University of BRISTOL

Department of Mechanical Engineering

VIRTUAL PRODUCT DEVELOPMENT (MENGM6049) – Lecture 3 Reverse Engineering 2017-2018

Dr Kazem Alemzadeh

The Purpose of the Lecture

- Reverse Engineering Methods and Processes: **Digitization**, **Segmentatio**n, **Curve**, **Surface Modelling** & **Quantification**.
- Strategy: a prerequisite to RE
- **Digitization**, contact and non-contact methods
- Contact, CMM and Robotic arm & Non-contact, optical
- Example of commercial system and videos
- **Digitization** and point clouds as an STL or polygon mesh output.

The Purpose of the Lecture

- Demonstration of **Segmentation**, point clouds curvature analysis & edge detection method using a car.
- Demonstration of **curve, surface modelling** and **quantification** process using a car.
- Biomimetic Modelling – Mandibular tooth example.

Reverse Engineering Methods & Processes

- RE involves **digitization**, **segmentation, curve** and **surfacing** of an existing physical model using 3D scanners (i.e. contact or non-contact) and dedicated RE and inspection/**quantification** software.

- The downstream process (e.g. solid modelling or FEA) will greatly affect the methods and processes of model creation.

- Therefore, it is critical to understand the requirements and develop a strategy for model creation. These requirements determine the quality level needed and the time it will take to complete the model.

R E Methods & Processes

- Application **strategy** helps efficiency and effectiveness during the processes.
- The table below describes the most common types of downstream applications and their requirements and limitations.

Type	Continuity	Restrictions
Manufacturing	Small gaps are acceptable. Tangent continuity should be within +0.5 or -0.5 degrees.	Some CAM systems may not accept trimmed surfaces.
Solid Modelling	Requires a totally closed and watertight model. Positional continuity should be 0.0012 mm.	Possible restrictions for using trimmed surfaces.
Packaging, Concept Visualization, or Prototyping	Requires a totally closed and watertight model.	Possible restrictions for using trimmed surfaces. Speed is more important than accuracy.
Animation	Visual continuity required, but not mathematical continuity.	Trimmed surfaces not allowed. Most systems only allow four-sided patches. Uniform parameterization is desirable.
Rapid Prototyping	Requires a closed model to be used for creating a closed STL model.	
Finite Element Analysis	Requires a closed model to be used for creating a closed STL model. Gaps should be no larger than 0.05 mm.	

Digitization

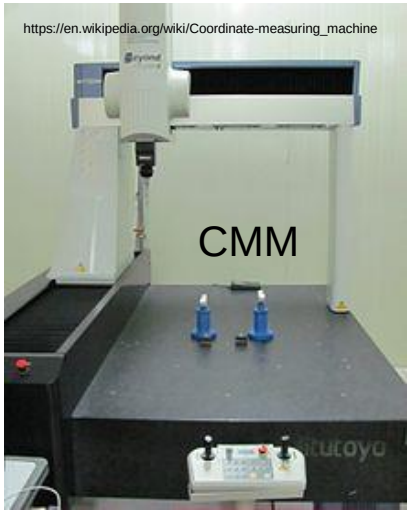
- Digitization is carried out by a probe attached to machines with moving axes. These machines can be Coordinate Measuring Machines (CMM) or robotic system.

- Probe can be contact (mechanical), or non-contact (optical, laser, or white light).

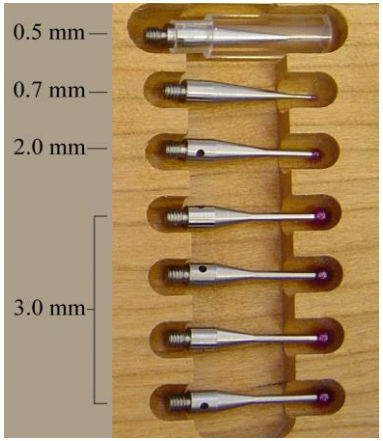
- The output of the digitization process is a dense set of points, called point clouds, which is the input for the segmentation process.

Contact (mechanical) Methods

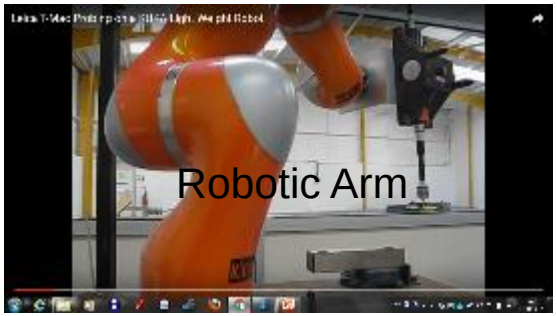
- Range of styli probe used with CMM or robotic arm



Standard Styli Sizes



Stylus Fitting



Star Styli

Digitization, Contact Methods

- Contact methods are amongst the most robust in terms of accuracy, repeatability and absence of noise, but they are the slowest methods of data acquisition.

- It involves minimal pre-processing to determine the contacting surface coordinates relative to the arm.

- Contact methods cannot be used on soft objects.

Commercial Examples

- 5 axis scanning CMM Measuring technology

https://www.youtube.com/watch?v=CsTQO-8dBdU [accessed Apr. 12, 2017]. 4.37M

- Leica T-Mac Probing on a KUKA Light Weight Robot

http://www.youtube.com/watch?v=rw9EDziOnFA&feature=related [accessed Apr. 12, 2017]. 0.26M

Non-Contact Methods – Commercial Examples

- Non-contact (laser, or white light) methods require more complex processing of the raw data collected to produce a useful point cloud compared to contact methods.

Non-contact 3D laser scanner

Non-contact 3D white-light scanning technology from Solutionix Rexcan4

Non-Contact Methods – Commercial Examples

3D laser scanner/Motion capture

Motion Capture System

- Leica Absolute Tracker with T-Scan on a robot

http://www.youtube.com/watch?v=aF9RaBJ_2xU [accessed Apr. 18, 2017]. 1.49M

- Arm-Free handheld 3D Scanner system - MetraScan

http://www.youtube.com/watch?v=FU4fQqh1_hg [accessed Apr. 18, 2017]. 3.30M

- Quick 3D Face scanning with Artec 3D Scanner

http://www.youtube.com/watch?v=-7SH3zxDfdU&feature=related [accessed Apr. 18, 2017]. 1.20M

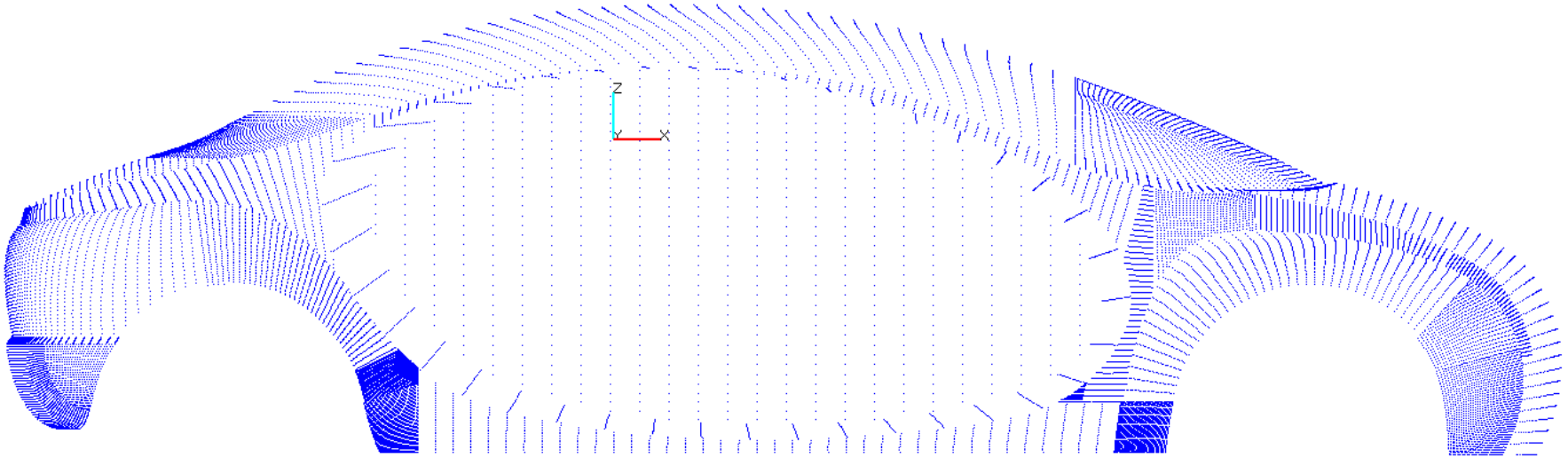
- Non-contact 3D white-light scanning technology from Solutionix Rexcan4

http://www.youtube.com/watch?v=xp3eO5ldAik [[accessed Apr. 18, 2017]. 2.58M

Digitization & Point cloud

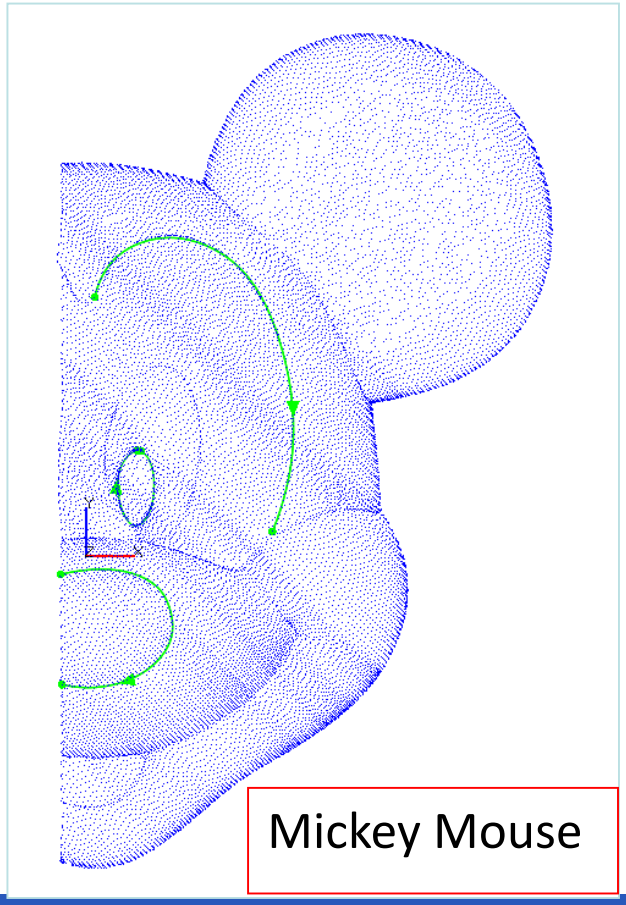
- The output of the digitization process is a dense set of points, called point clouds, which is the input to the segmentation process.

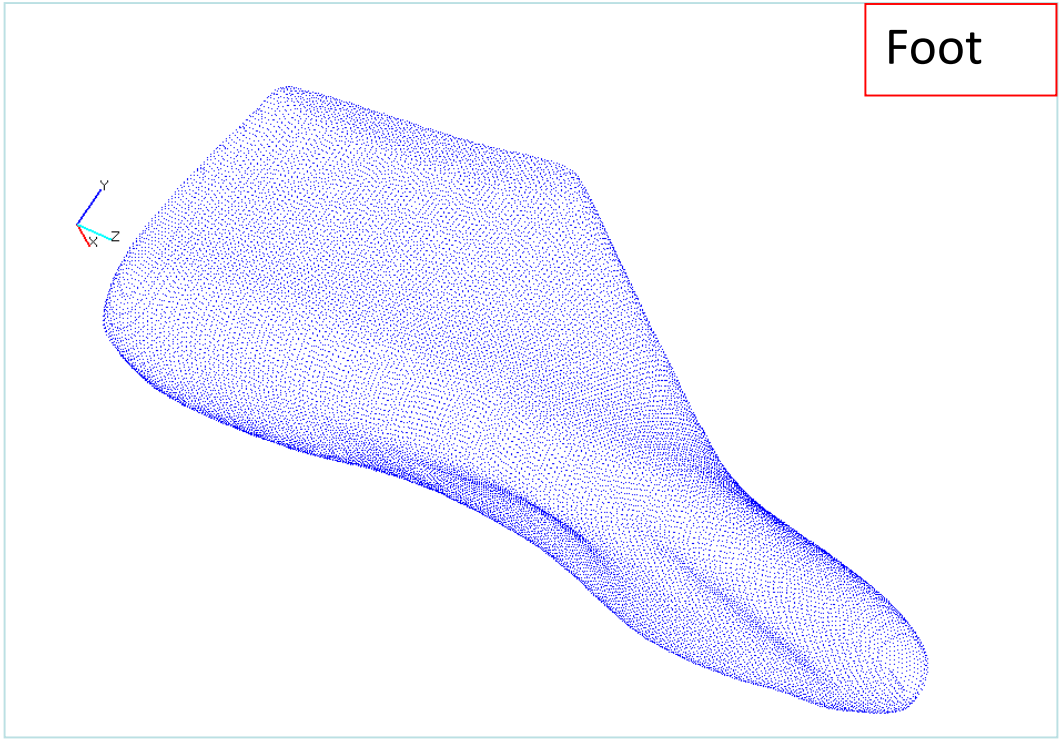
- Example below shows a car point cloud.



Digitization & Point cloud

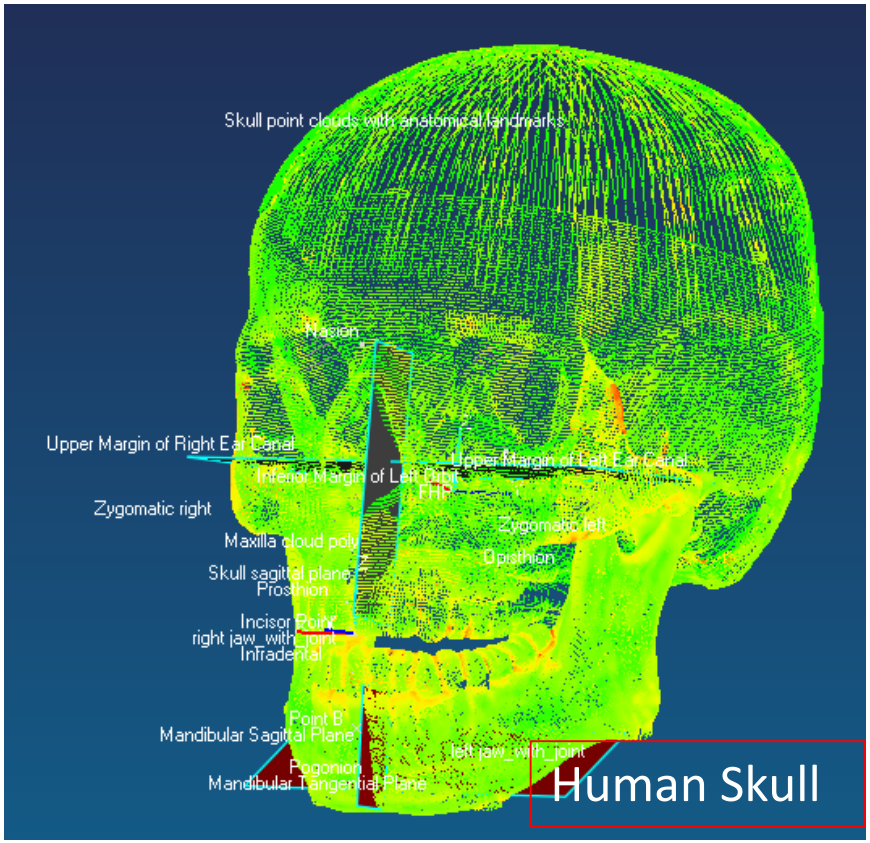
- Examples below show Mickey Mouse and foot point clouds. These clouds are cleaned from noise and aligned.





Digitization & Point cloud – Biological

- Biological point clouds are cleaned from noise and clinically aligned.

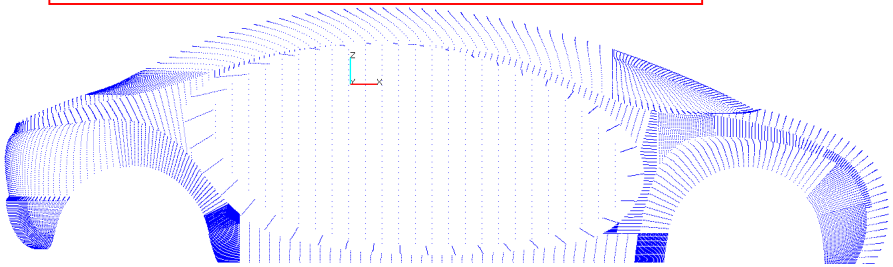


The Output of Digitization Representation

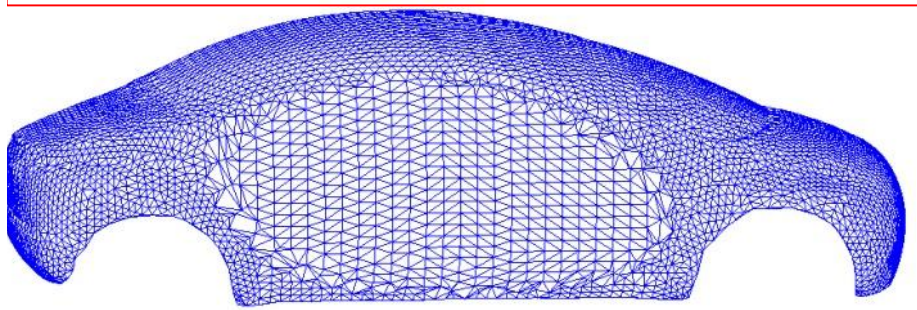
- The point clouds can be ASCII text file containing the x, y , z values, or triangular polygon mesh representation known as an STL file format.
- STL file format is supported by many software packages, widely used for rapid prototyping and CAM software.
- Below is an example showing a car in both representations.

Car

Point cloud representation



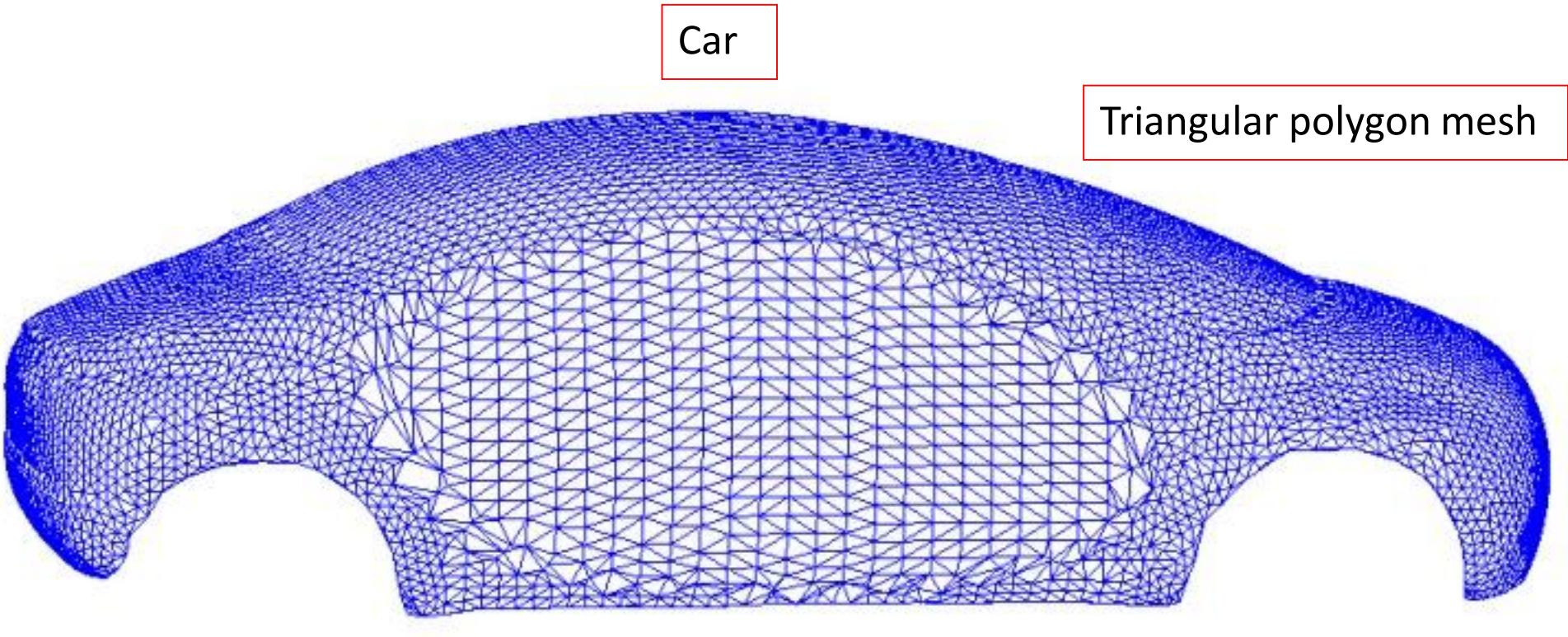
Triangular polygon mesh representation



The Output of Digitization – STL File

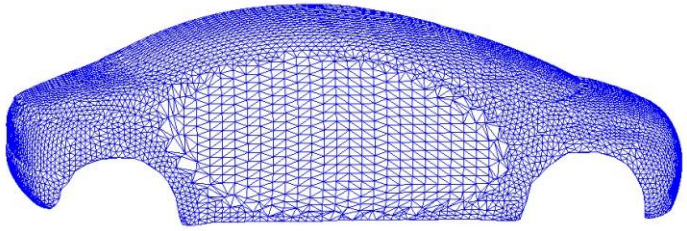
- Polygon mesh or STL file describes only the surface geometry of the object, without any specifications of colour, texture or other common CAD model attributes.

- Therefore it cannot be modified or made smoother.

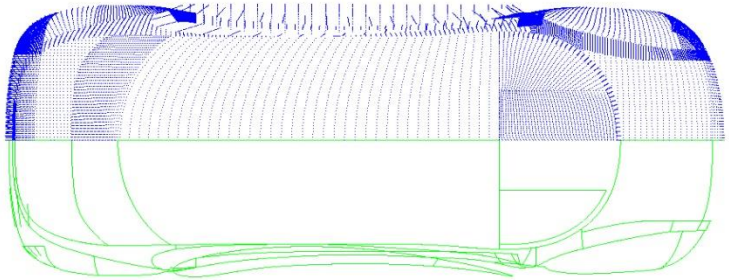


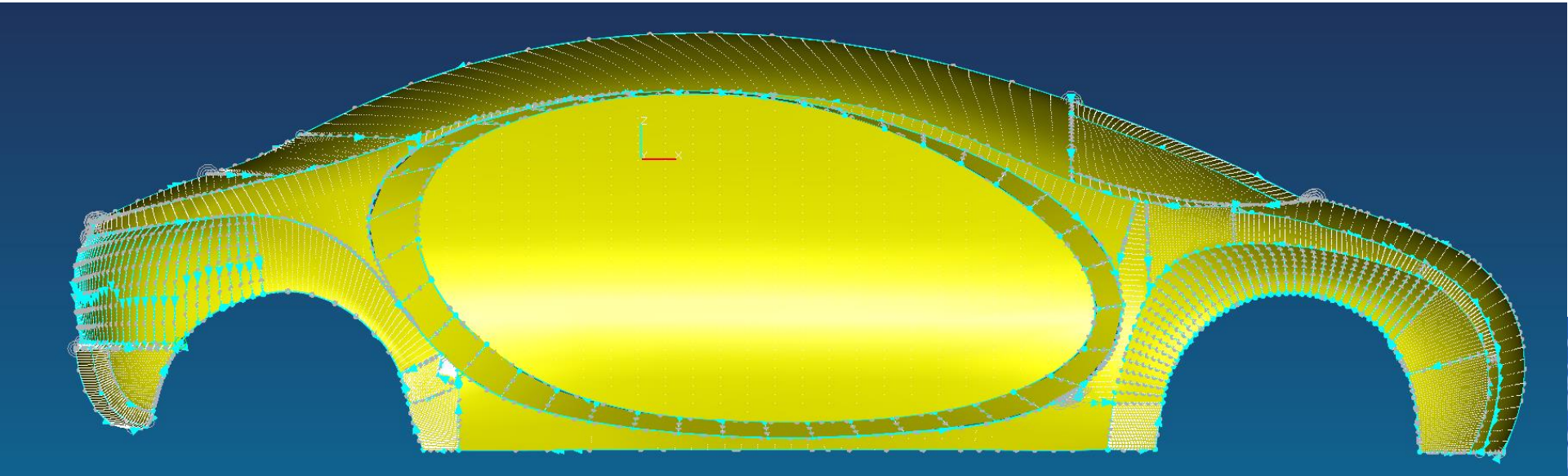
Surfacing Modelling - Point-Curve-Surface

- Polygon mesh is incapable of accurately representing curved surfaces.



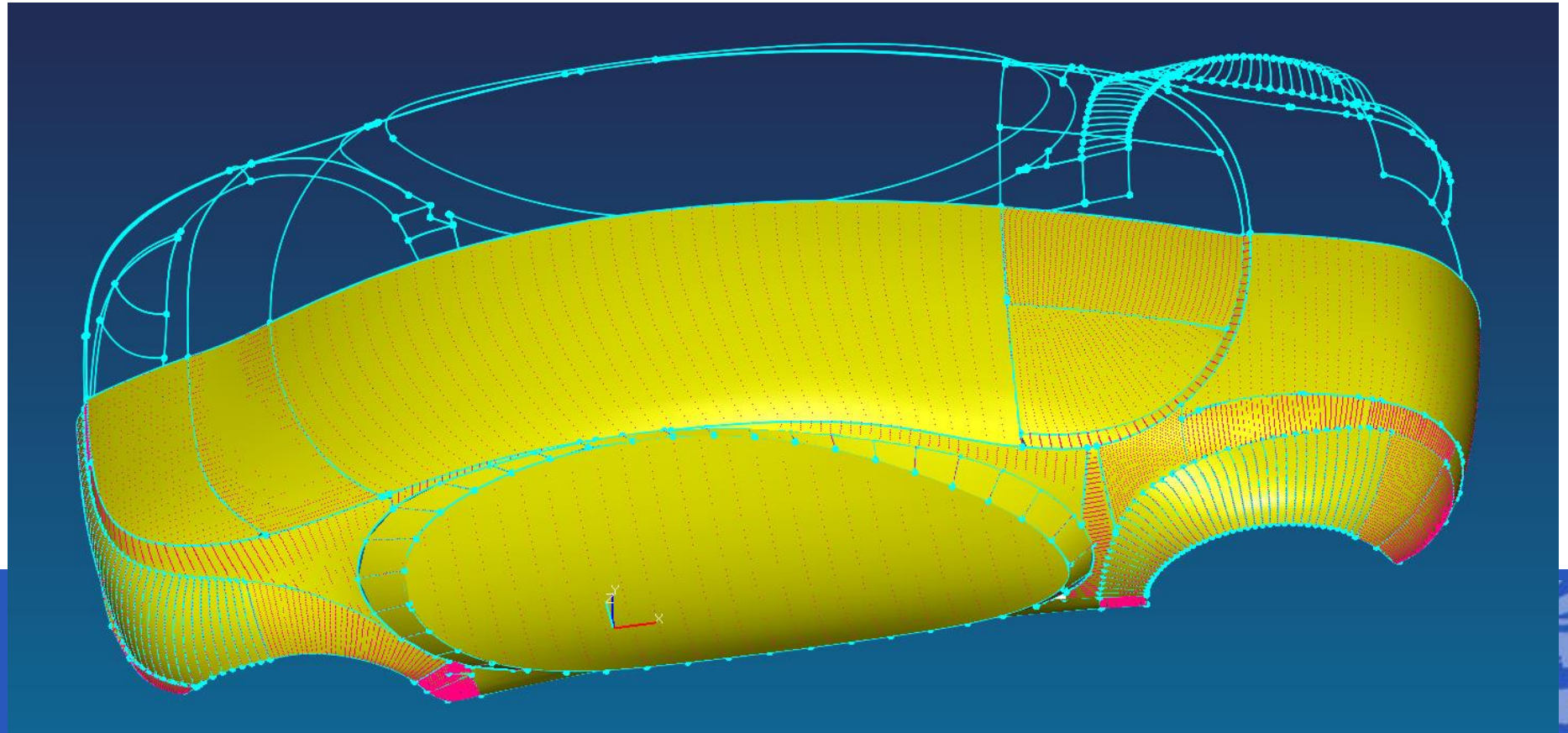
- **Point-curve-surface is the only method** to surface the car very accurately. In total 33 surface patches were modelled.





Segmentation - Methods & Processes

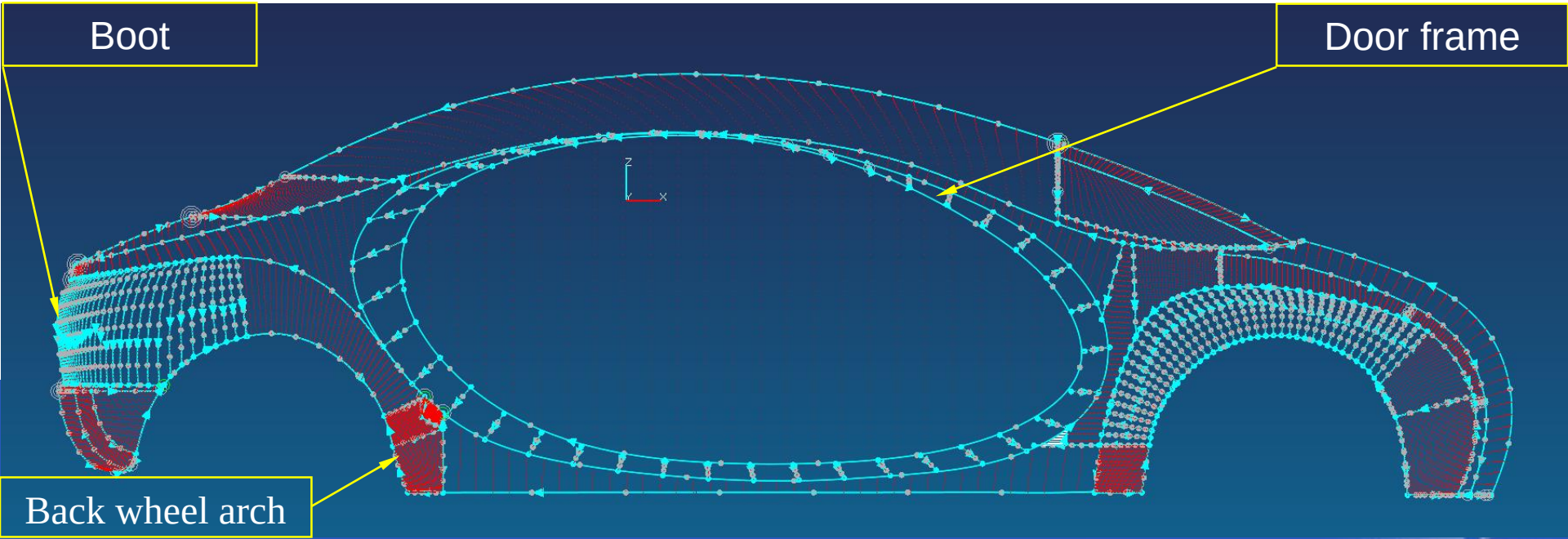
- Segmentation, or feature extraction, is a multi-step process of partitioning the 3D data into intersection homogenous regions.
- Segmentation is the most critical phase of the process in RE to preserve the design intent; one of the methods is edge detection.



Segmentation - Methods & Processes

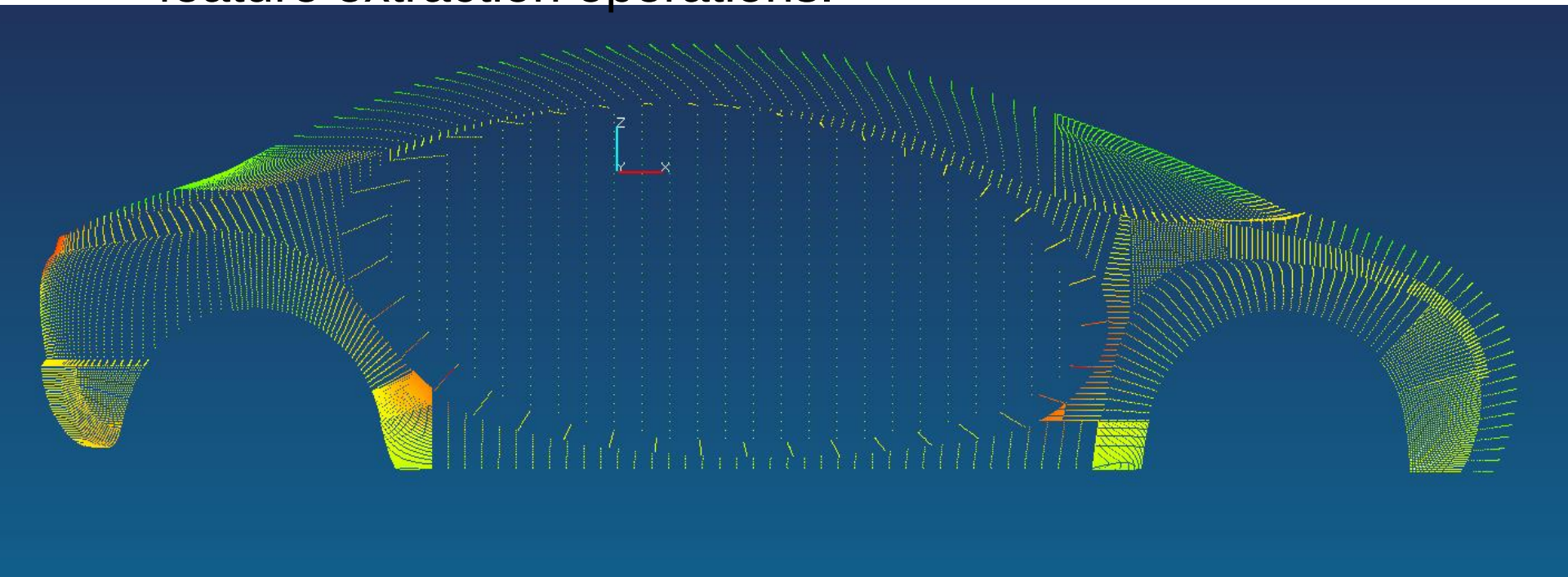
- Edge based segmentation algorithms have two main stages: edge detection which outlines the borders of different regions, followed by the grouping of the points inside the boundaries giving the final segments.

- Edges in a given depth map are defined by the points where changes in the local surface properties exceed a given threshold. The local surface properties mostly used are surface normals, gradients or principal curvatures.



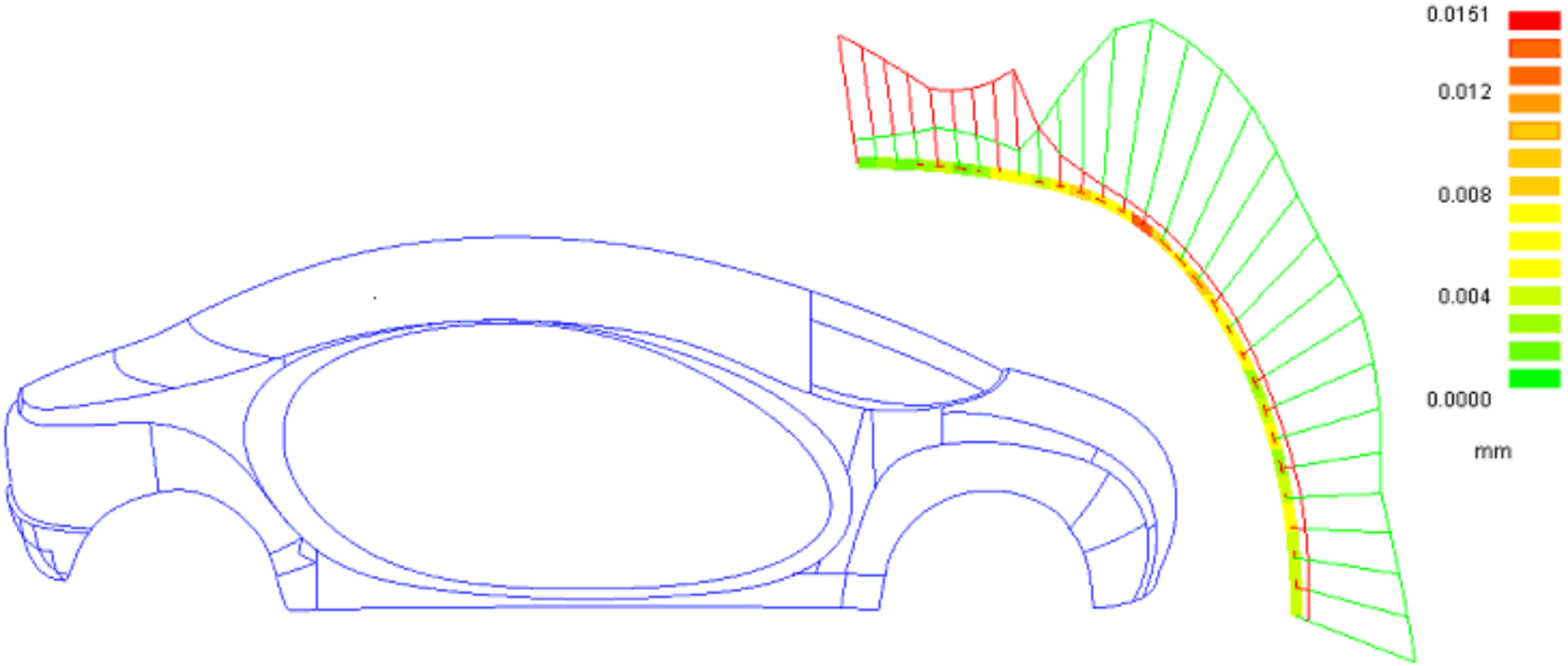
Segmentation – Cloud Curvature Analysis

- *Point Cloud Curvature* is used as a tool to interpret where the high and low curvature areas lie, making it easier to visualise areas of high and low curvature and to locate features for feature extraction operations with proper neighbourhood size.
- Below uses cloud curvature to evaluate curvatures at various points in a car cloud for visualization and feature extraction operations.



Curve Modelling – Car

- A car body point cloud chosen to demonstrate curve and surface modelling.

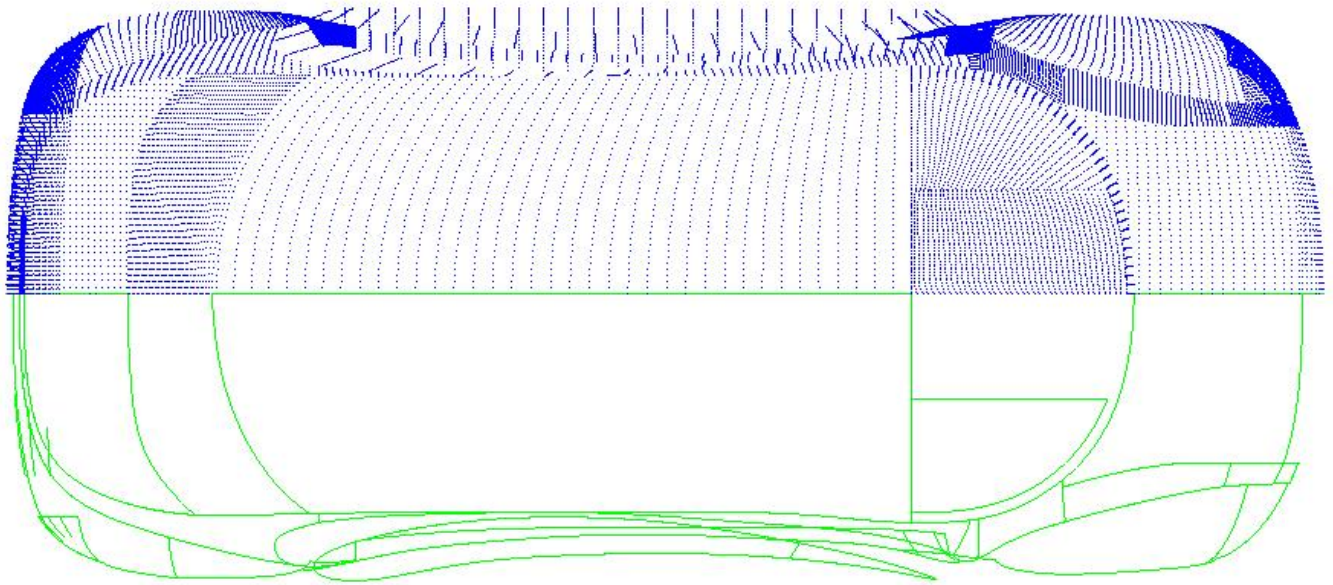


Curve Modelling – Car

- Figure below shows point and curves representation. The shape has been optimised and originated from a test centre in an automobile company.

Point cloud

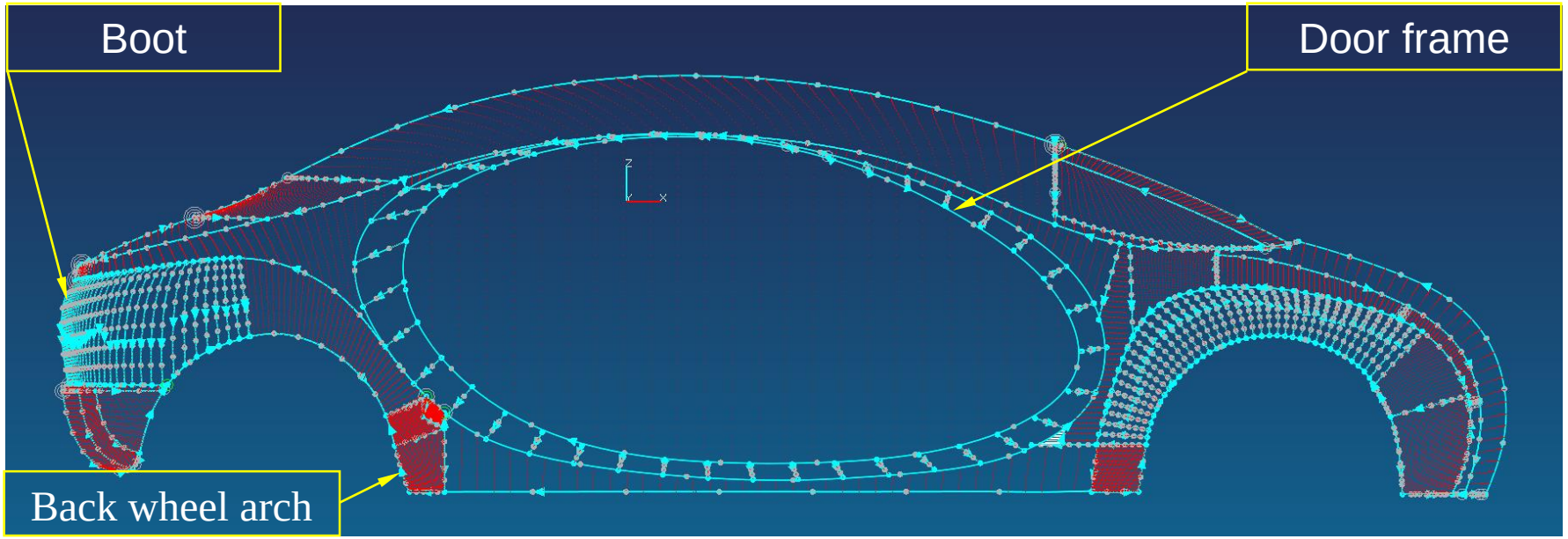
Curves representation



Curve Modelling – Car

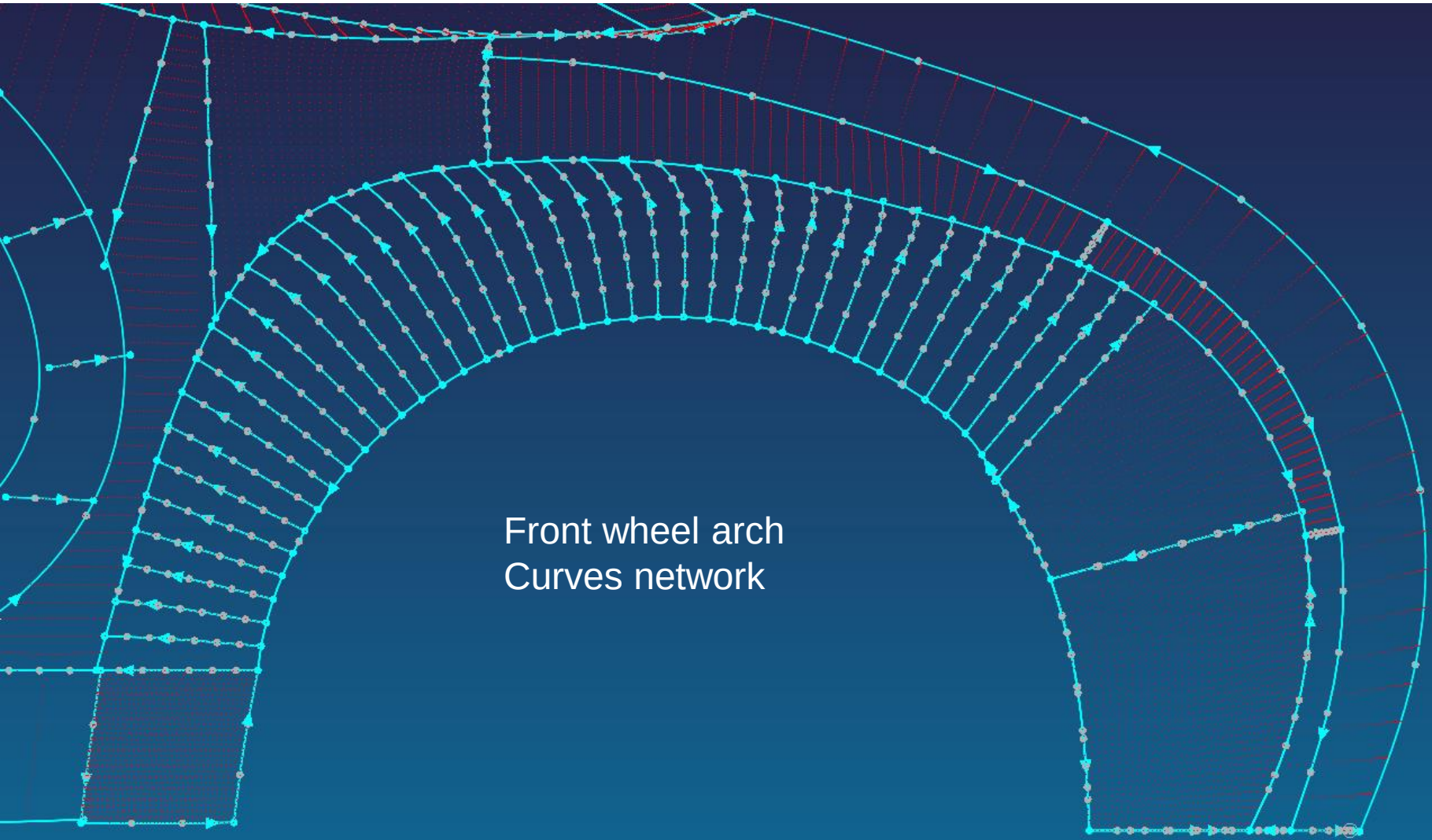
- Figure below shows car features with point and curves representation showing their control points and directions.

- **Surface Strategies** have been implemented to be more efficient and effective during the curve and surface modelling.



Curve Modelling – Car

- Figure below shows a front wheel arch with point and curves representation showing their control points and directions.

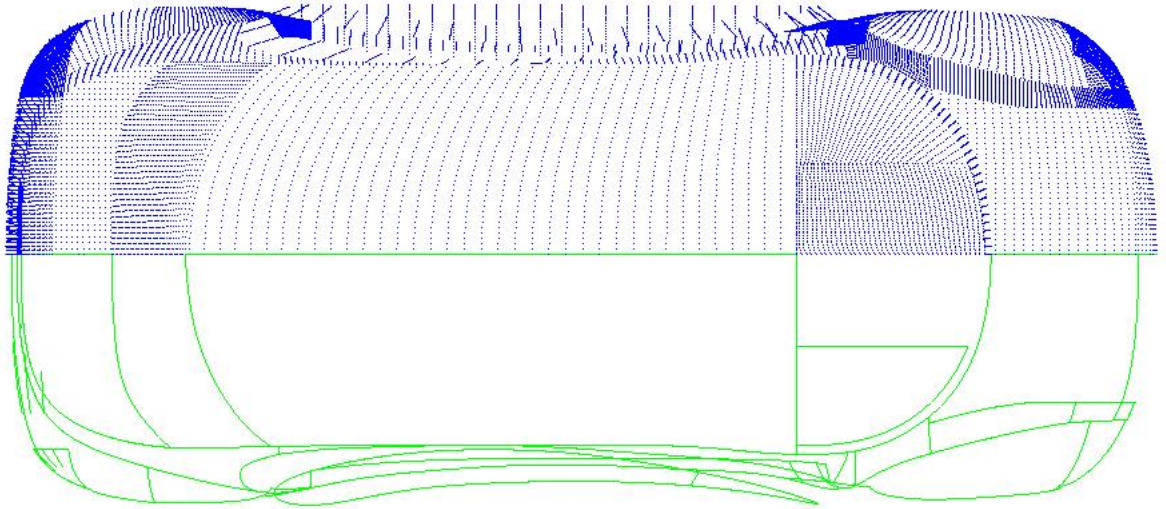


Curve Modelling – Car

- Figure below shows point and curves representation. The shape has been optimised and originated from a test centre in an automobile company.
- Four features with different shape characteristics have been selected to demonstrate the processes.

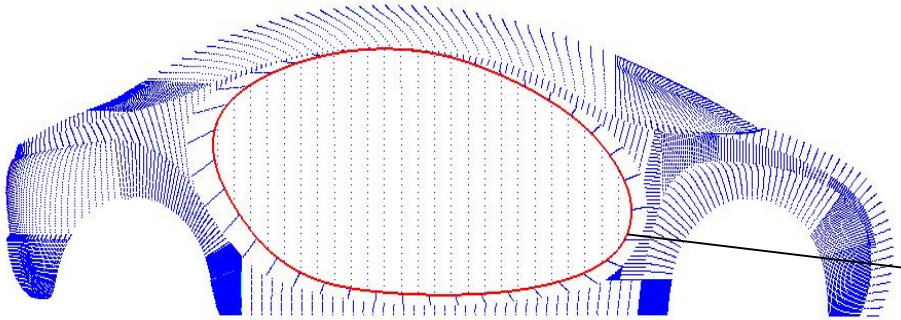
Point cloud

Curves representation

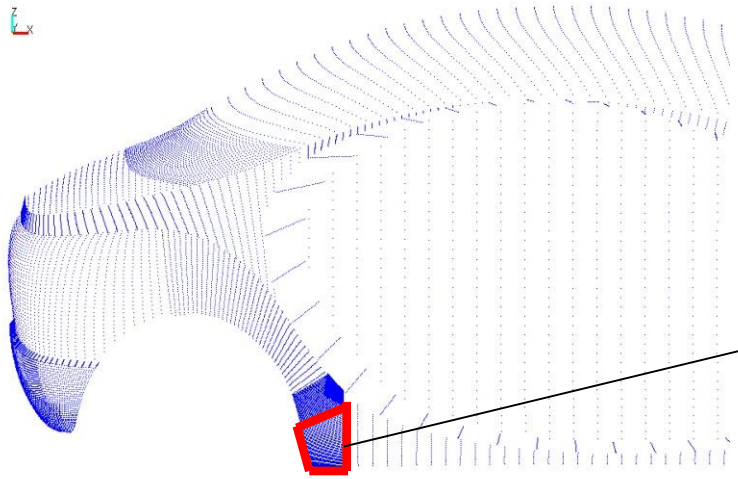


Curve Modelling – Car

- Door frame and back wheel arch features with different shape characteristics have been shown below.



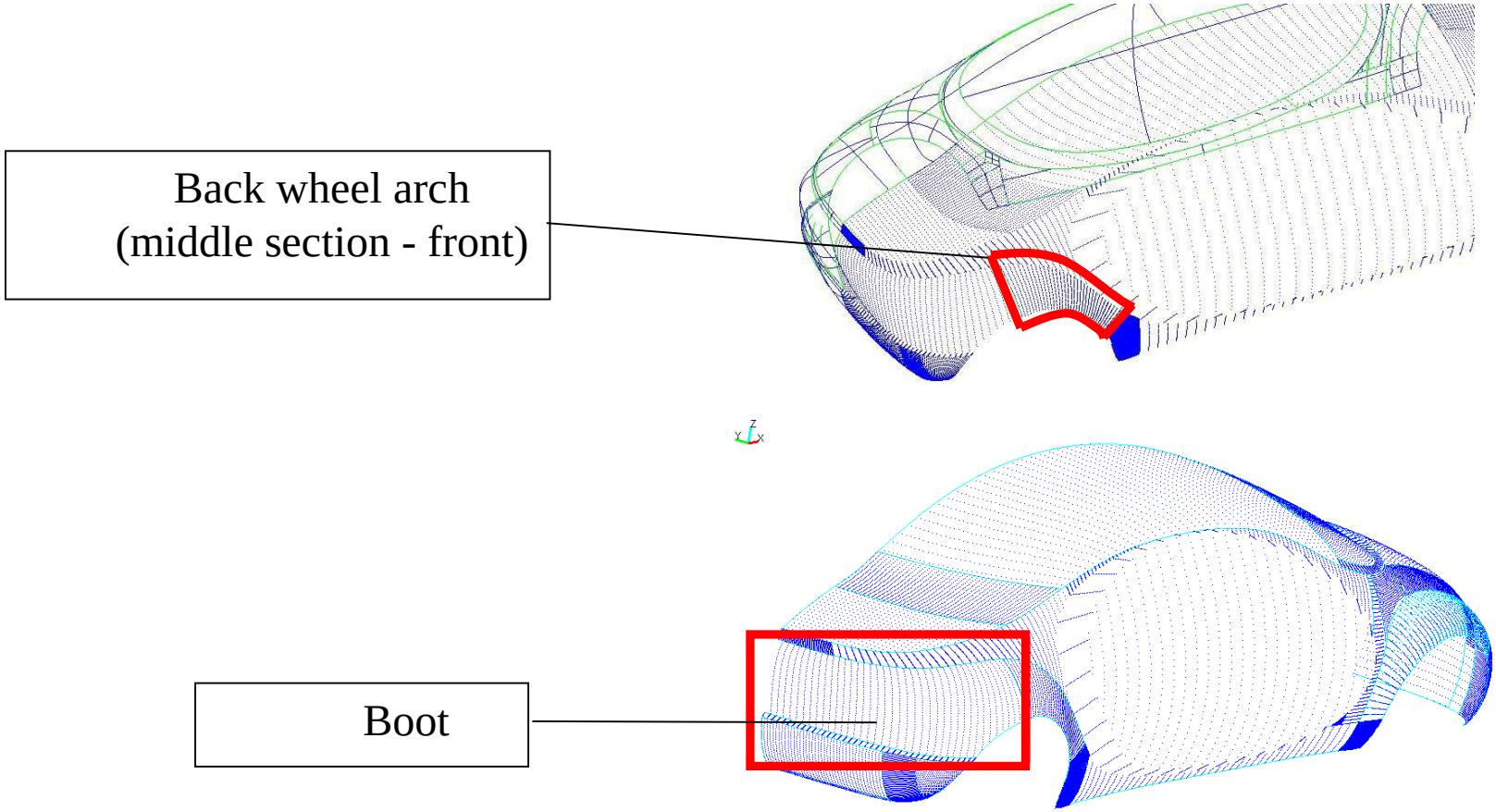
Door frame



Back wheel arch
(bottom section - front)

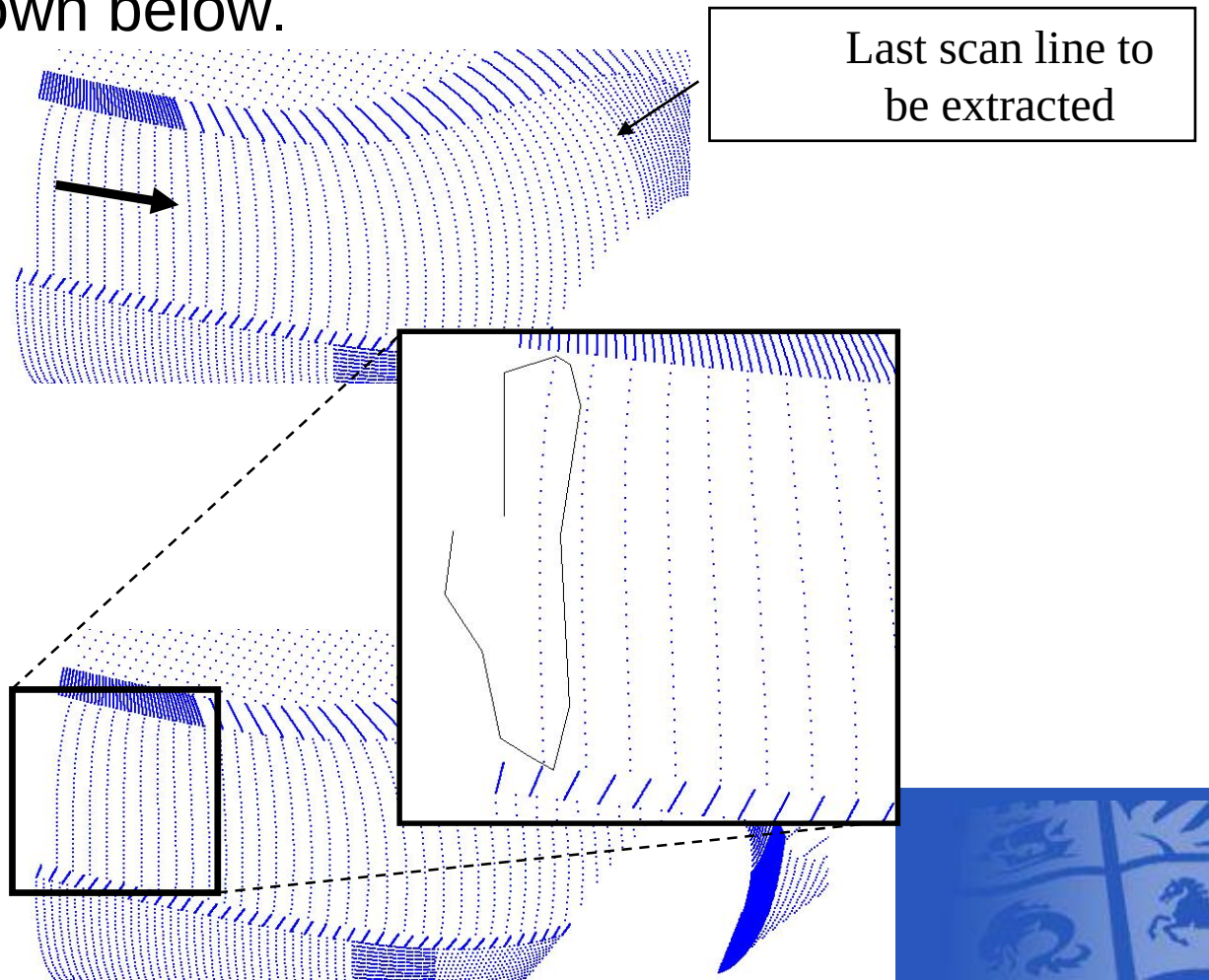
Curve Modelling – Car

- Boot and back wheel arch middle section with different shape characteristics have been shown below.



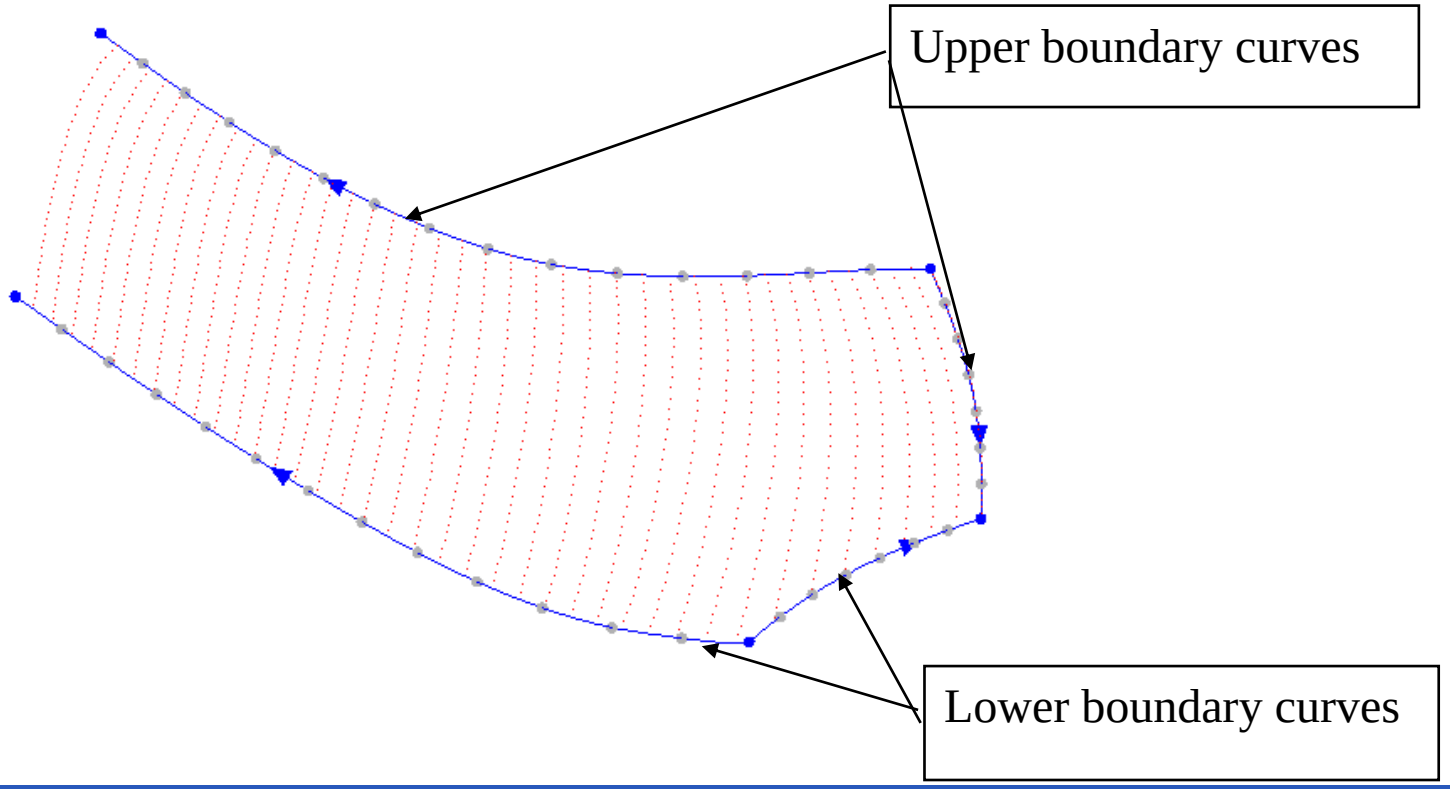
Car – Boot Modelling

- The boot feature is selected to demonstrate the techniques and processes of curve and surface modelling.
- The scan point clouds are used to create a set of parallel and boundary B-spline curves. Each curve is extracted from left to right as shown below.



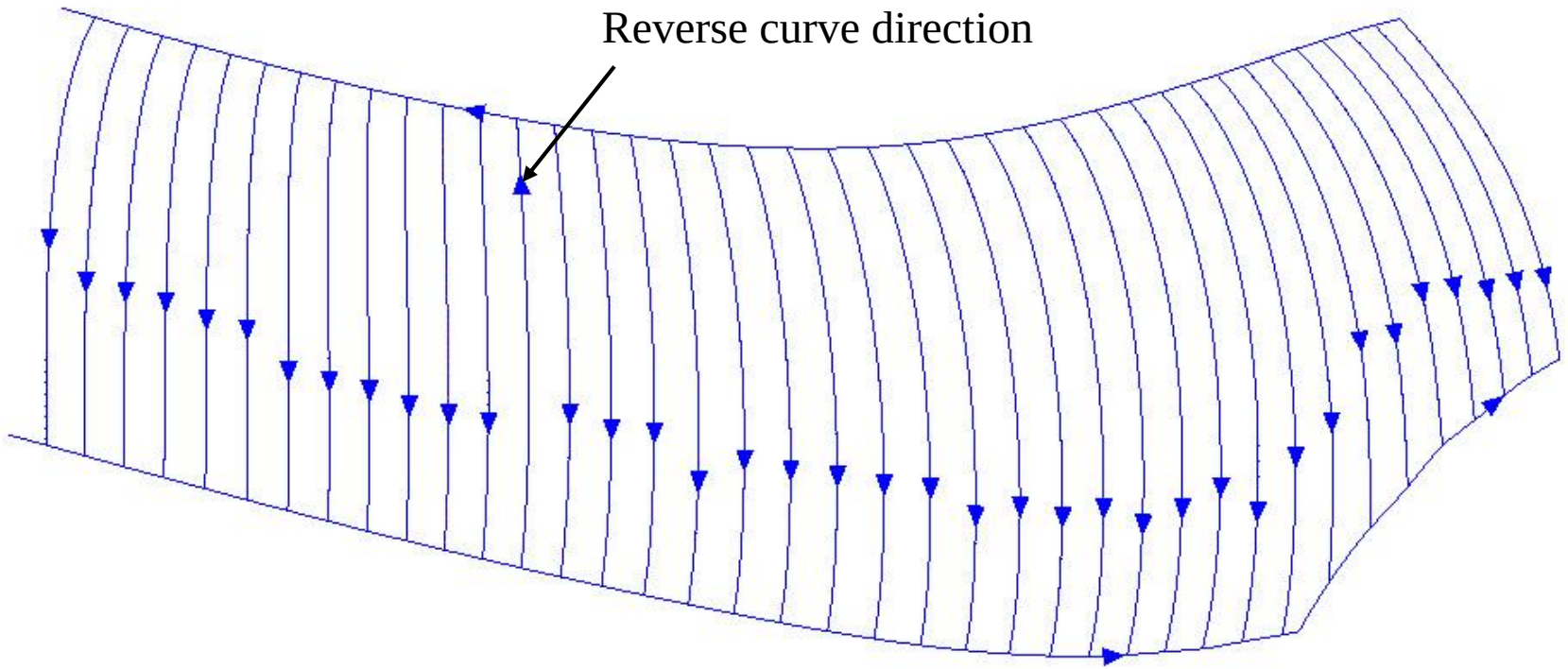
Car – Boot Modelling

- Four B-spline boundary curves are created and reparameterized which will form the structure of the surface.



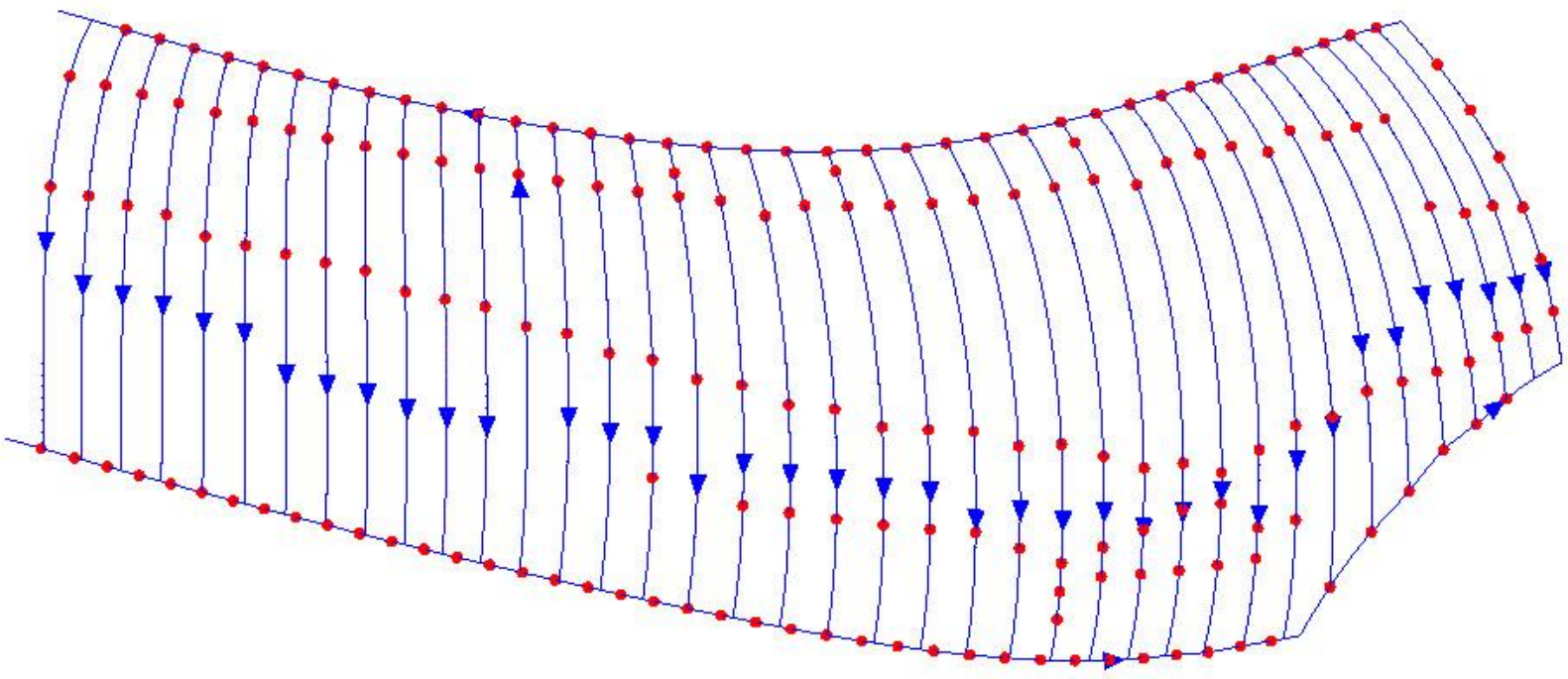
Car – Boot Modelling ; Reparameterization

- Reparameterization is to put the curves in a uniform direction.



Car – Boot Modelling ; Reparameterization

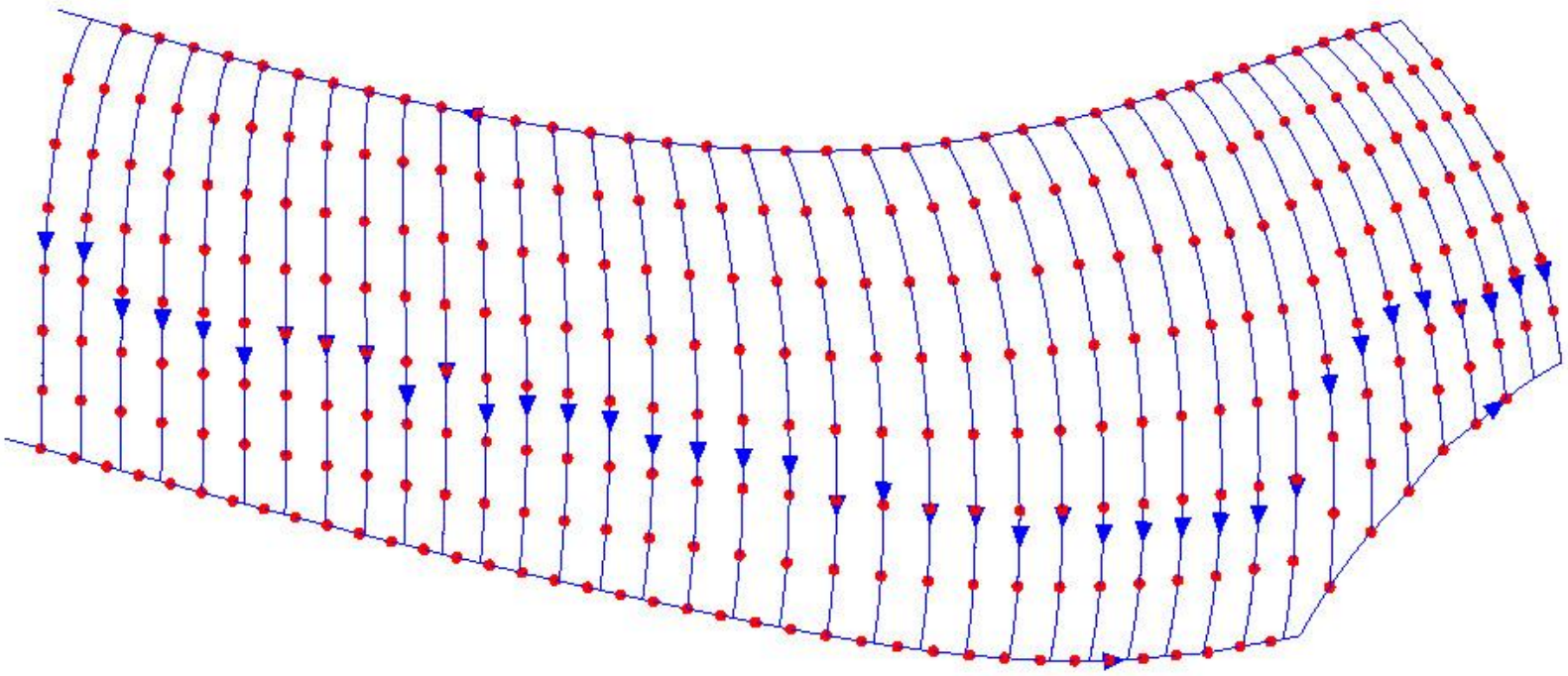
- Reparameterization also makes sure each curve has the same number of control points/knots.



Displayed points/knots

Car – Boot Modelling ; Reparameterization

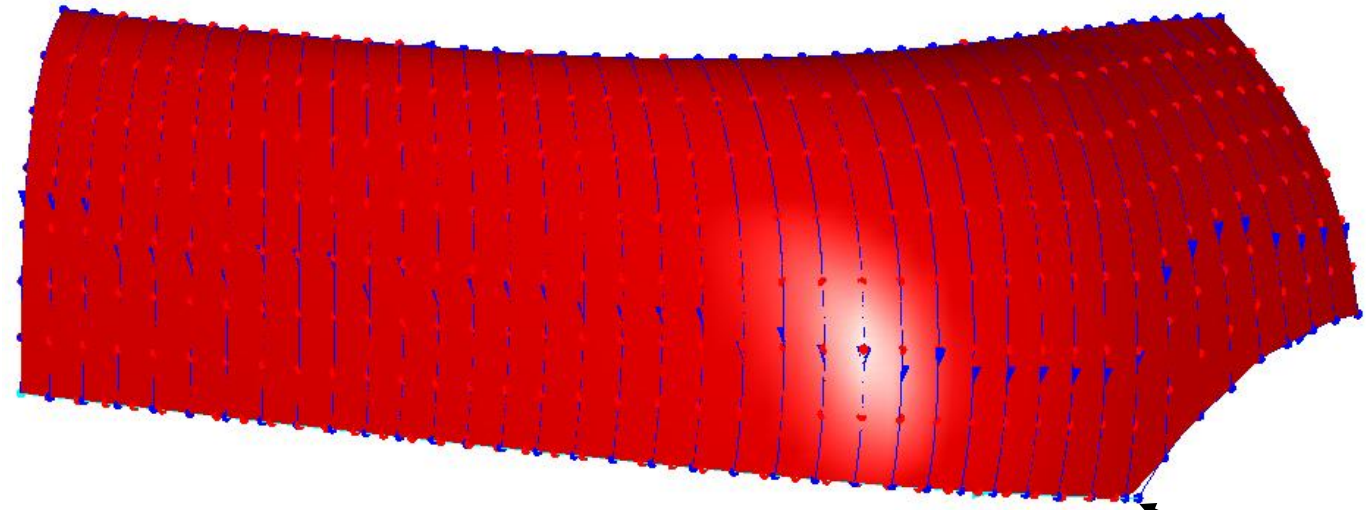
- Reparameterization includes putting the curves in a uniform direction as well as assuring each curve has the same number of control points/knots.



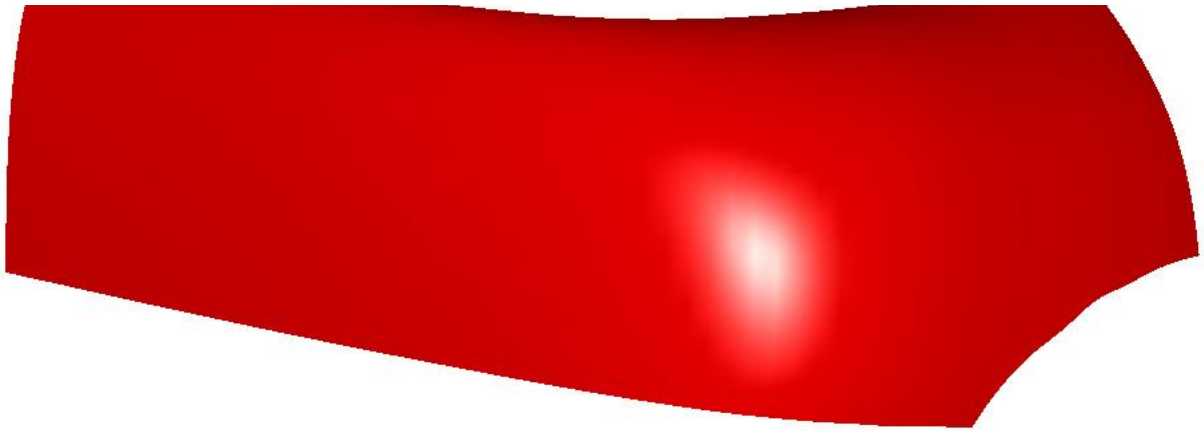
Equally spaced knots and harmonized curve directions

Car – Boot Modelling; Surfaces

- Display of surfaces and detection of problem area.



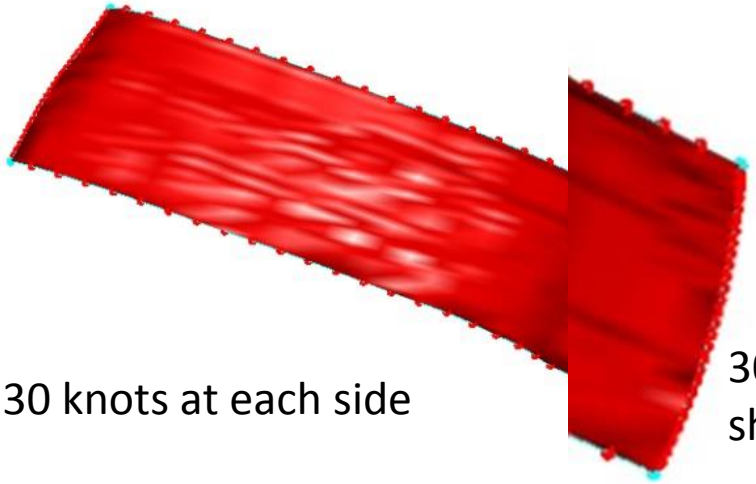
Corner not filled!

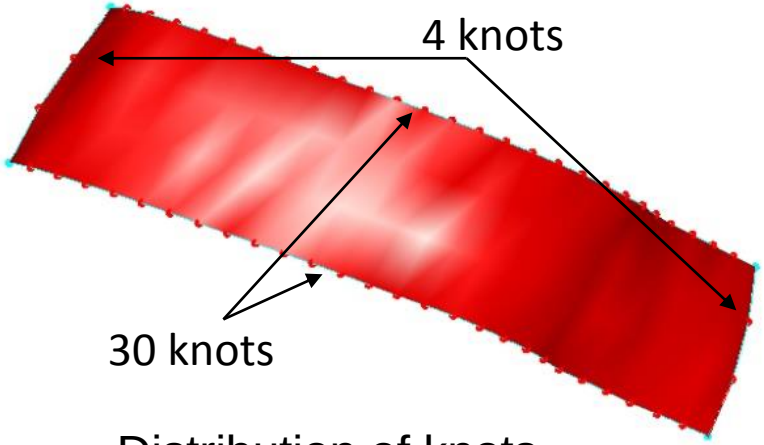


Corrected loft surface

The effect of Reparameterization on surface quality

- Figure below shows a stripe with 30 knots at each side. This creates an undulated texture in the longitudinal direction, which is a clear indication for too many knots on the short sides.
- Reducing the knot density from 30 to 4, the long sides give a considerably smoother result.





Distribution of knots

Surfacing Modelling - Point-Curve-Surface

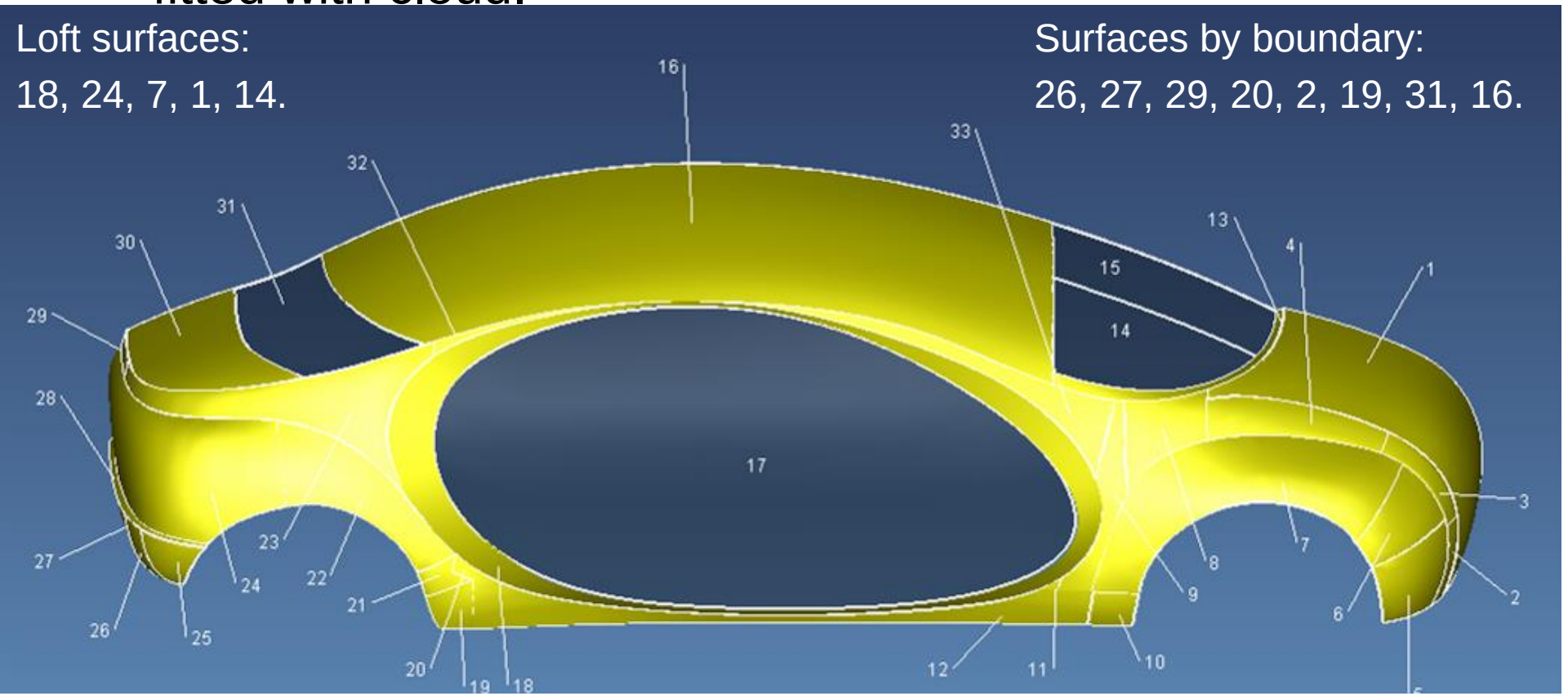
- In total 33 surface patches were modelled, and categorised in four different surfacing techniques: Uniform surface, Loft surface, Surface by boundary and Surface fitted with cloud.

Loft surfaces:

18, 24, 7, 1, 14.

Surfaces by boundary:

26, 27, 29, 20, 2, 19, 31, 16.



Trimmed uniform surfaces:

11, 21, 23, 30, 12, 33, 9, 17, 25, 13.

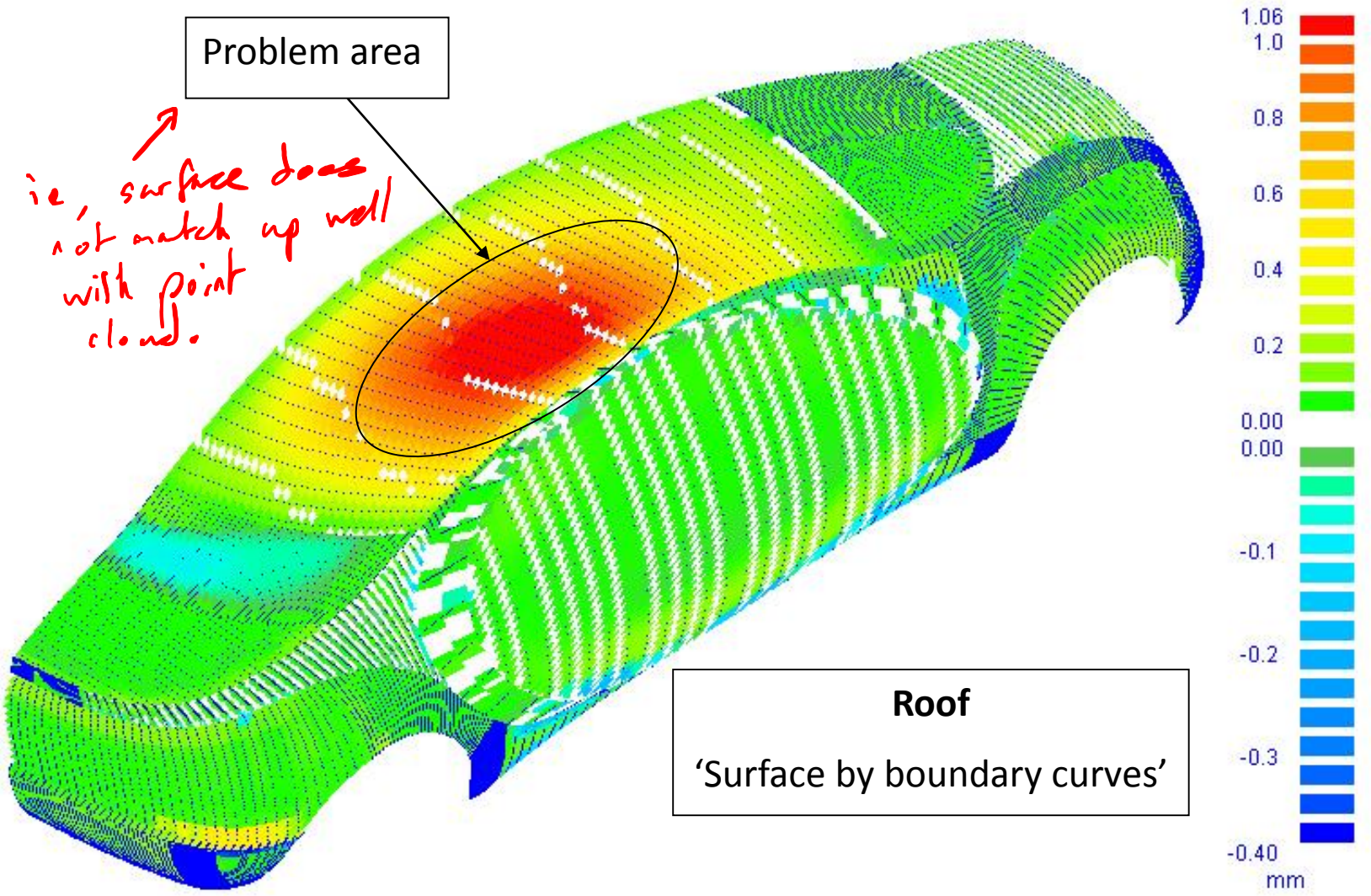
Fitted surfaces with cloud and curves:

15, 22, 6, 10, 5, 8, 4, 3, 28.

Very Accurate.

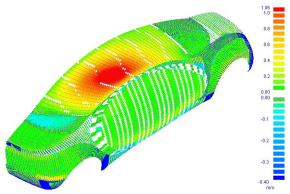
Quantification - Surfacing Modelling quality check

- Surface modelling techniques are normally compared with original point clouds to optimise the shape as shown below for the roof.



Surfacing Modelling – Quality check

- Roof surface modelling technique has changed from “Surface by boundary curves” to “Surface fitted with cloud and boundary curves”.

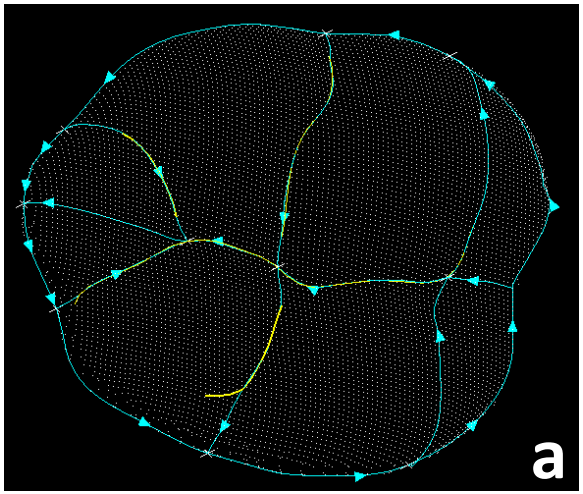


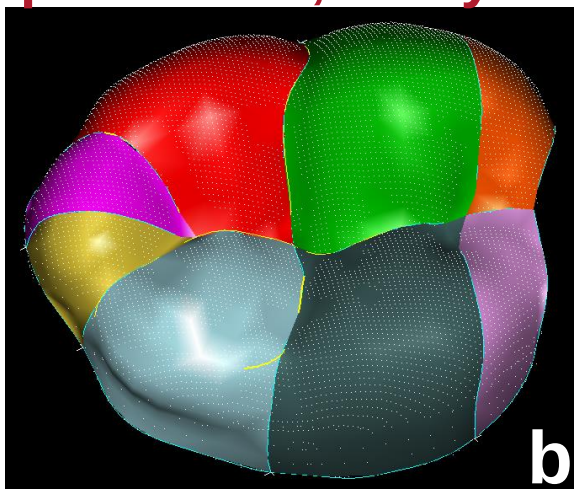
‘Surface fitted with cloud and boundary curves’

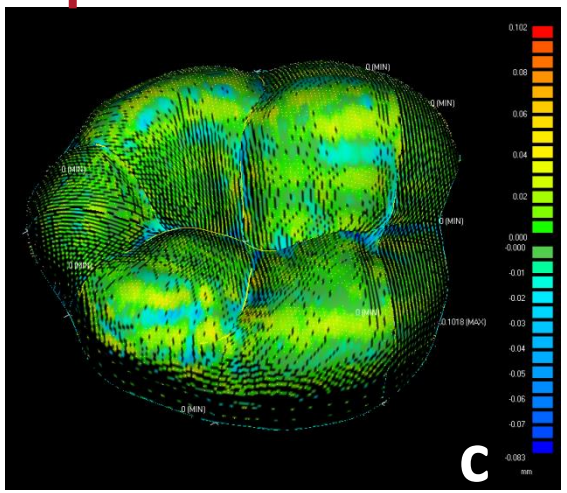
Much Better!
Takes longer to implement

Biomimetic Modelling - Mandibular teeth

3rd molar: detailed processes, analysis & quantification







- Figs. show 3D geometric morphometric processes of a 3rd molar, having 8 cusps,
- **a)** the morphological traits of the molar crown & B-spline curves network
- **b)** cusps featured surface model,
- **c)** Optimum tooth/cusps morphology, surface quality analysis with needle plot, plot displays values of the error which is the difference between the cusps surfaces created with the corresponding point clouds - the colour of the needle is green almost everywhere on 8 cusps which mean the accuracy is very good. (the maximum and average values are 101 µ and 7.5 µ respectively).

R E Presentation

Any questions?