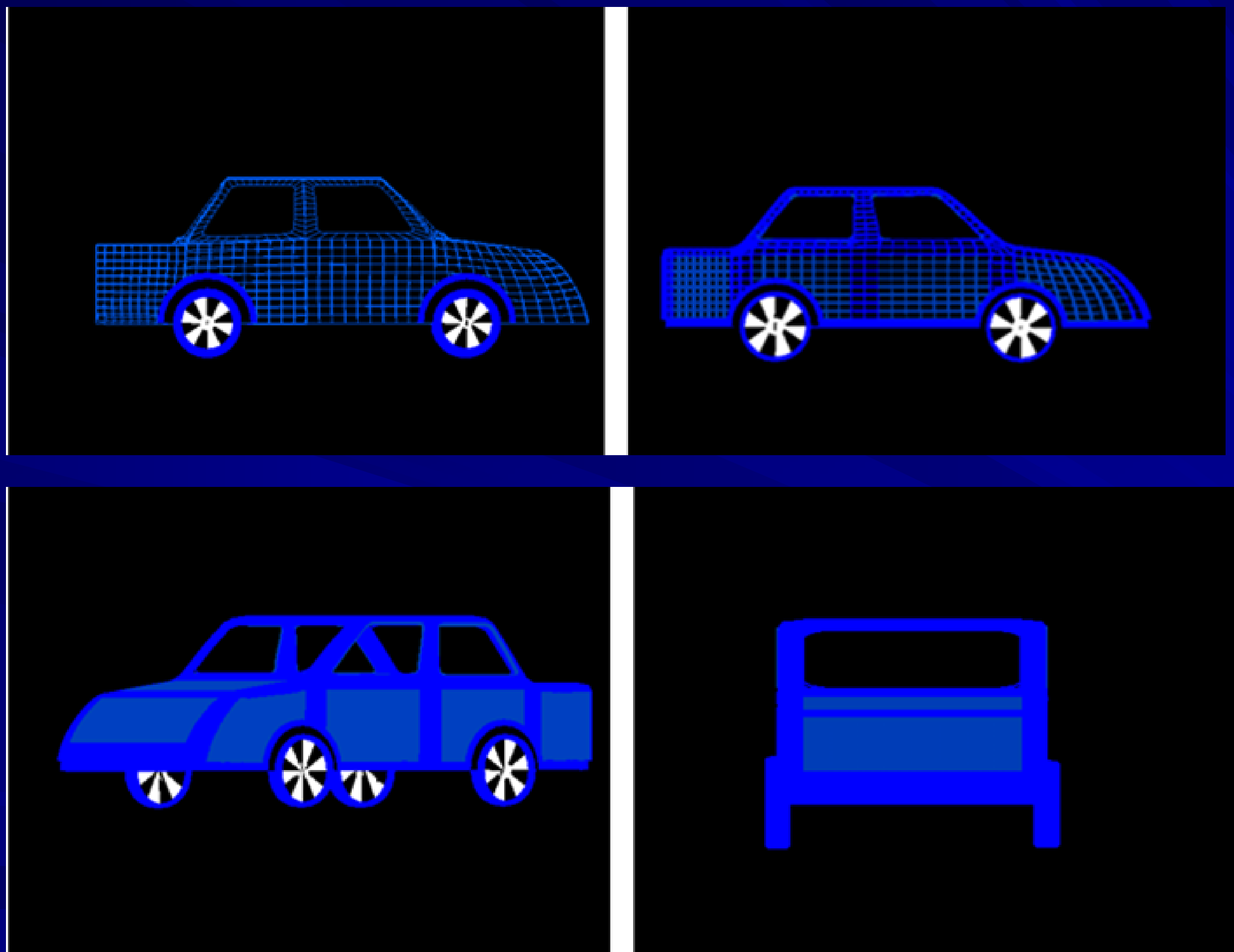
- The second trimming approach we employed is
  - First, take out the NURBS surface local points to reconstruct the outline curves
  - Next, by using the background color (suppose dark color) with a certain thickness to hide the undesired images around the shape outline curves, we can display the desired images.
- This approach enables us to generate highly complex geometries using parametric equations.
- Since the main motivation is “Conceptual Design”, not removing the actual data is not giving any drawback

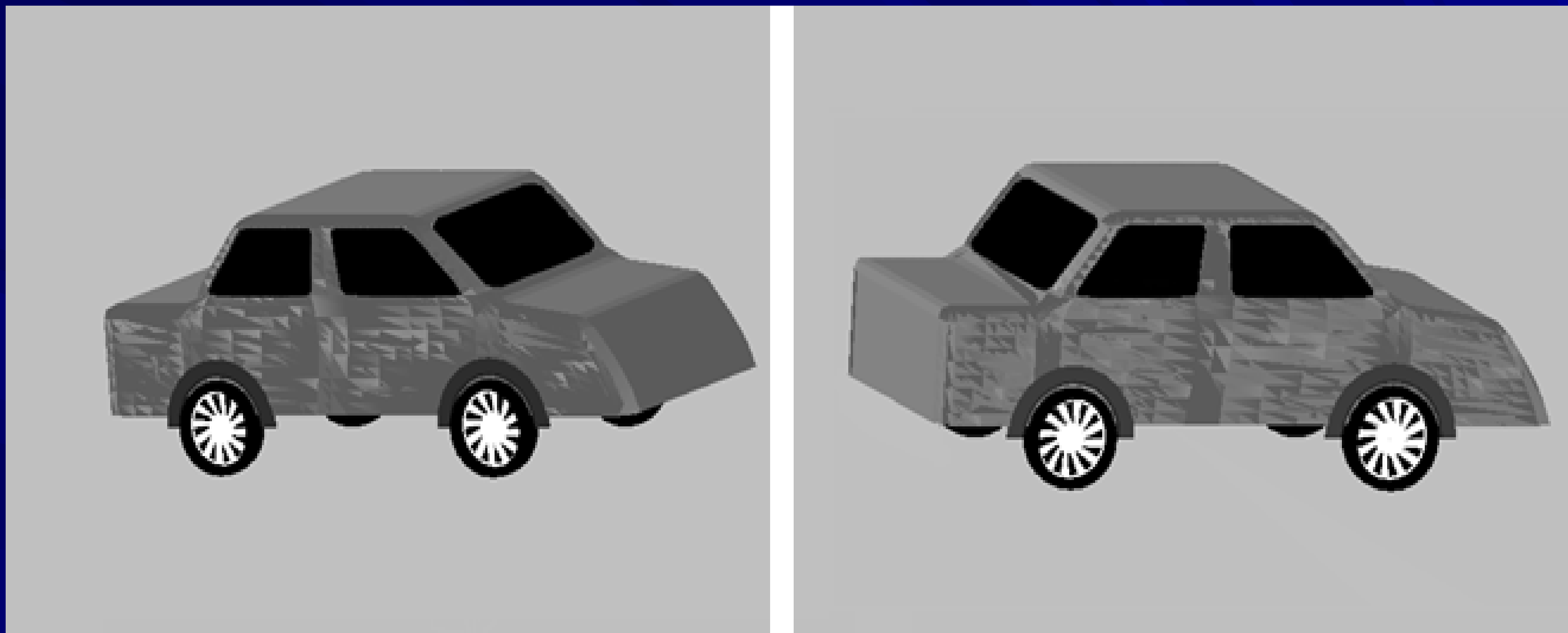
# Trimming the NURB surface

# Summary of the Proposed Method

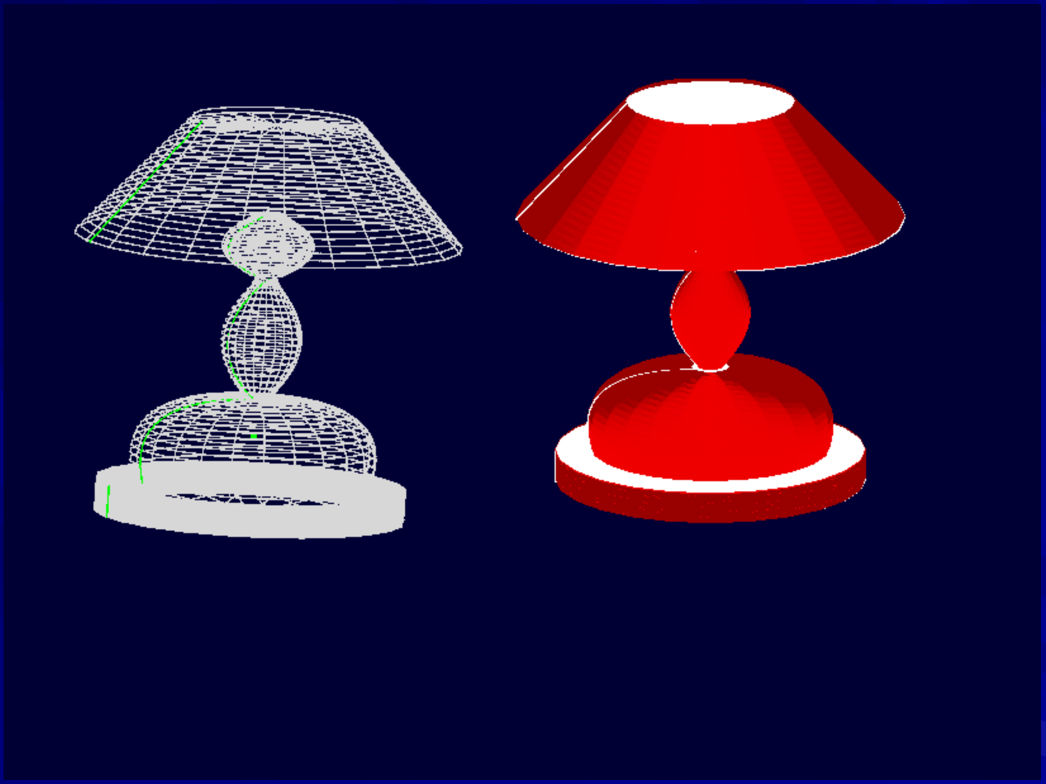
- By now, we introduce our methods used to perform free-form conceptual design in four steps
  - The generation of the NURB patch
  - C1 smooth connection
  - Adding the thickness
  - Trimming the NURB surface
- Next, we use four examples to show the results of our methods

# Example 1. Car modeling

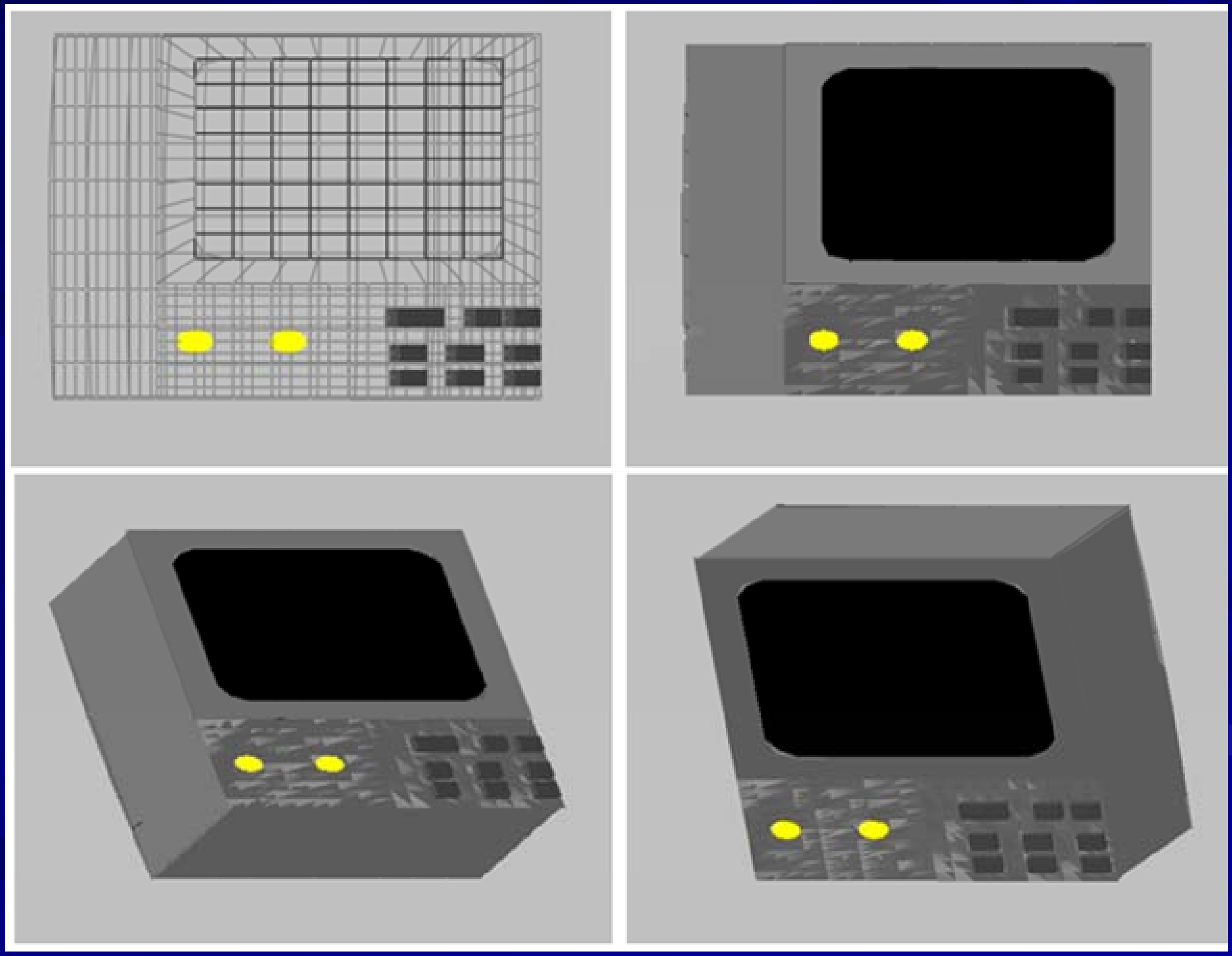




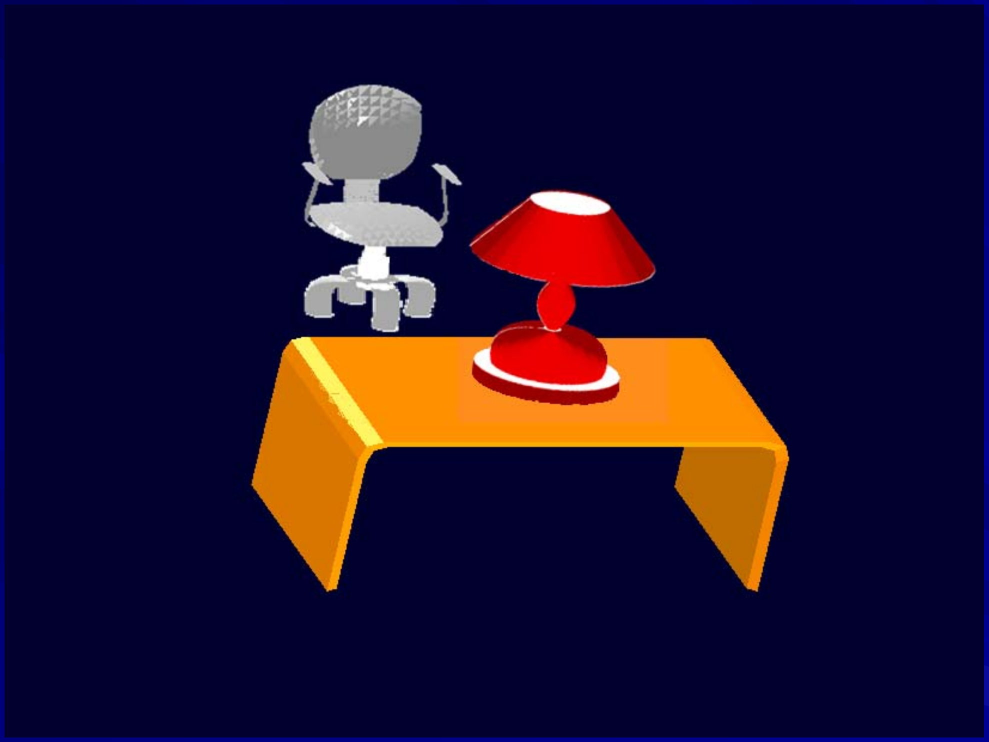
# Example 2: Table lamp



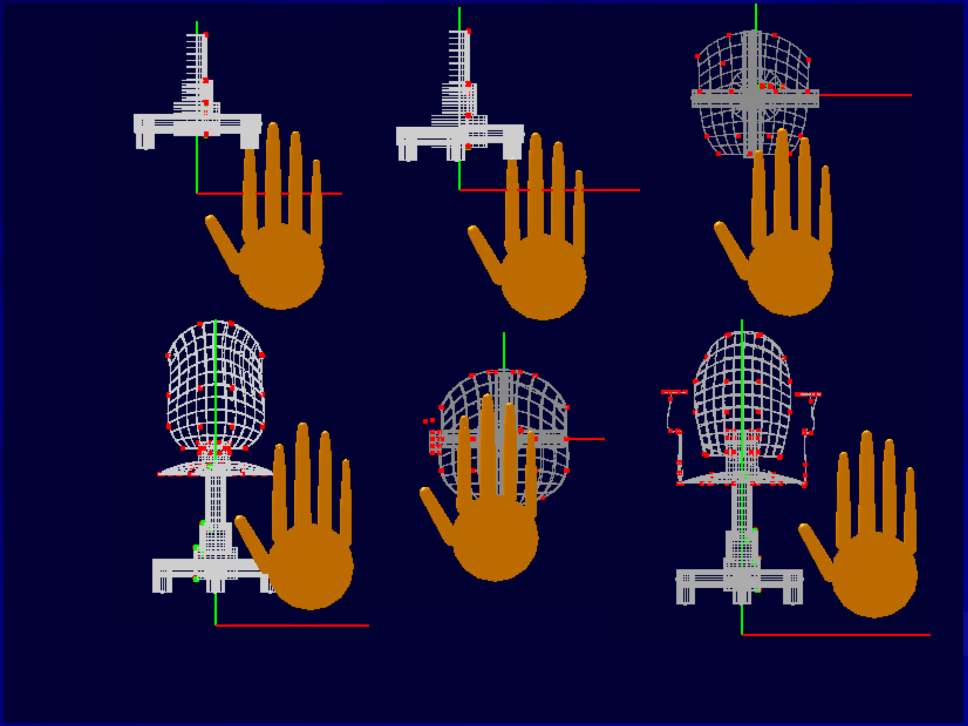
# Example 3: Microwave



# Example 4: A chair and table

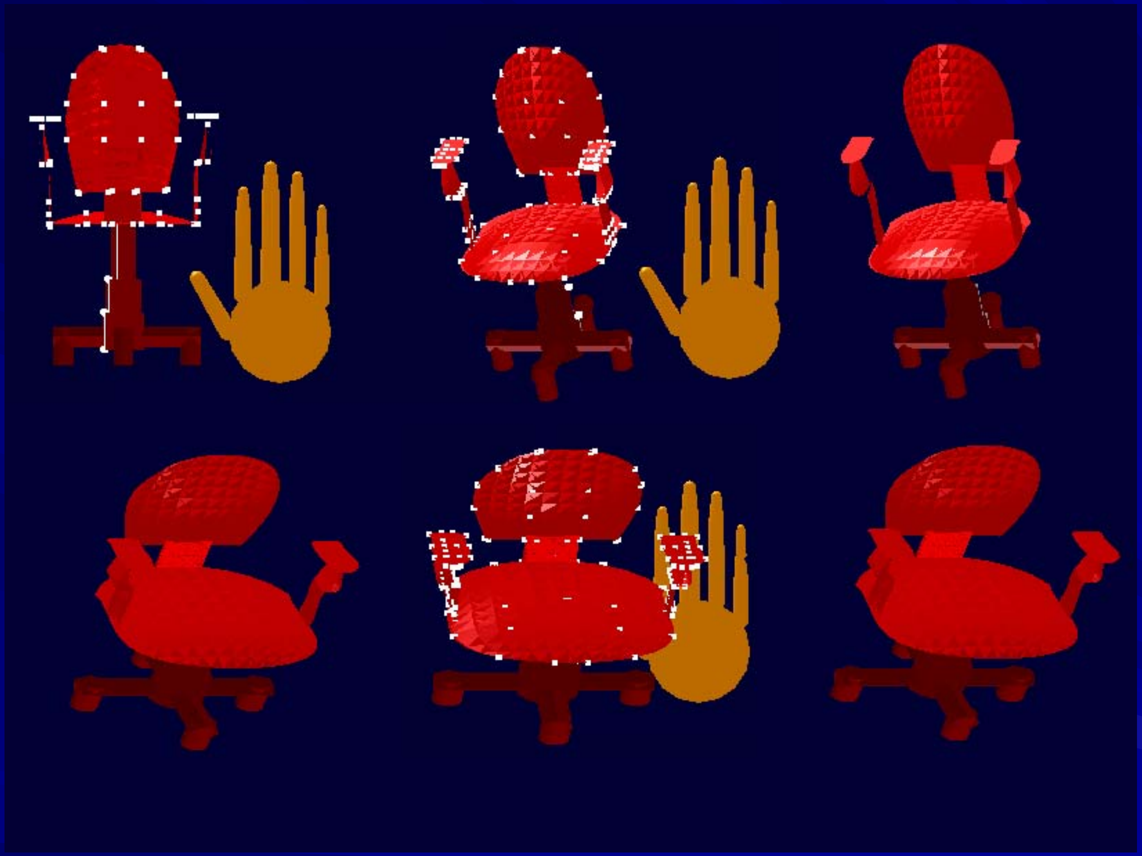


# Example 5: A chair image



A  chair image wire model and drawing sequence.

# Example 5: A chair image



# Contributions and Future Works

*Questions ?*

# Thank You !