Autonomous Geometry Processing using Machine Learning & Forge

Sandip Jadhav

CEO, CCTech

AUTODESK. UNIVERSITY

About the speaker

Sandip Jadhav, CEO, CCTech

CEO and Co-Founder of Centre for Computational Technologies (CCTech). CCTech is a certified Autodesk FORGE SYSTEMS INTEGRATOR partner and leading cloud platform developer such as simulationHub CFD.

Co-Speaker

Vijay Mali, CTO, CCTech

Vijay is a technology explorer, a visionary and a product maker. As CTO of the company, he plays a critical role in deciding the technology vision of the company. He also leads the center of excellence (CoE) department at CCTech which is responsible for exploring new technologies & building a strategy to bring it to common designers.

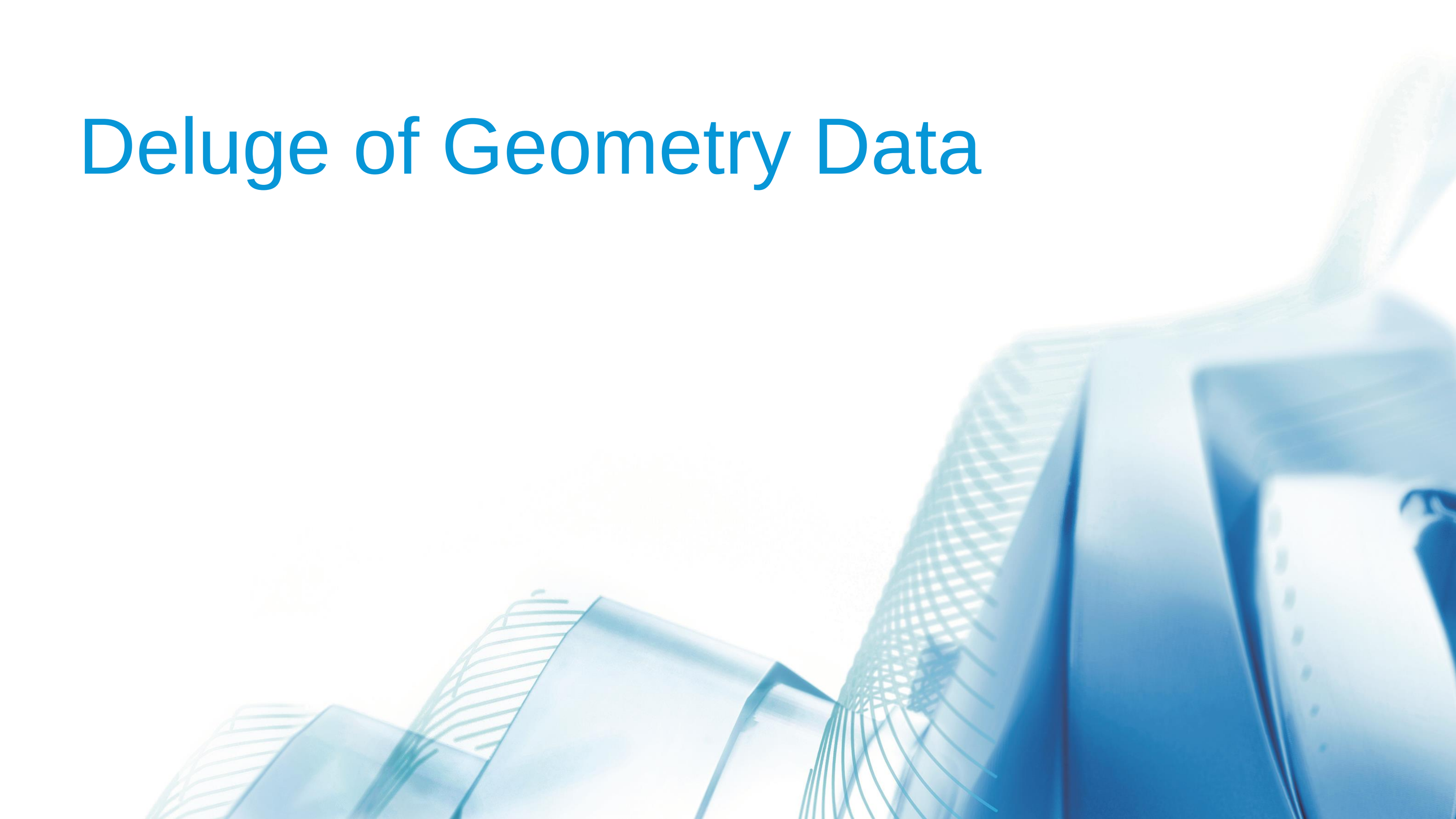
Nem Kumar, Director - Consultancy, CCTech

Nem Kumar is director of consulting at CCTech and has been doing product development with companies from Manufacturing, Oil & Gas and AEC domain. He has experience in Desktop, Cloud software development involving CAD, CAM, complex visualization, mathematics and geometric algorithms. He has been actively working with Autodesk Vertical, Research and Fusion 360 teams. His current areas of interest are Generative Modeling and Machine Learning.

Outline

- Deluge of geometry data
- Why mesh data ?
- Quick Demo
- Autonomous Geometry Processing – Mesh Segmentation
  - Mesh representation
  - Derived Features & Feature Engineering
  - Training and validation
  - Autodesk Forge Application
- Autonomous Geometry Processing – 3D Object Detection
  - Google AutoML
  - Autodesk Forge Application
  - Live application

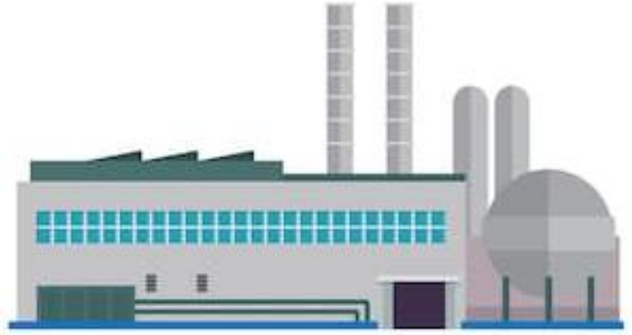
Deluge of Geometry Data

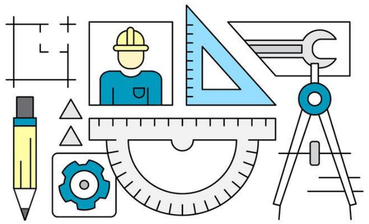


Deluge of Geometry Data

JT 3DS

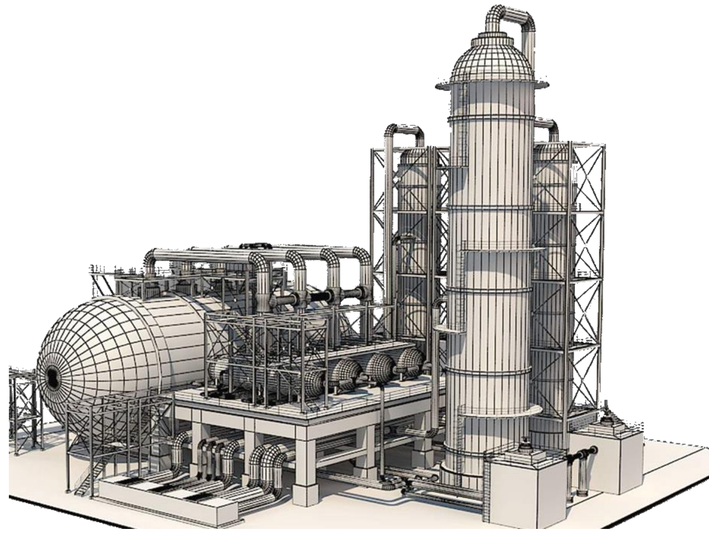
BIM CAD





3D PDF STL

OBJ STL

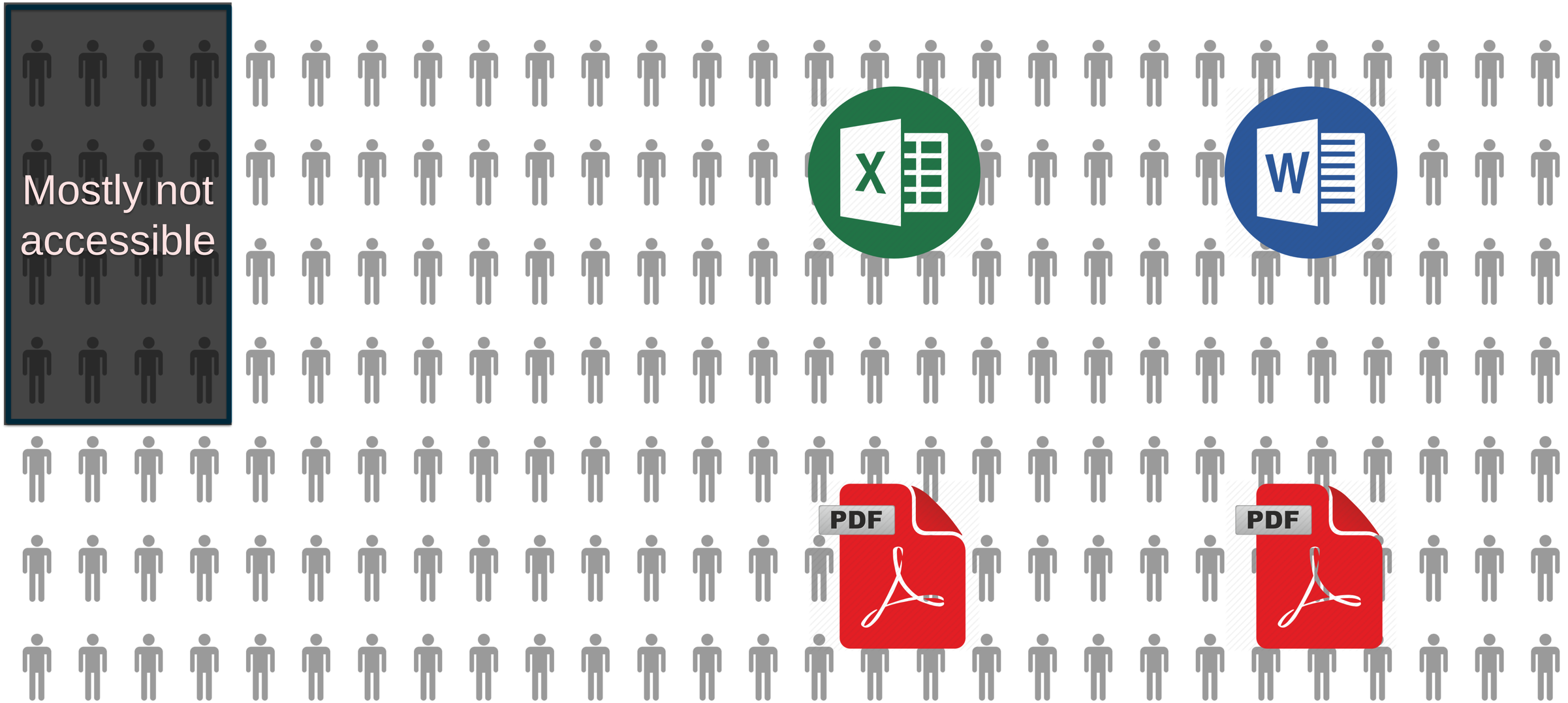


Why Data is Converted?

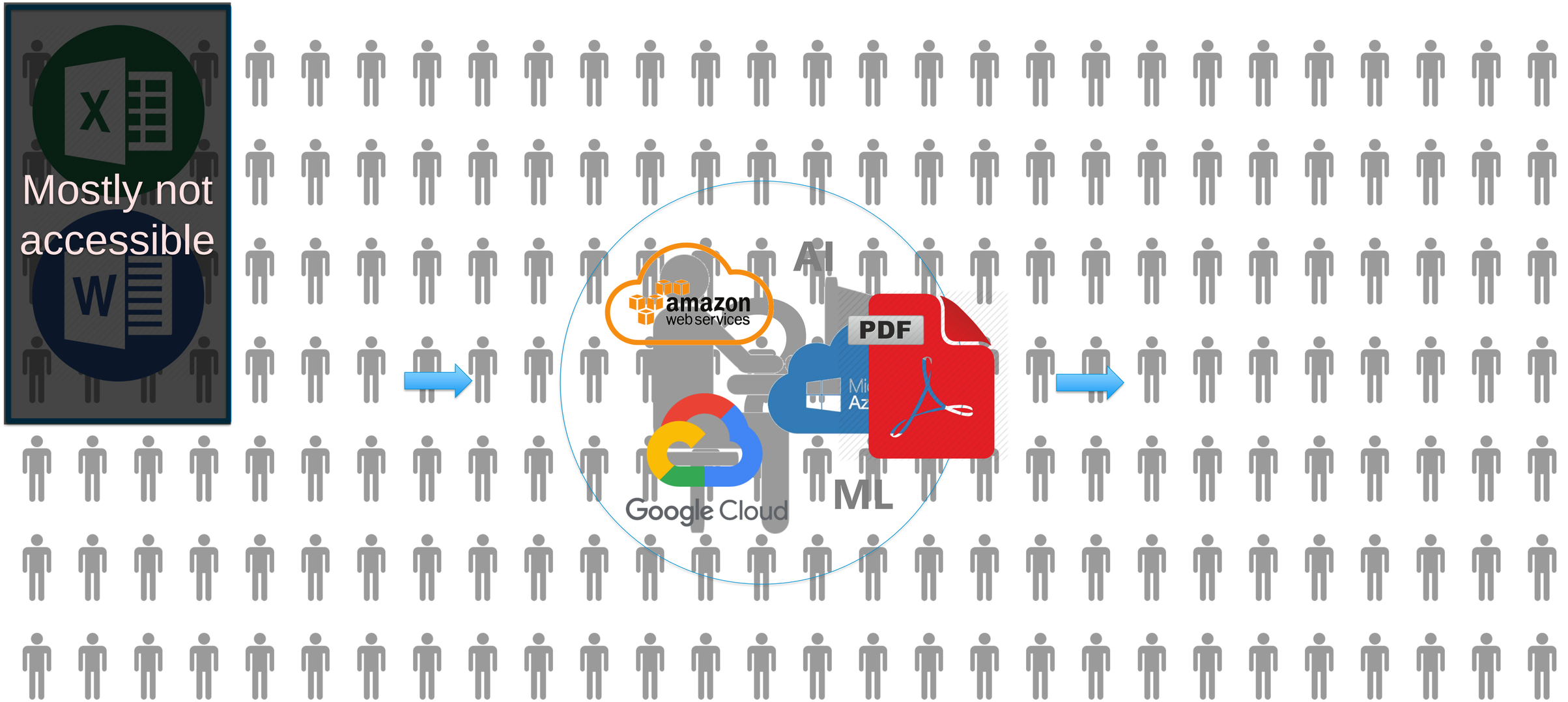
Source formats

Widely used formats

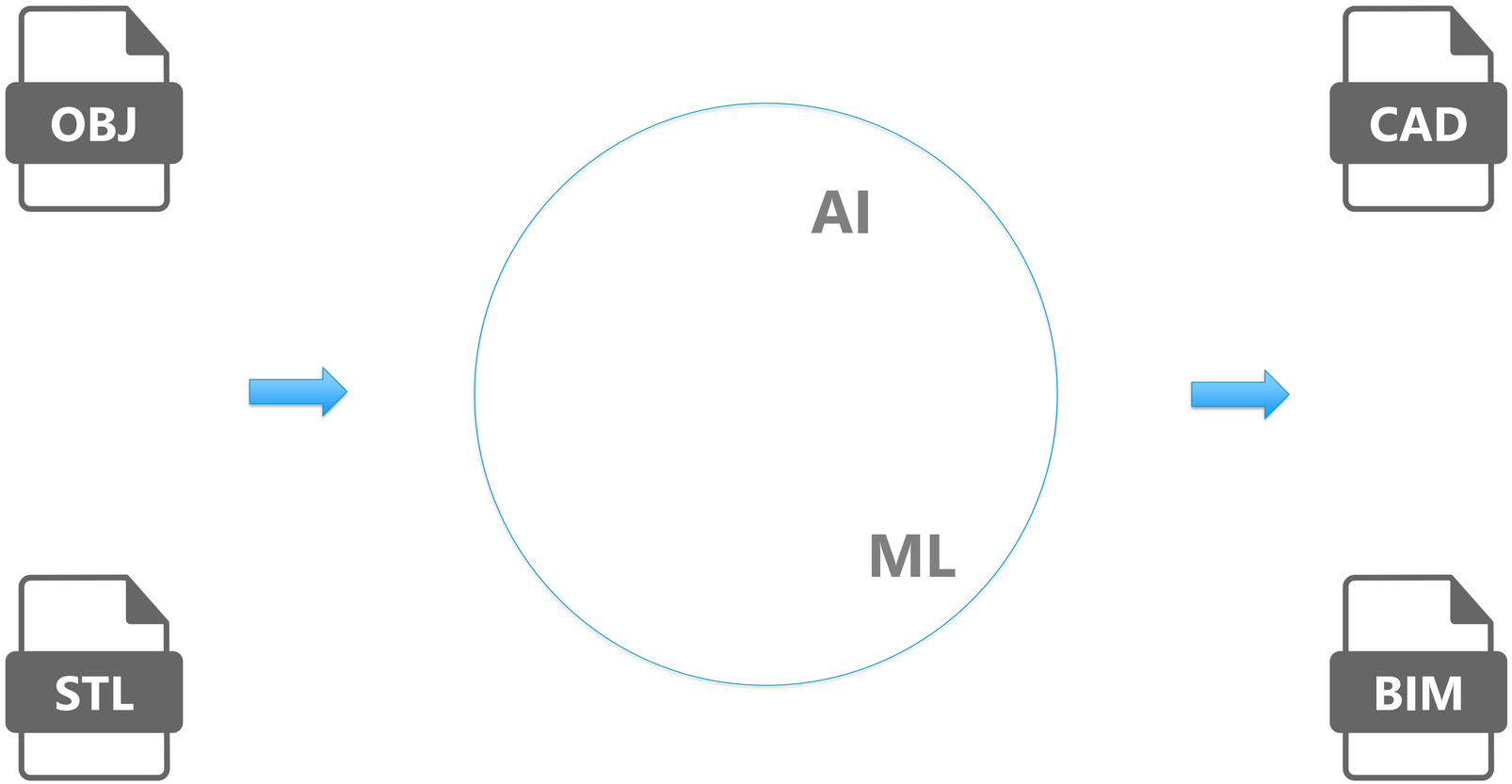
Why Data is Converted?



Reverse Engineering !!

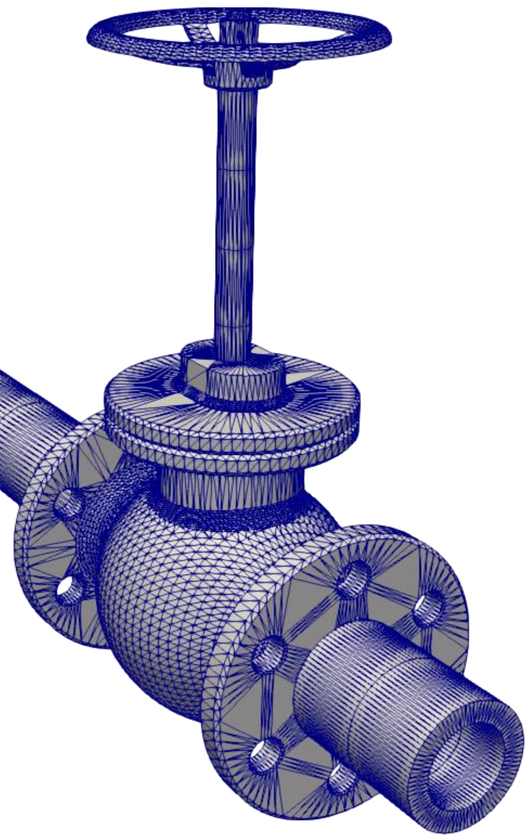


Reverse Engineering !!



Mesh most widely used representation

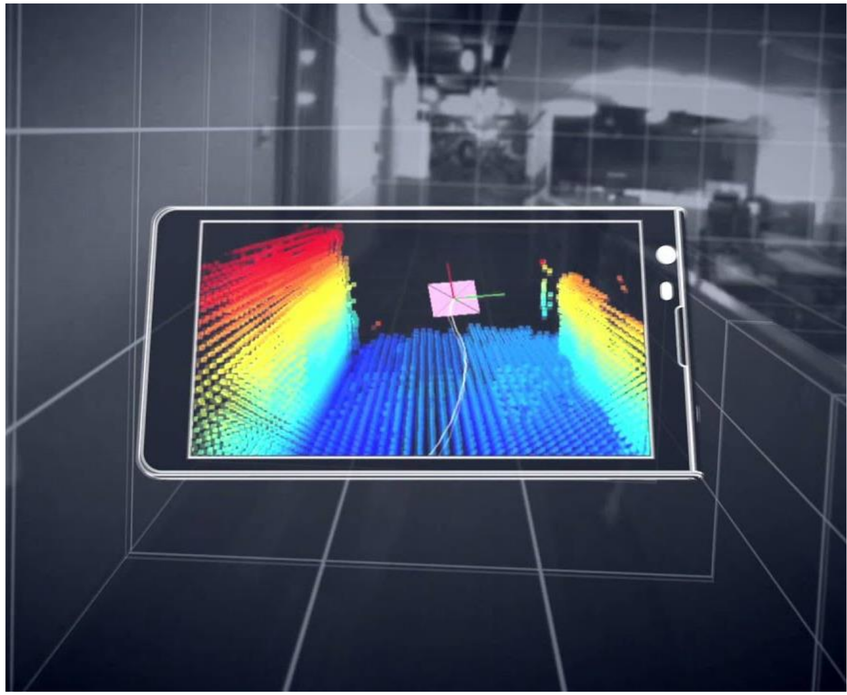
STL Files



OBJ Files

Point Cloud Data

Augmented Reality

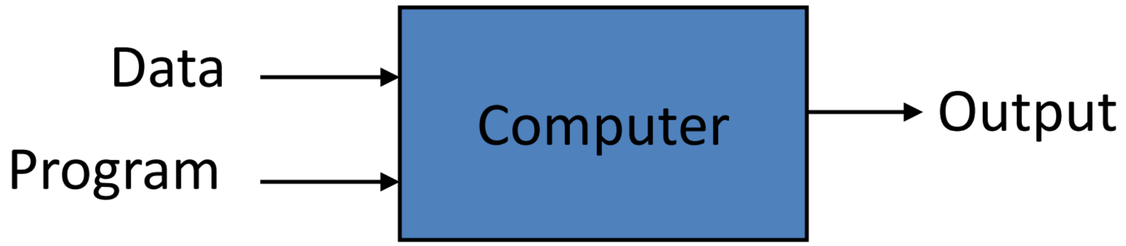


How to apply AI to geometrical data

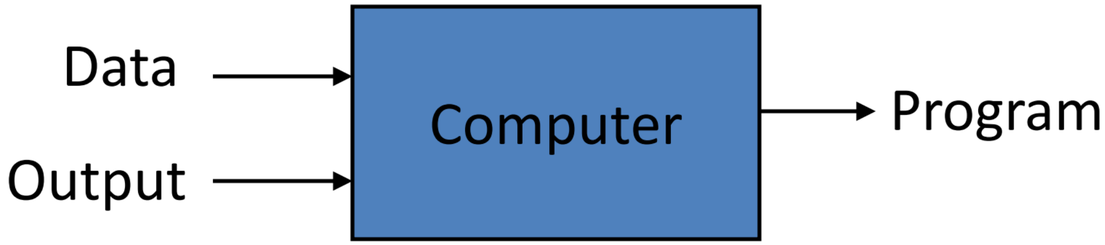
WHAT IS MACHINE LEARNING ?

"Field of study that gives computers the ability to learn without being explicitly programmed“ - Arthur Samuel 1959

Traditional Programming

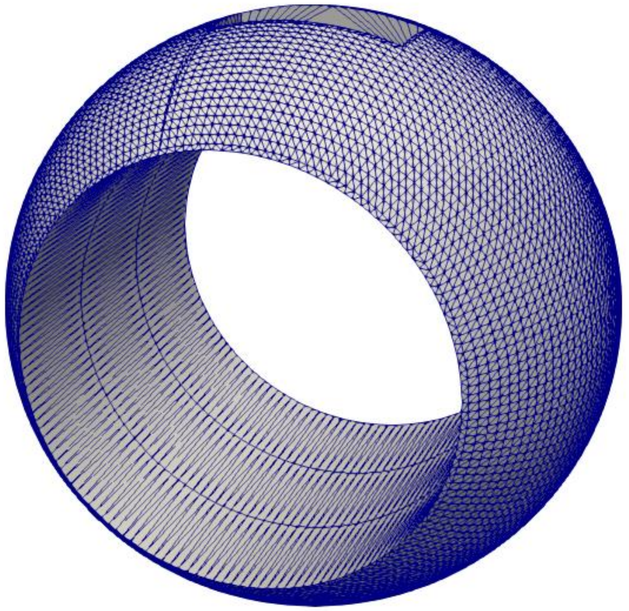


Machine Learning

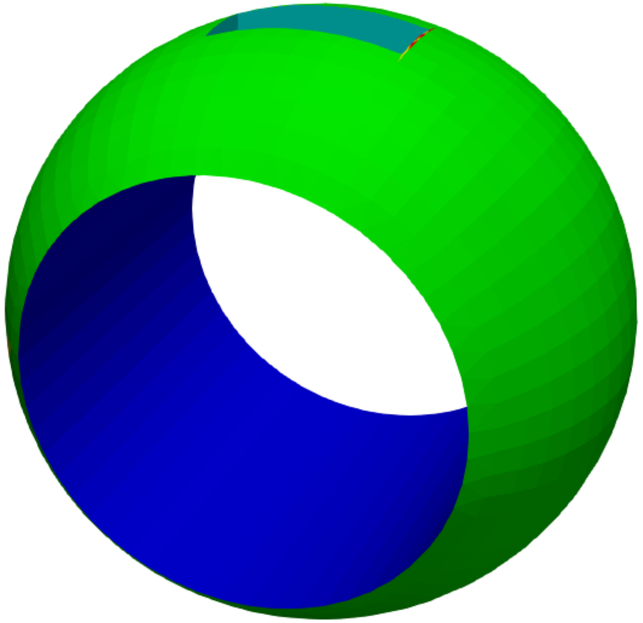


Autonomous Geometry Processing (in a nut-shell)

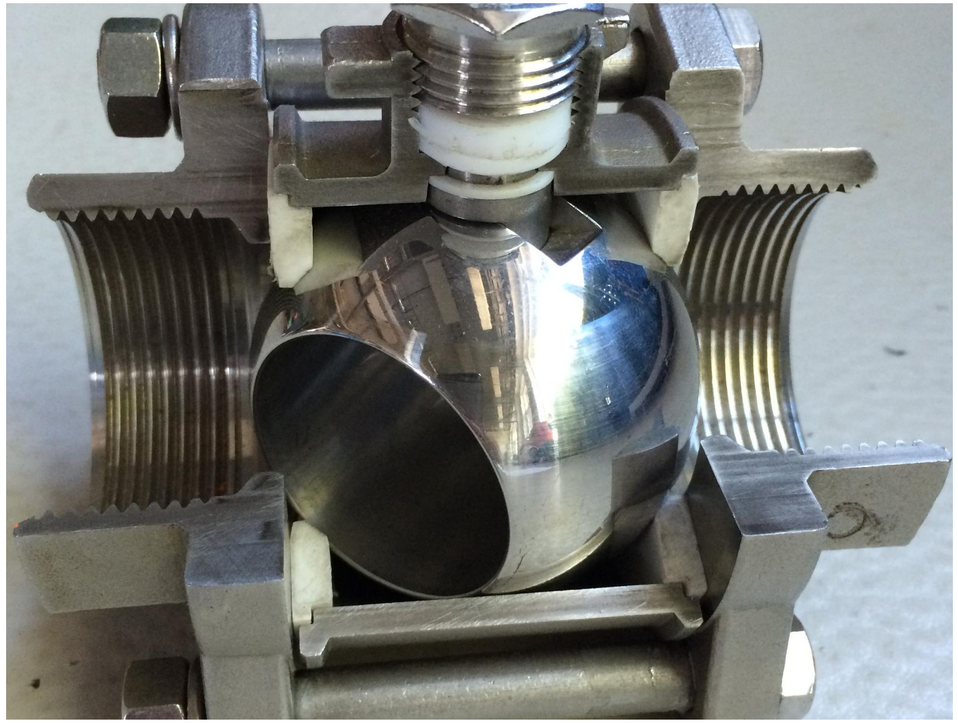
Tessellated Mesh



Feature Rich
CAD Model



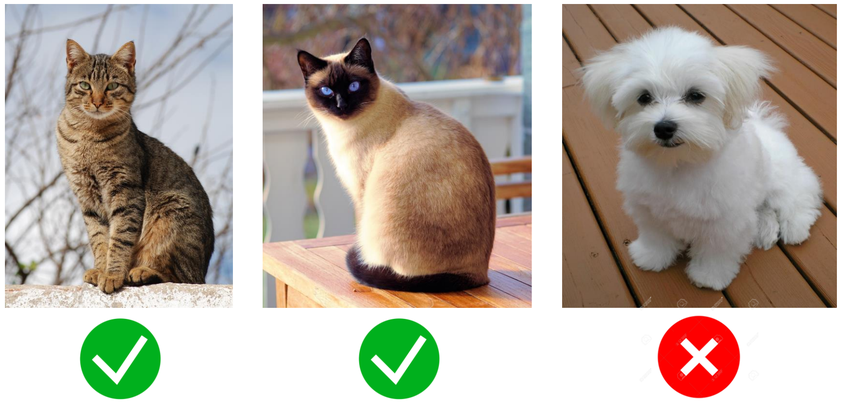
Closing Member of
a Ball Valve

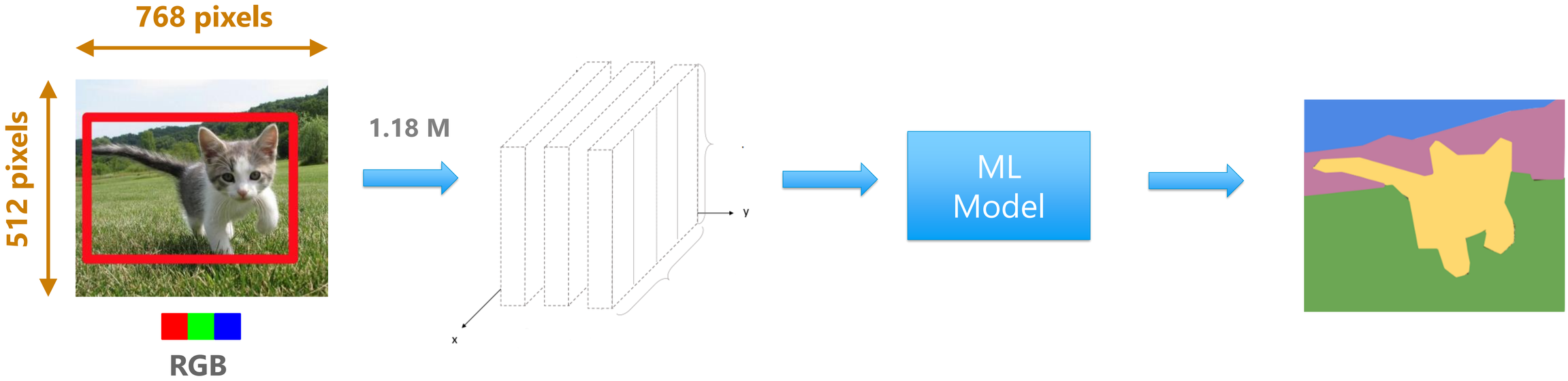


Challenges in applying AI to mesh data

Image can be described using a fixed number of properties :

$512\,px \times 768\,px \times 3 = \mathbf{1.18M}$ properties

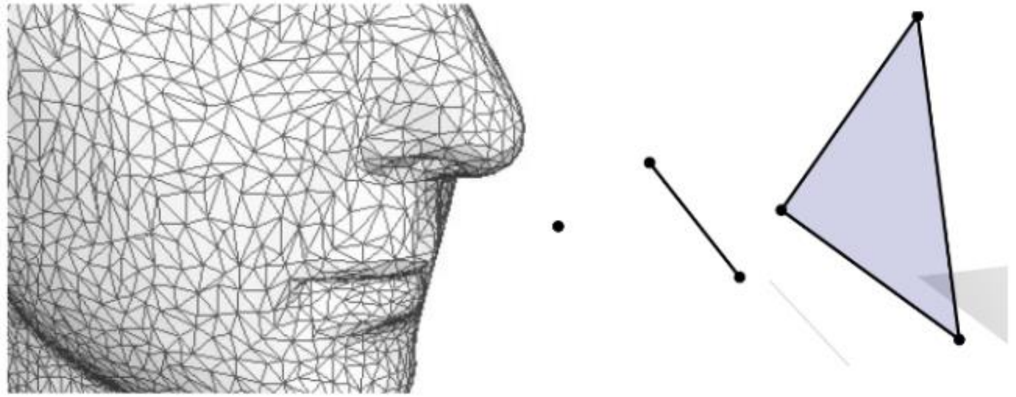




Challenges in applying AI to geometrical data *contd…*

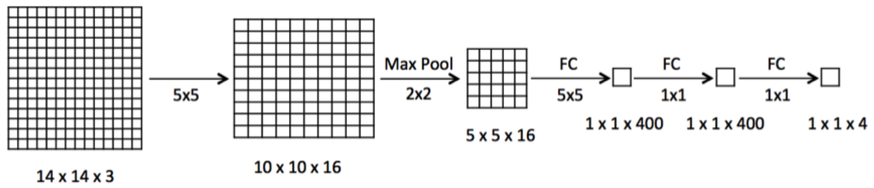
Pixel in Image

Triangle in Mesh

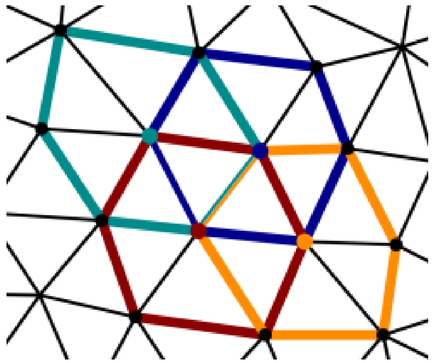


vs

Structured



Unstructured



What the world is experimenting?

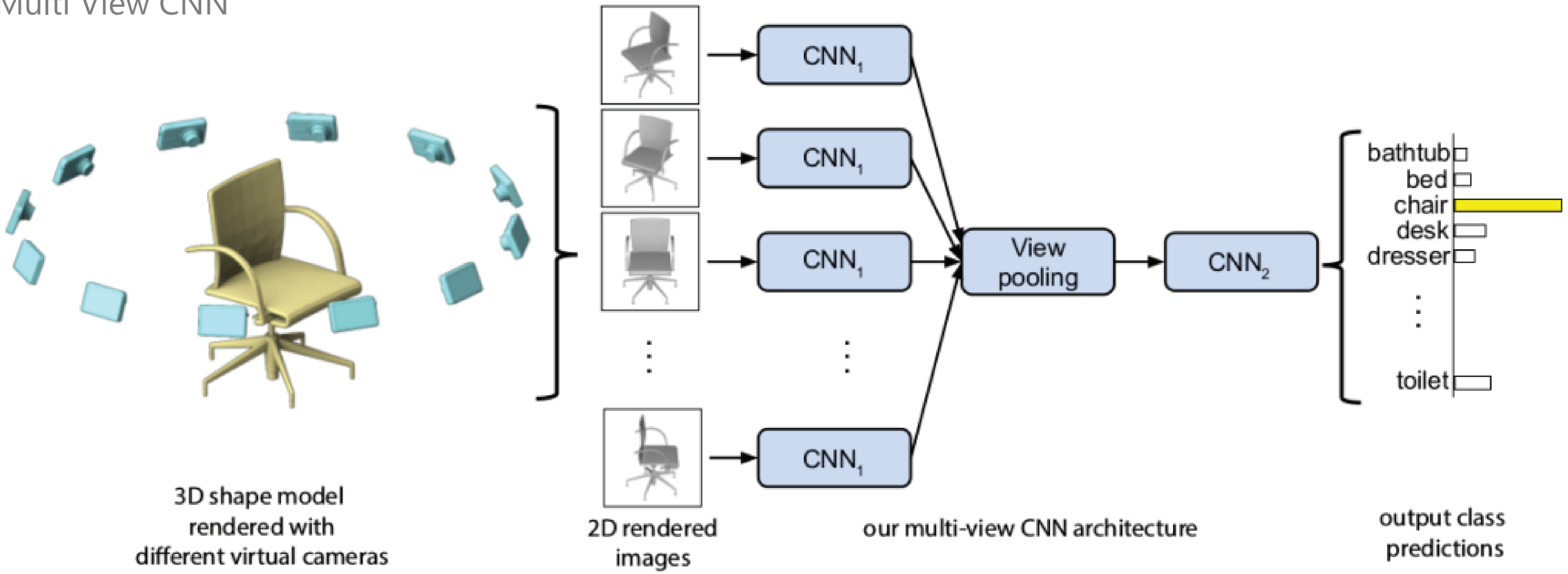
3D semantic segmentation

- Goal : Label each voxel of an scene with a corresponding class of what is being represented
- Idea : Recognizing, understanding what’s each voxel represent

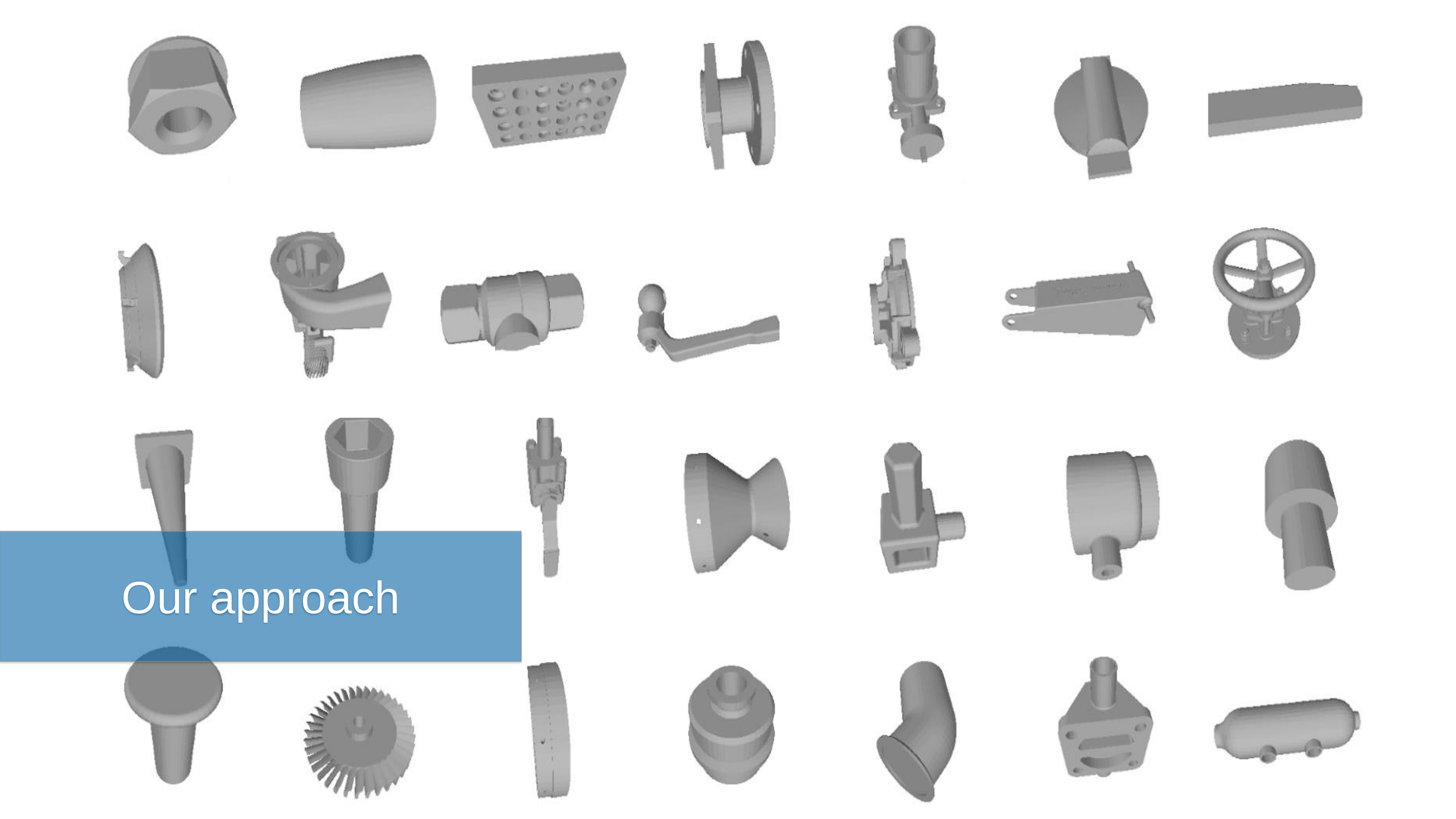
Source : http://dx.doi.org/10.1016/j.cagd.2016.02.015 & [Geometric Deep Learning by Michael Bronstein]

3D CNN

Multi View CNN

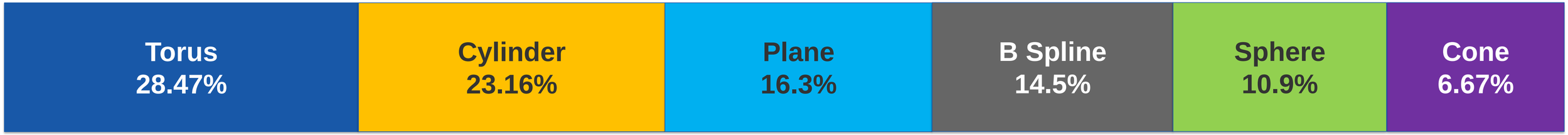


Source https://www.dropbox.com/s/oj3olyzxvnchrqs/SGP%202018.pdf?dl=0 & Geometric Deep Learning by Michael Bronstein



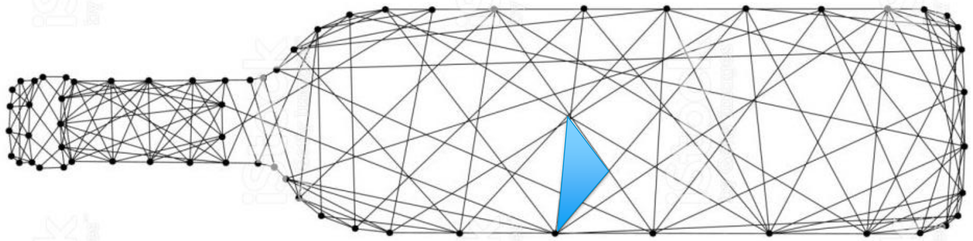
Our approach

Dataset Distribution and Coverage

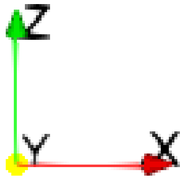


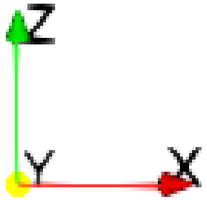
Geometry Count	1500 CAD Files
Triangle Count	19 Million
STL Source	Autodesk Inventor
Type	Multi-part & Assembly
Geometry Type	Mechanical Components
Dataset Size	10 GB
Feature Count	100

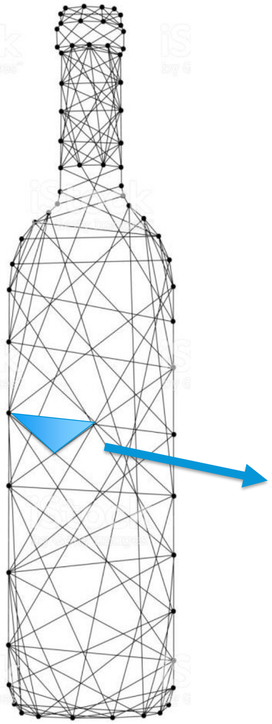
Mesh Data Representation



```
facet normal 0.78 0.61 -0.003
    outer loop
        vertex 86.05  4.49  10.87
        vertex 88.79  6.87  12.27
        vertex 85.79  6.85  11.49
    endloop
endfacet
```





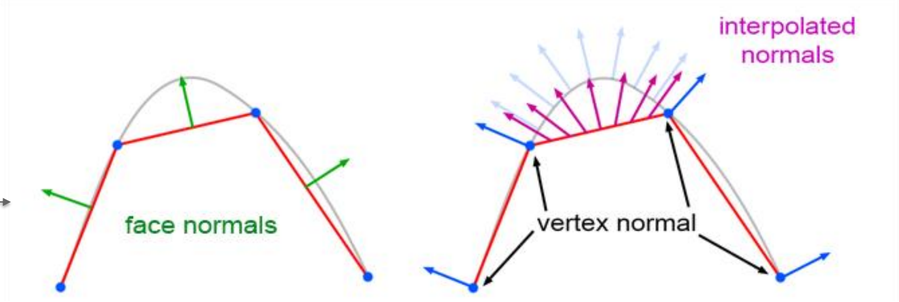


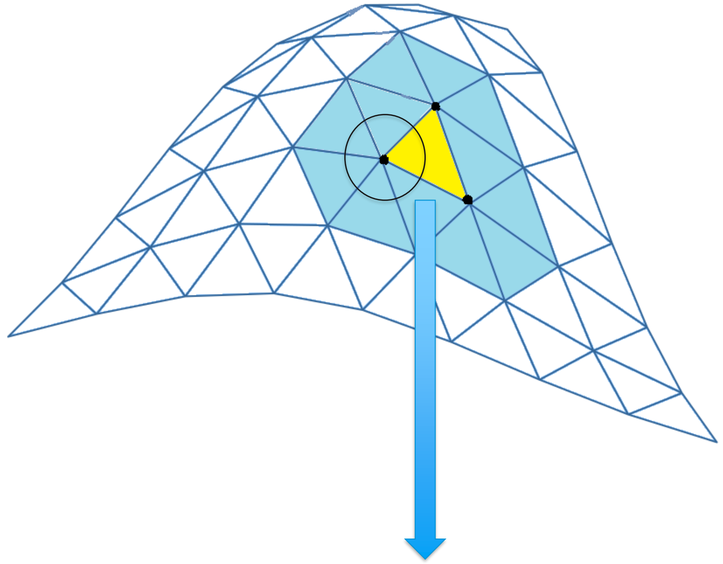
```
facet normal 0.95 0.28 0.004
    outer loop
        vertex 13.59  6.90  42.49
        vertex 25.89  6.87  40.27
        vertex 16.69  6.85  34.49
    endloop
endfacet
```

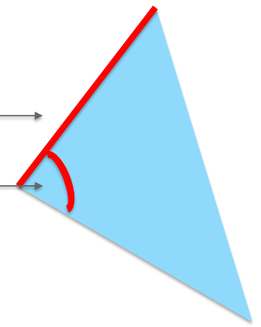
How to represent 3D mesh data in Affine Invariant manner ?

Machine Learning – Derived Features

- Angle between Normal
- Valency of Triangle
- Edge Length
- Area
- Centroid Distance from Vertex
- Internal Angles
- Ratio of Edge Length
- Area Ratio
- Perimeter

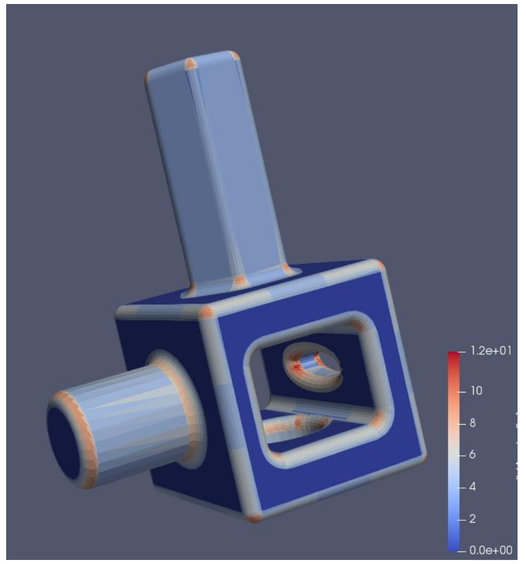


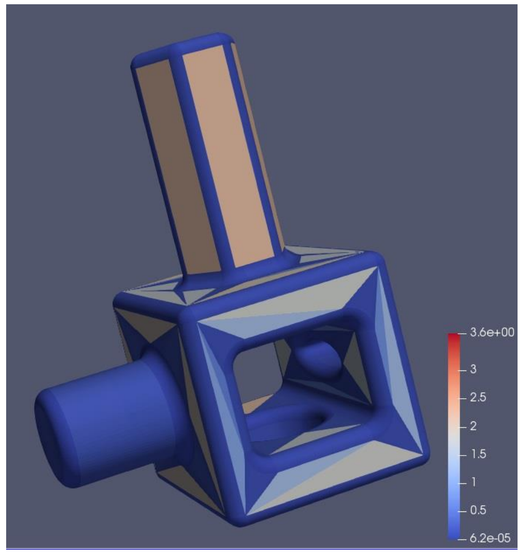




Derived Features - Geometry Illumination

Computing the visibility index for each mesh element from different camera angle

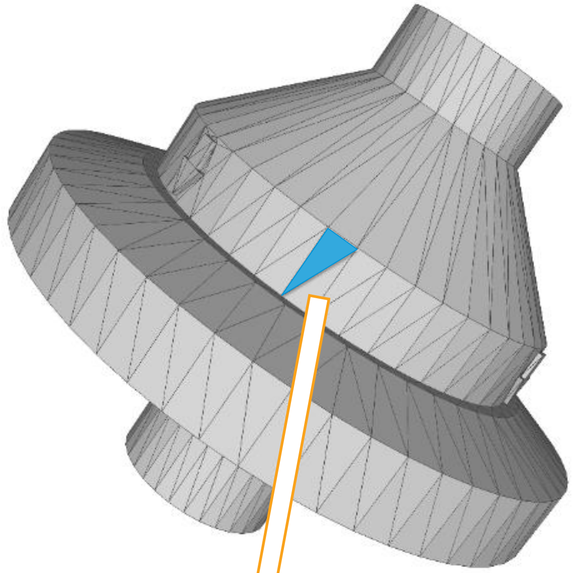




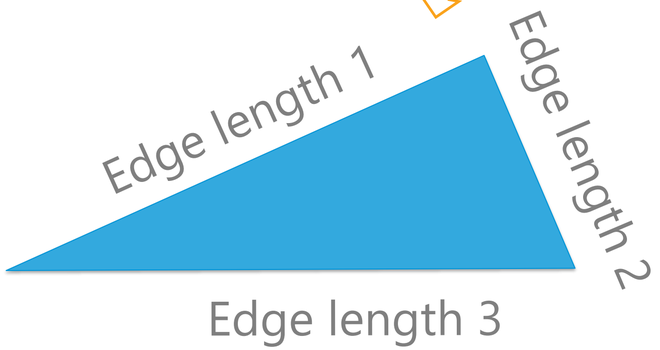
Feature Engineering

Edge Length 1	Edge Length 2	Edge Length 3
0.053882	0.022519	0.059965
0.199127	0.166064	0.259055
0.812115	0.150837	0.790616
0.139474	0.010000	0.139832

Aspect Ratio
0.37553
0.64103
0.18573
0.07151



$$Aspect\ Ratio = \frac{Min\ Edge}{Max\ Edge}$$



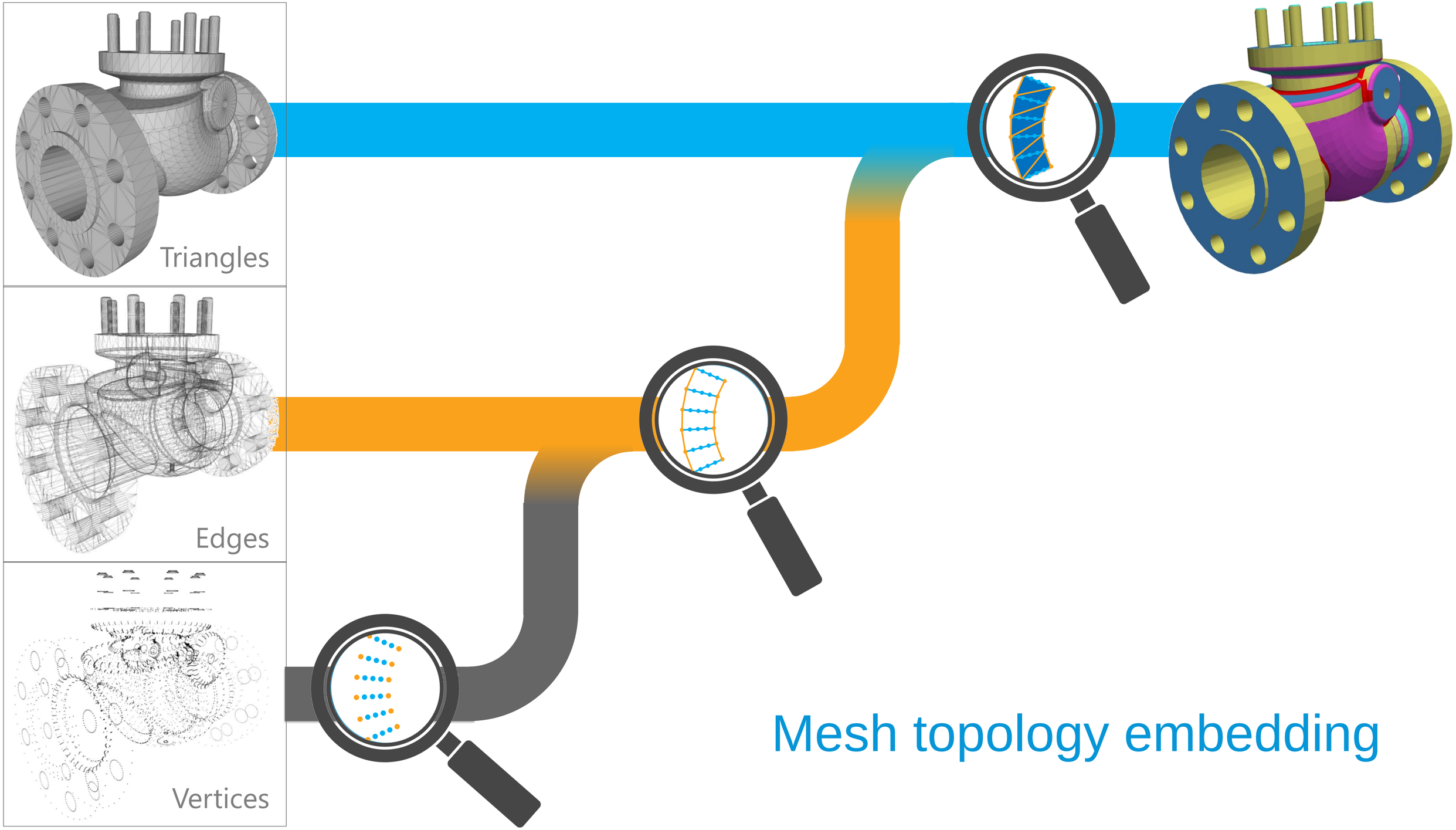
Feature Engineering

	Area	Aspect Ratio	Perimeter	Angle 1	Angle 2	Angle 3
Mean	0.12	0.29	1.33	44.97	132.97	151.87
Std	1.03	0.23	2.31	32.43	34.69	30.62
Min	0.00	0.00	0.00	0.00	0.02	0.03
25 %	0.00	0.09	0.24	14.57	108.91	140.25
50 %	0.01	0.24	0.59	38.28	137.40	162.87
75 %	0.03	0.47	1.41	74.3	163.70	173.95
Max	63.48	1.00	46.14	119.87	179.89	180.00

Normalization

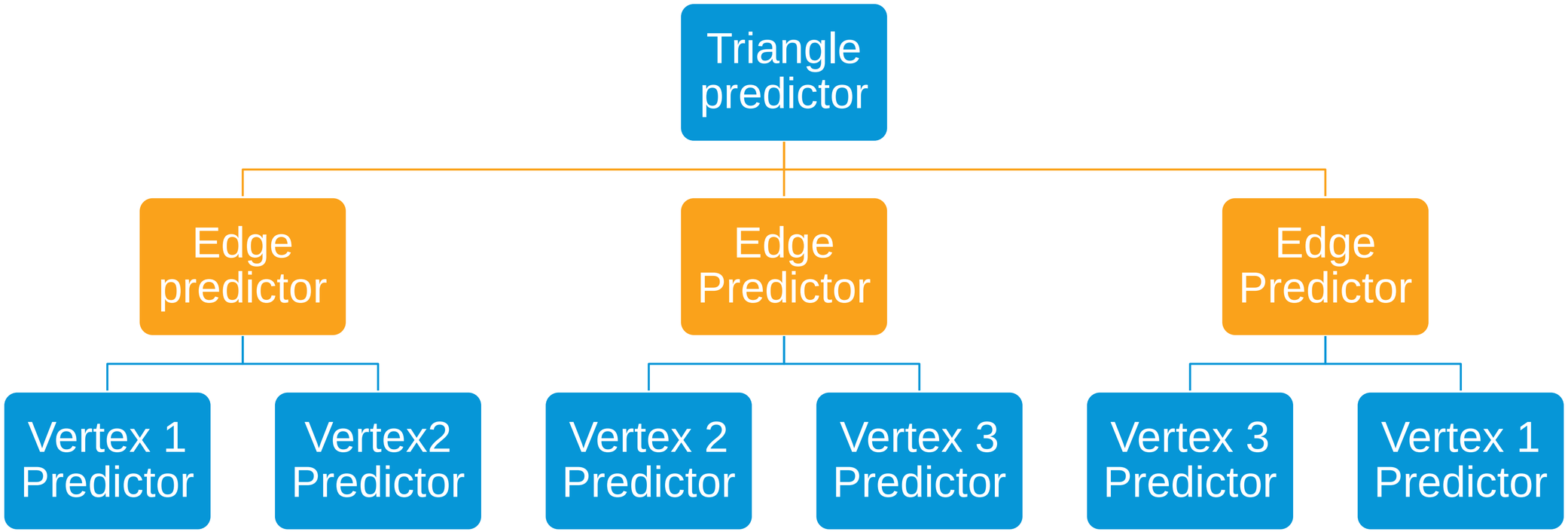
	Area	Aspect Ratio	Perimeter	Angle 1	Angle 2	Angle 3
Mean	0.00	0.29	0.03	0.38	0.74	0.84
Std	0.02	0.23	0.05	0.27	0.19	0.17
Min	0.00	0.00	0.00	0.00	0.00	0.00
25 %	0.00	0.09	0.01	0.12	0.61	0.78
50 %	0.00	0.24	0.01	0.32	0.76	0.90
75 %	0.03	0.47	0.03	0.62	0.91	0.97
Max	1.00	1.00	1.00	1.00	1.00	1.00

Topology Embedding



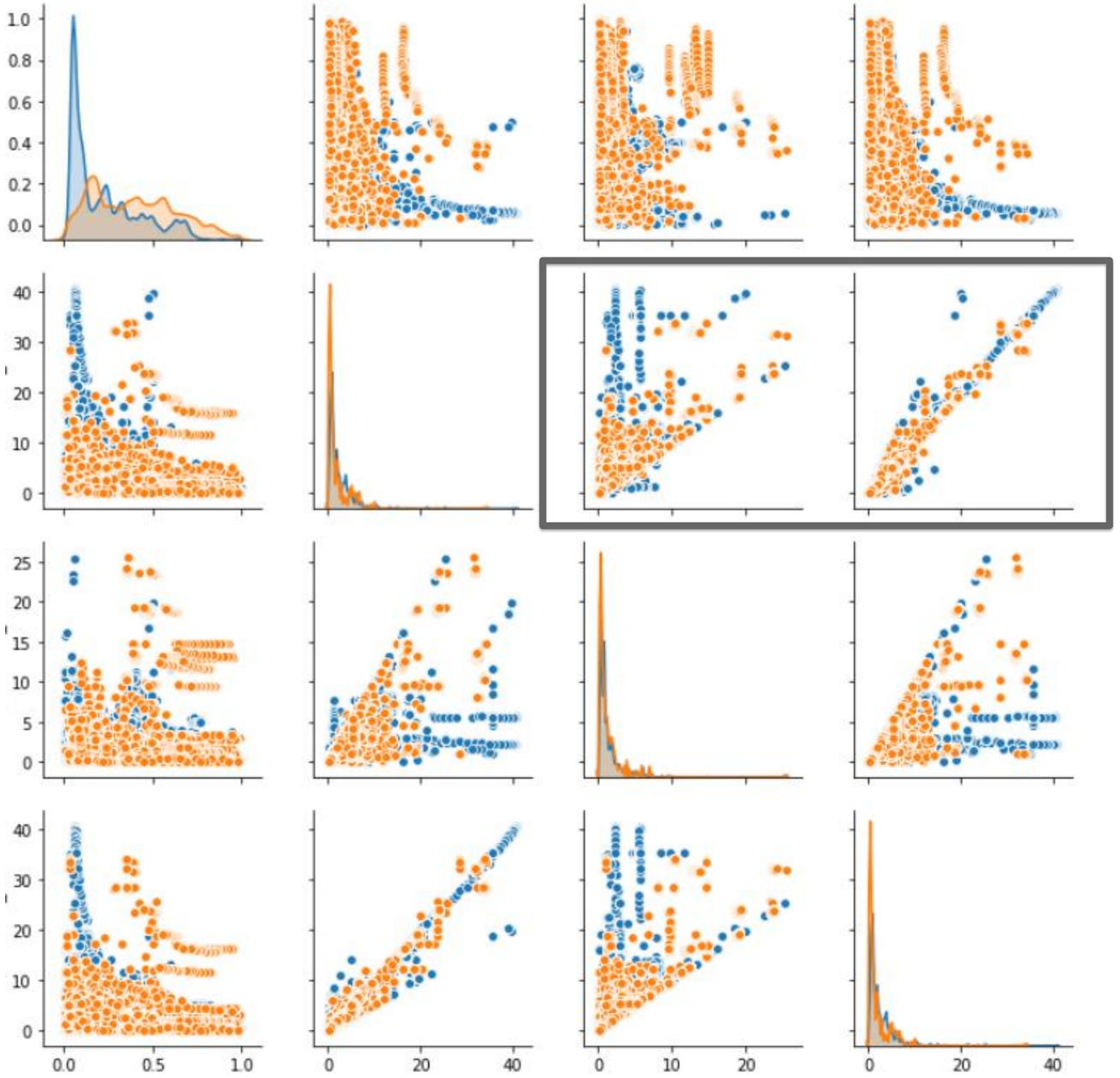
Mesh topology embedding

Mesh topology embedding



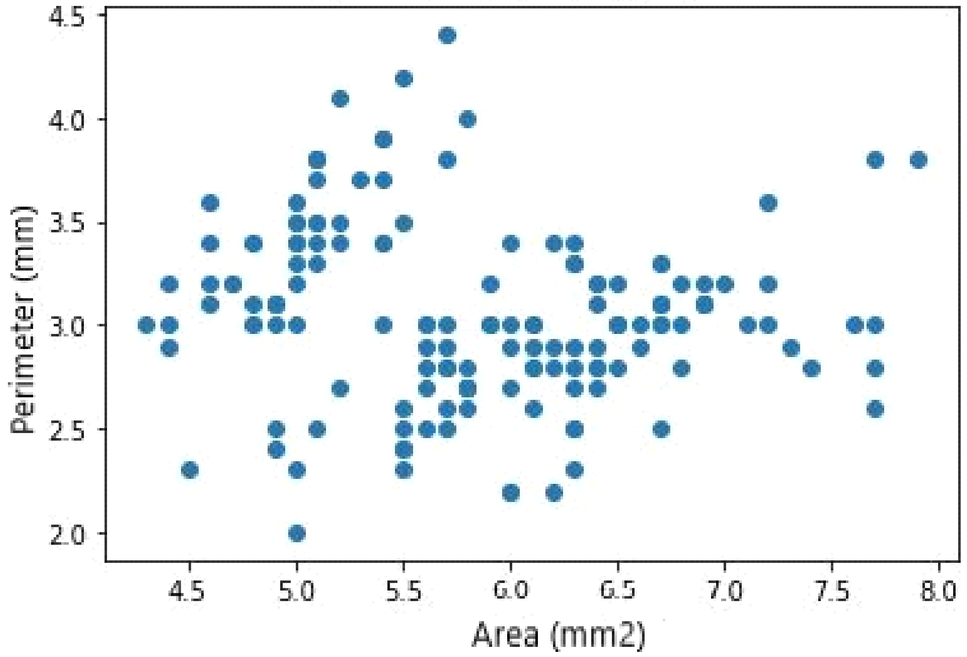
Visualization

Co-variance matrix
and its visualization

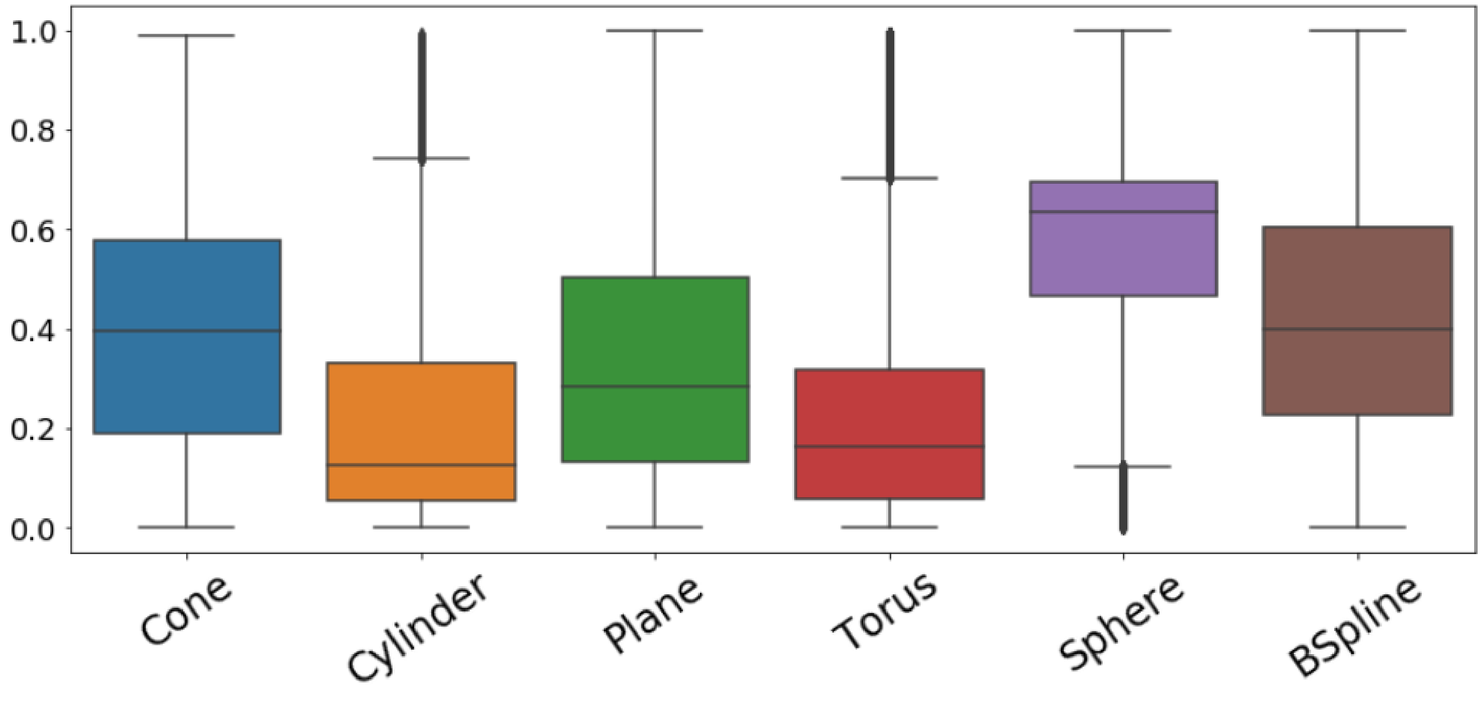


Visualization

Scatter Plot



Box Plot

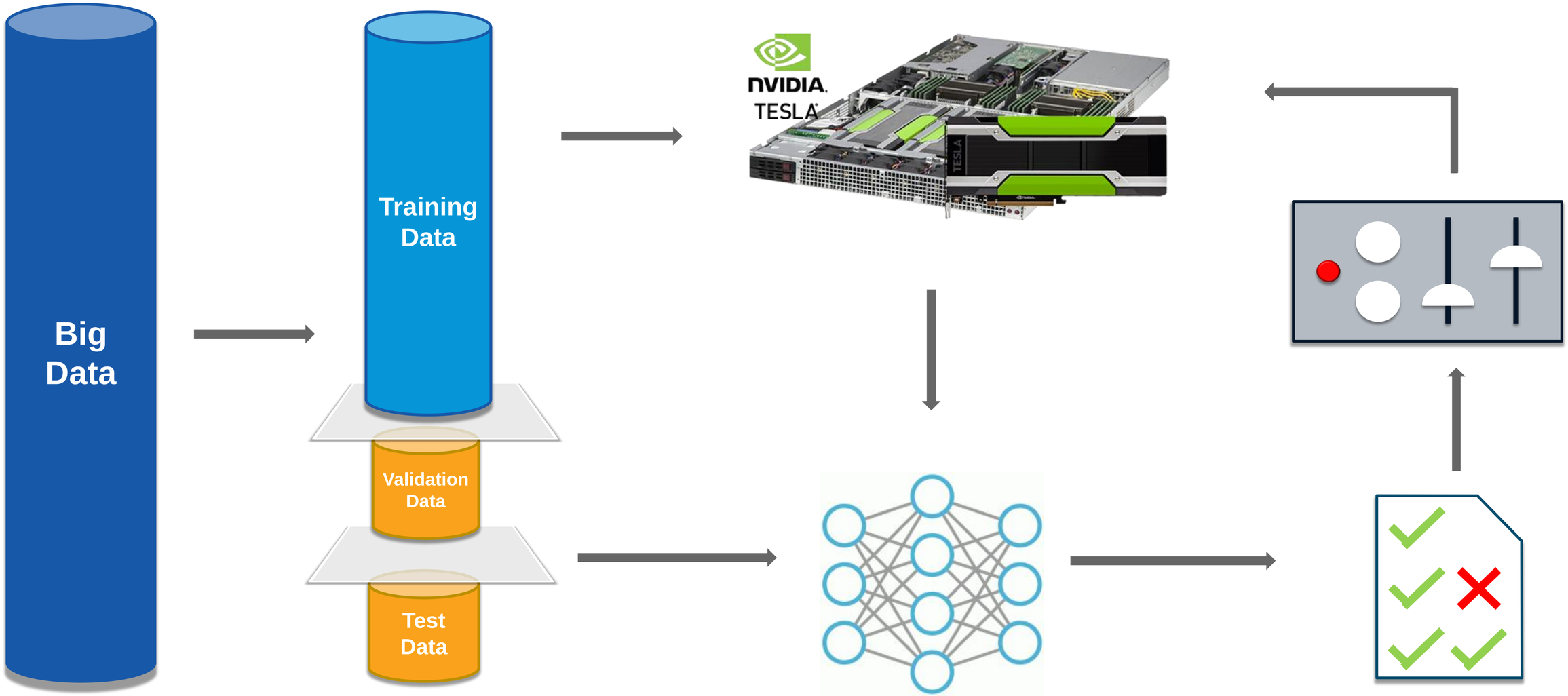


Feature Importance

- eli5 provides a way to compute feature importance for any black-box estimator by measuring how score decreases when a feature is not available

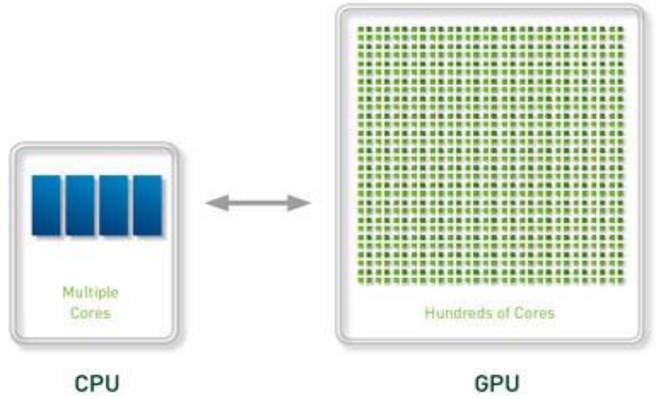
Feature	Weight
Angle Between Normal	0.6789
Area Ratio	0.5134
Valency	0.3685
Centroid Angle	0.3125
Edge Length Ratio	0.2786
Aspect Ratio	0.2564
Angle 2	0.2032
Angle 3	0.1103
Angle 1	0.1032

Training and Validation



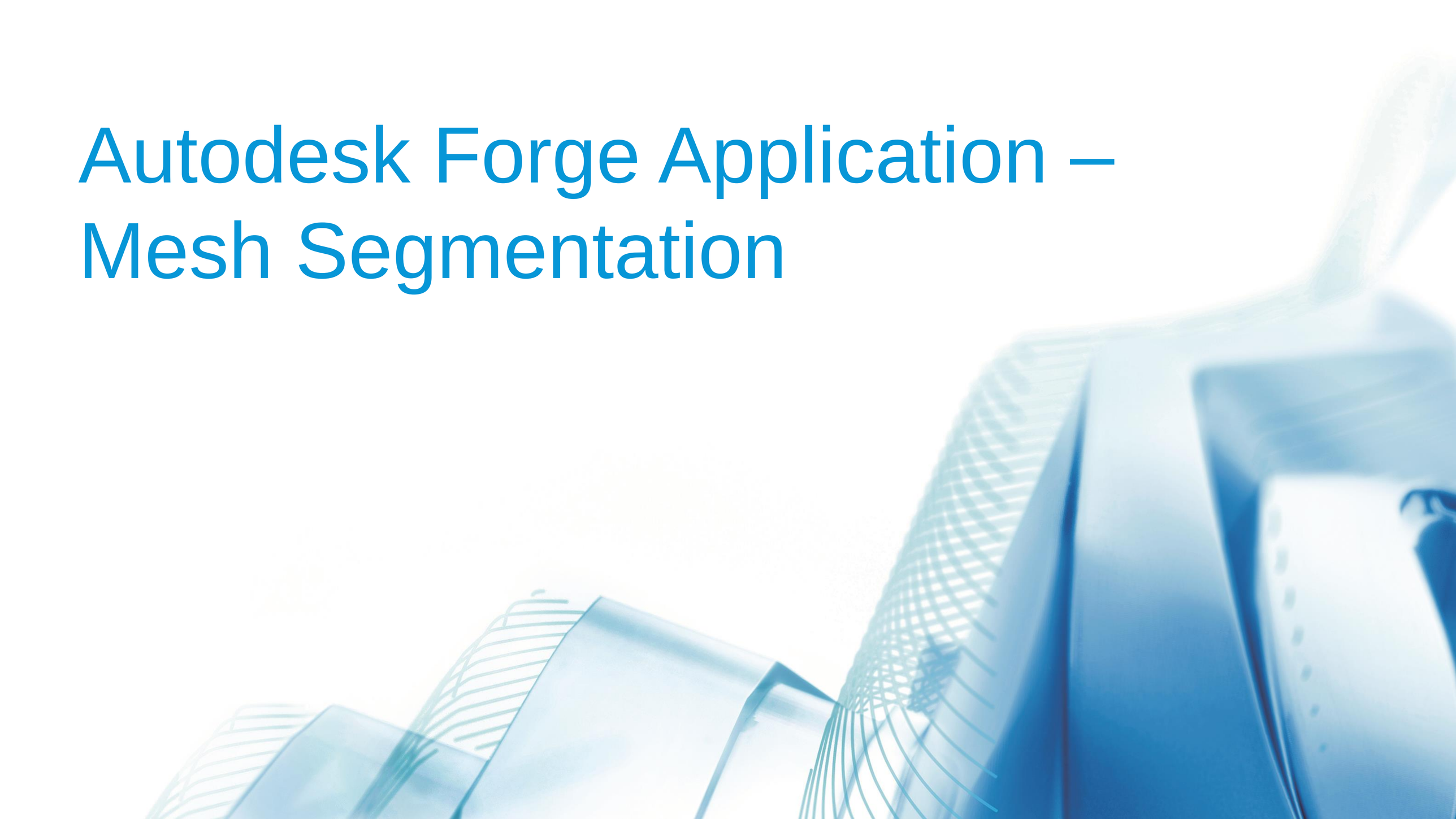
ML Training on AWS Cloud

Amazon EC2

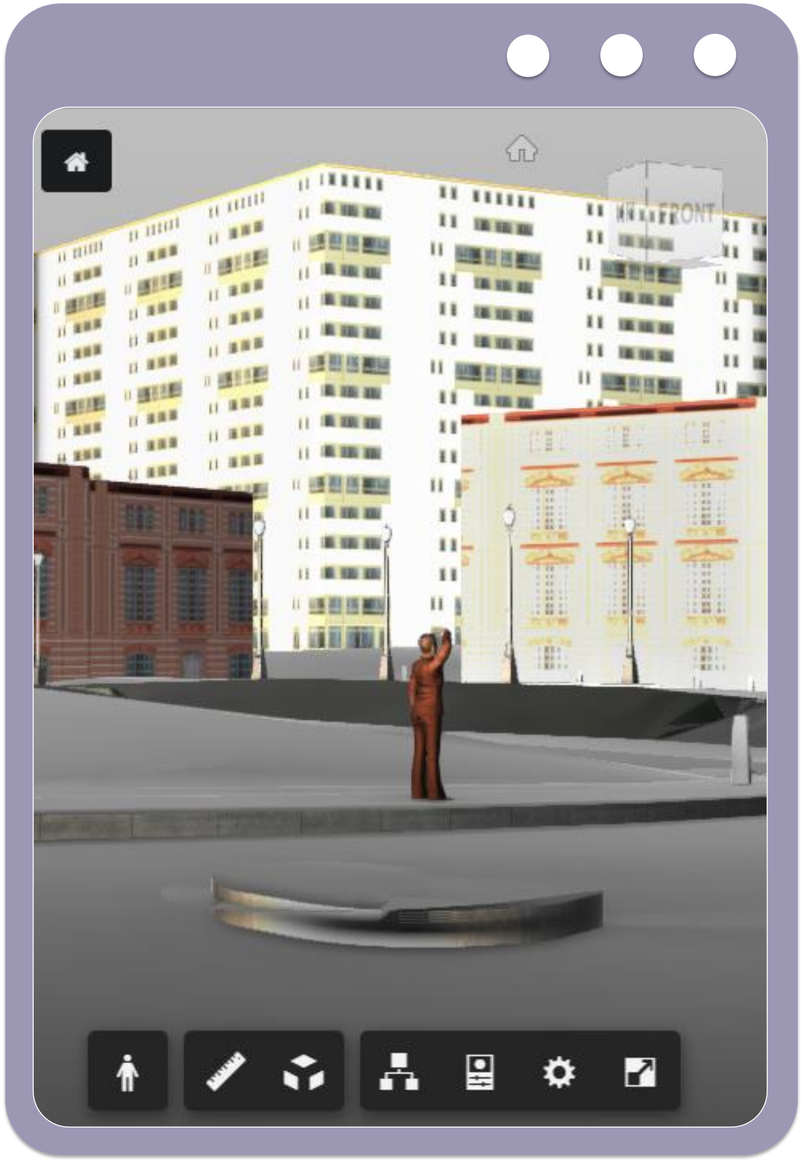


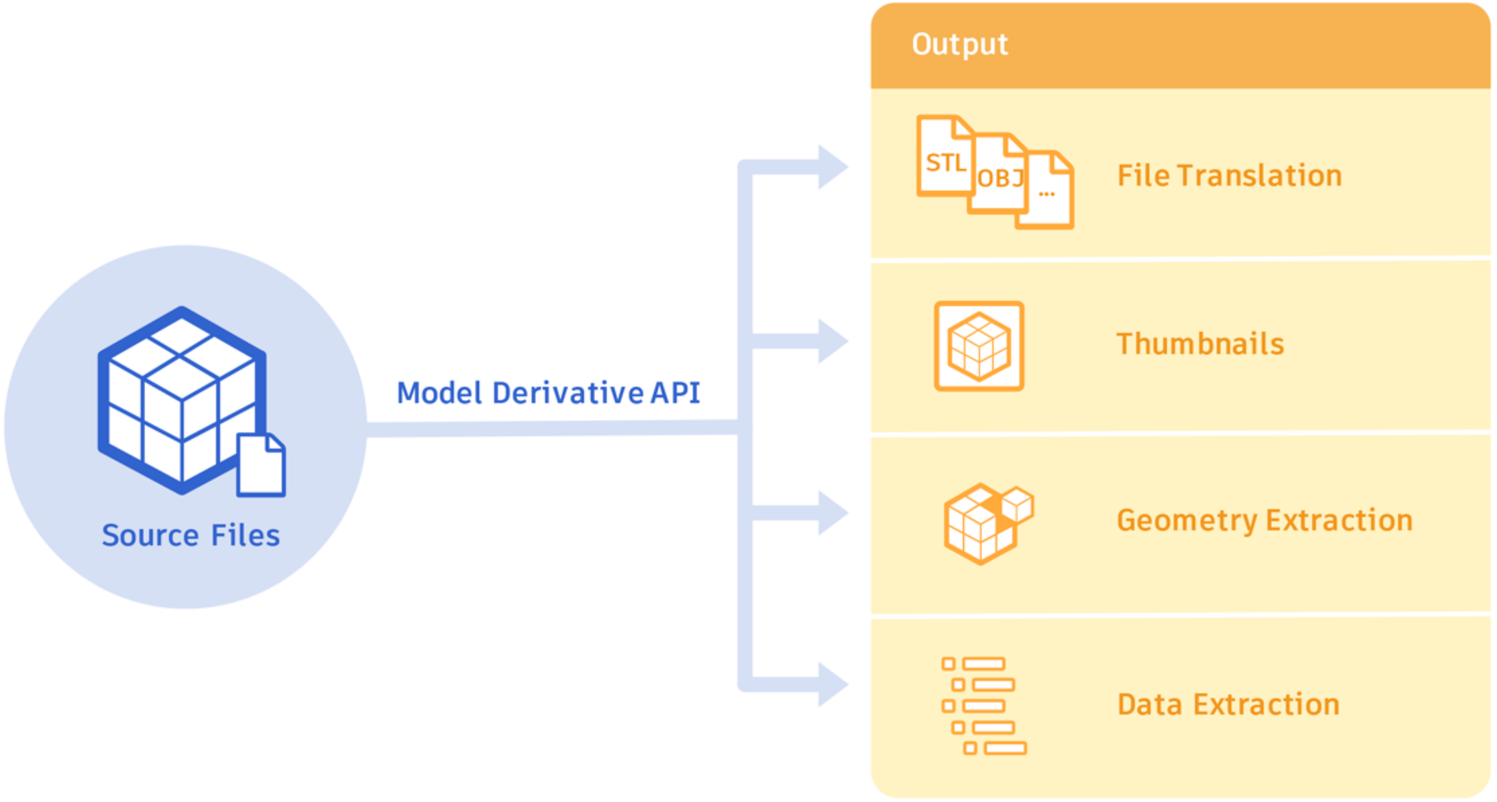
- 4 x Tesla V100
- 64 GB GPU Memory
- 32 CPU Cores
- 244 GB Ram Memory
- **Cost - $12.24 / hour**
- 2000 ML training iterations completed in 25 hours using above machine (~ $150)

Autodesk Forge Application – Mesh Segmentation



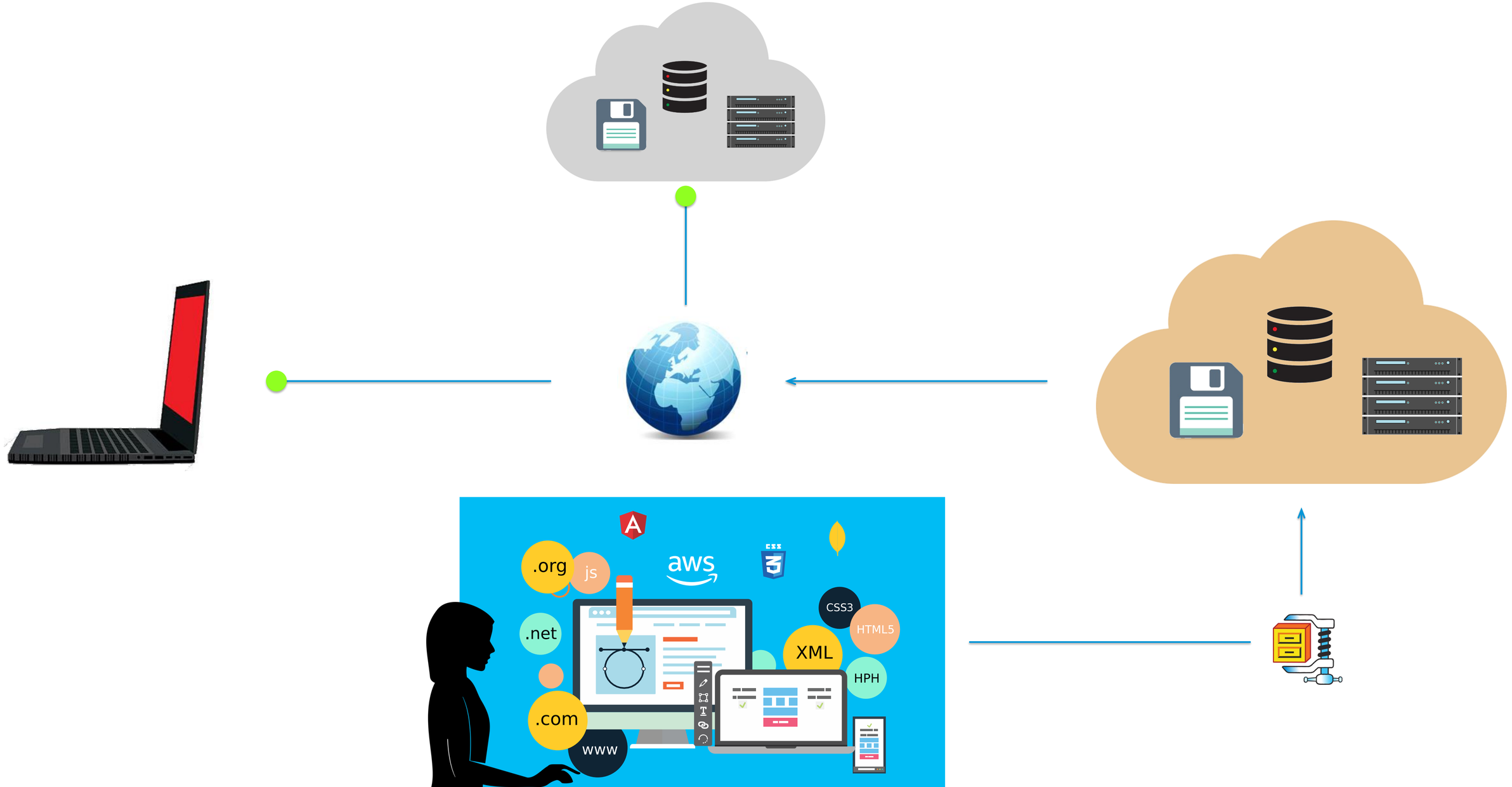
Geometry Processor for the Web



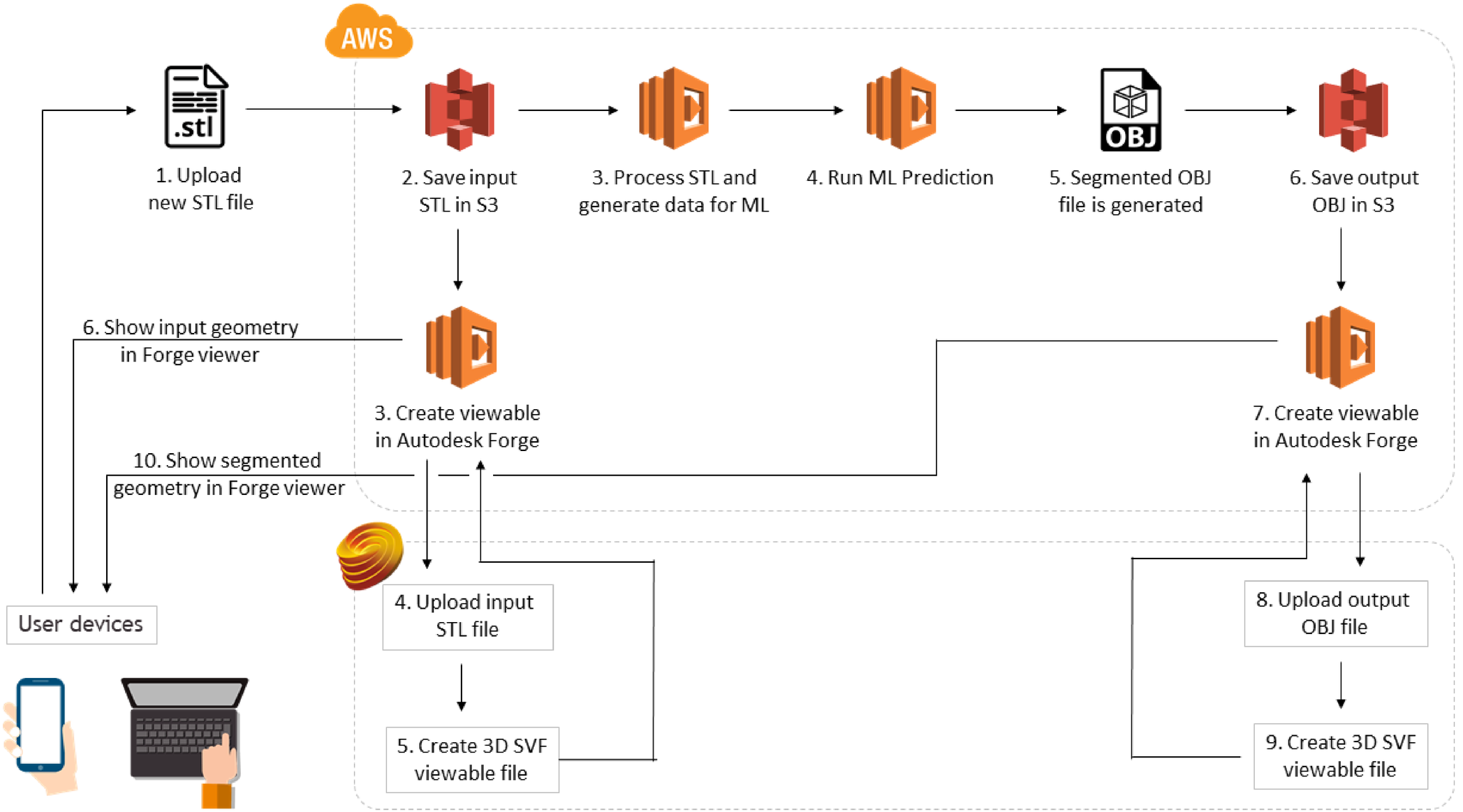


AUTODESK®
FORGE

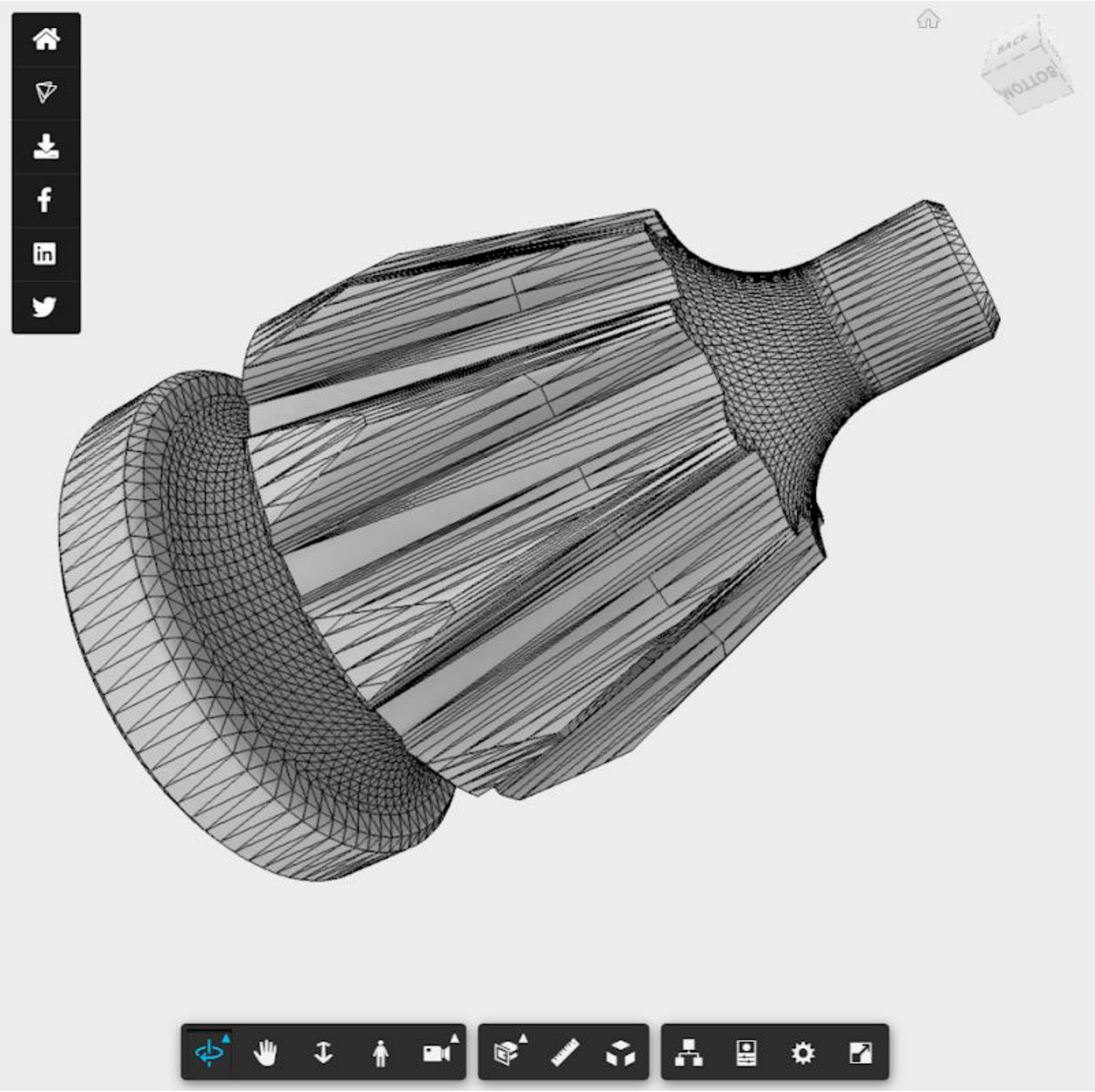
Serverless Micro Web Service

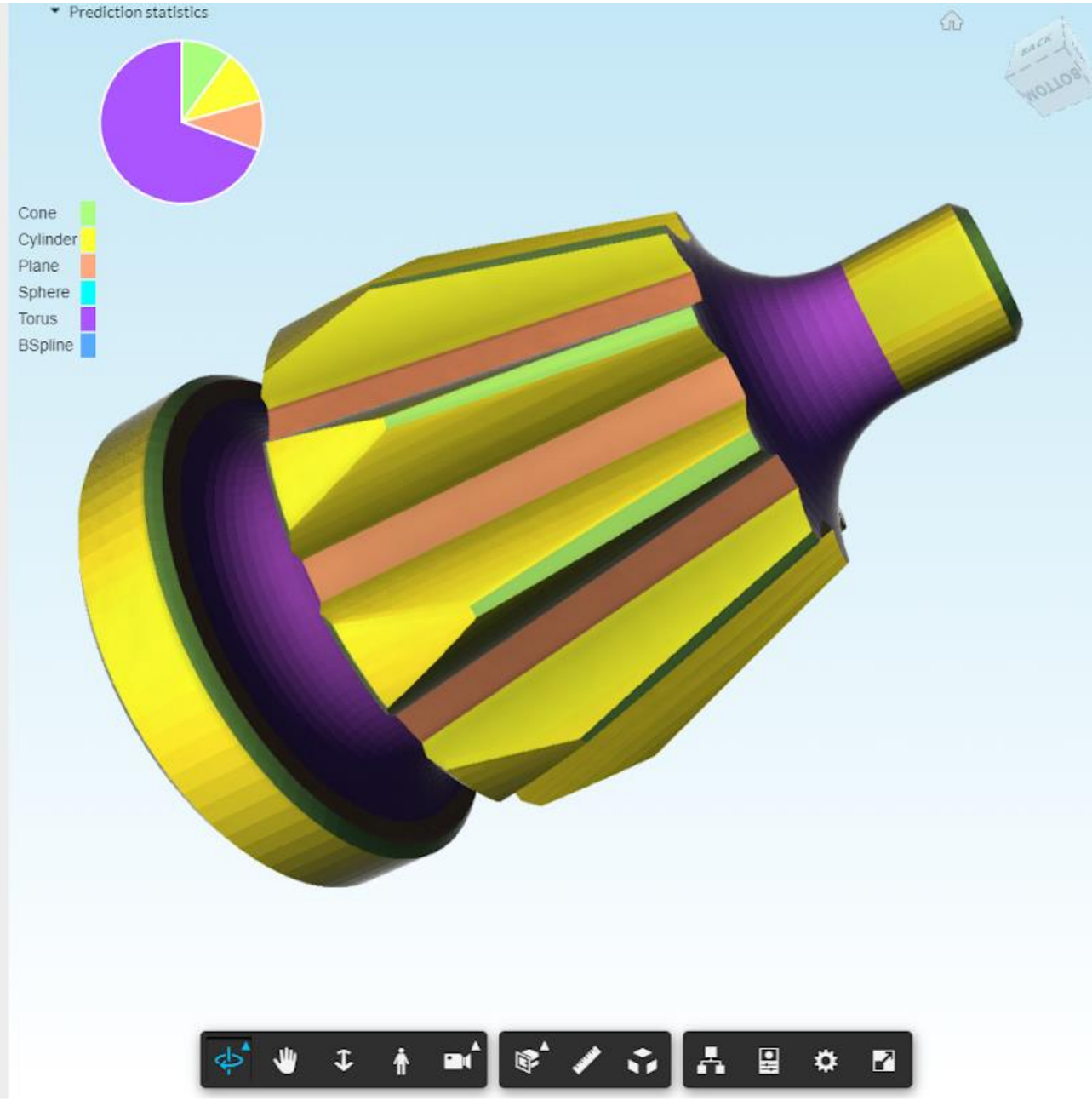


Autonomous Mesh Segmentation - Architecture

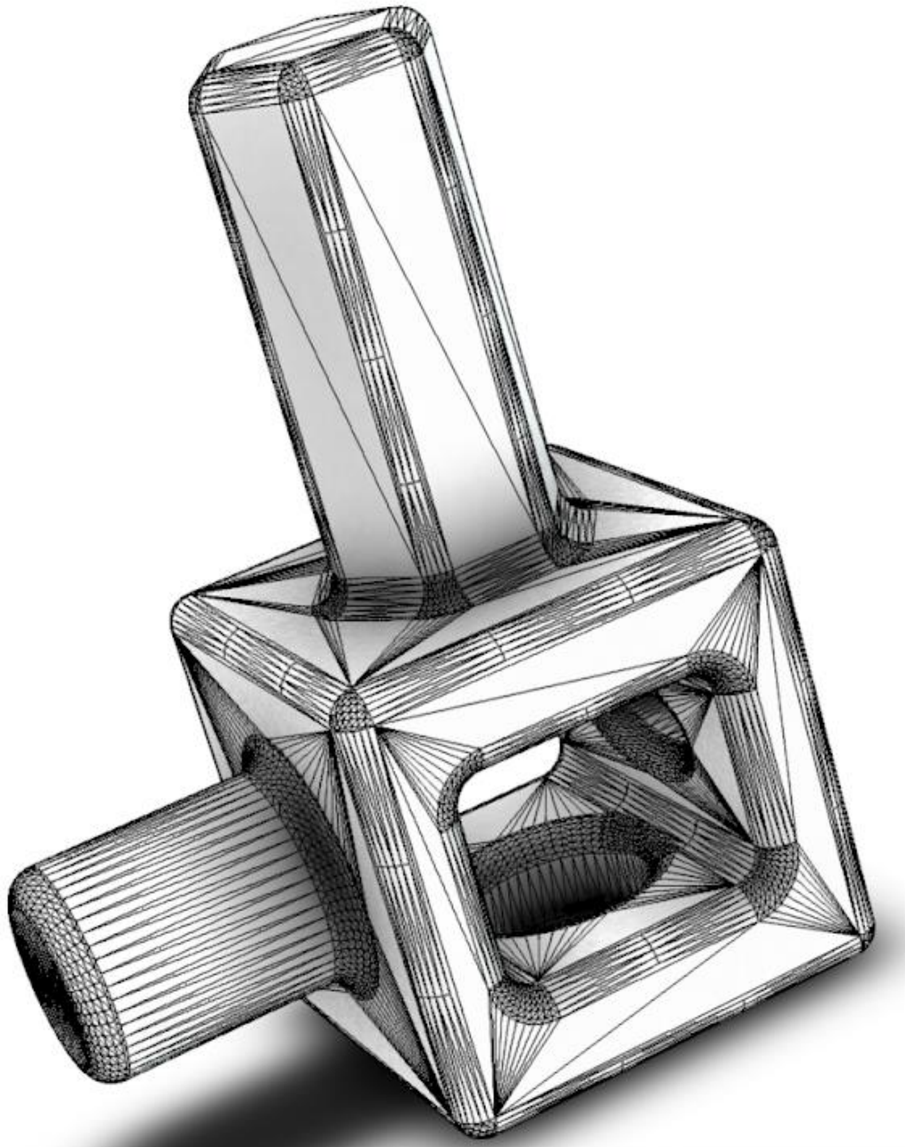


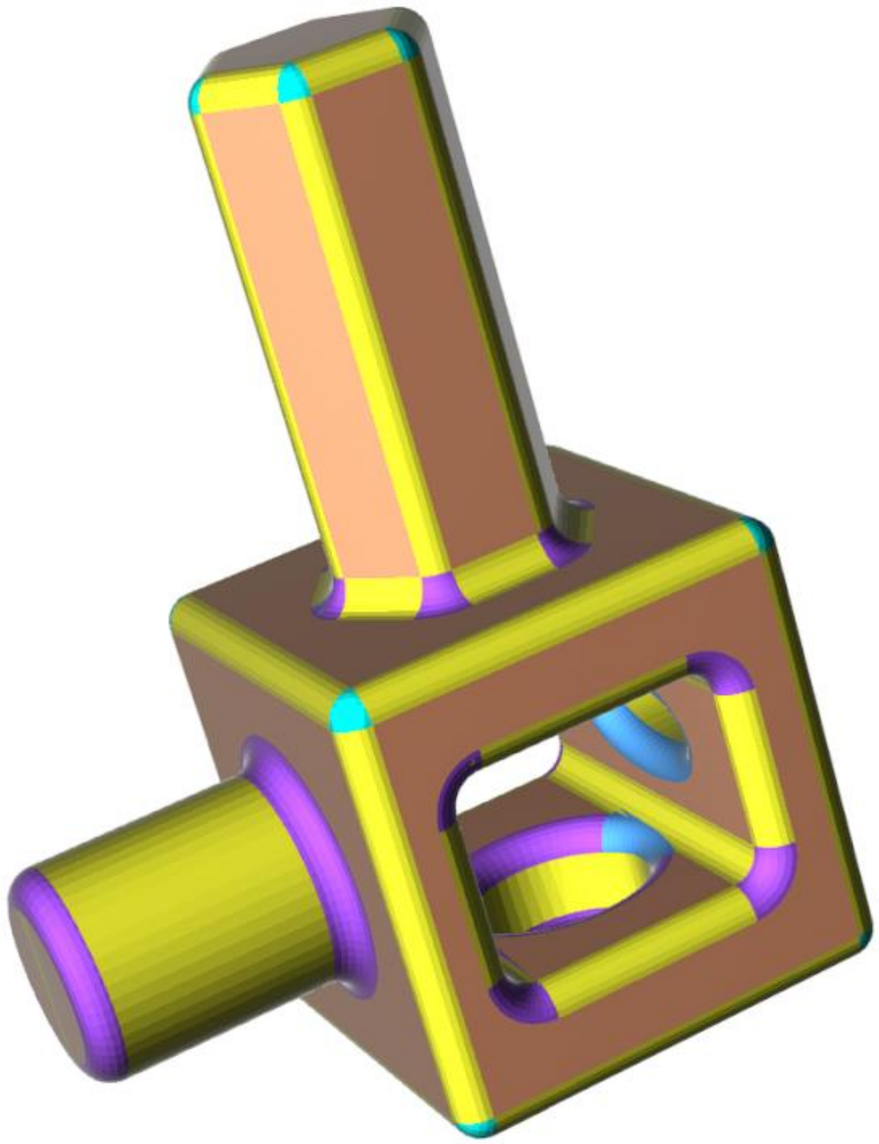
Autonomous Mesh Segmentation – Results



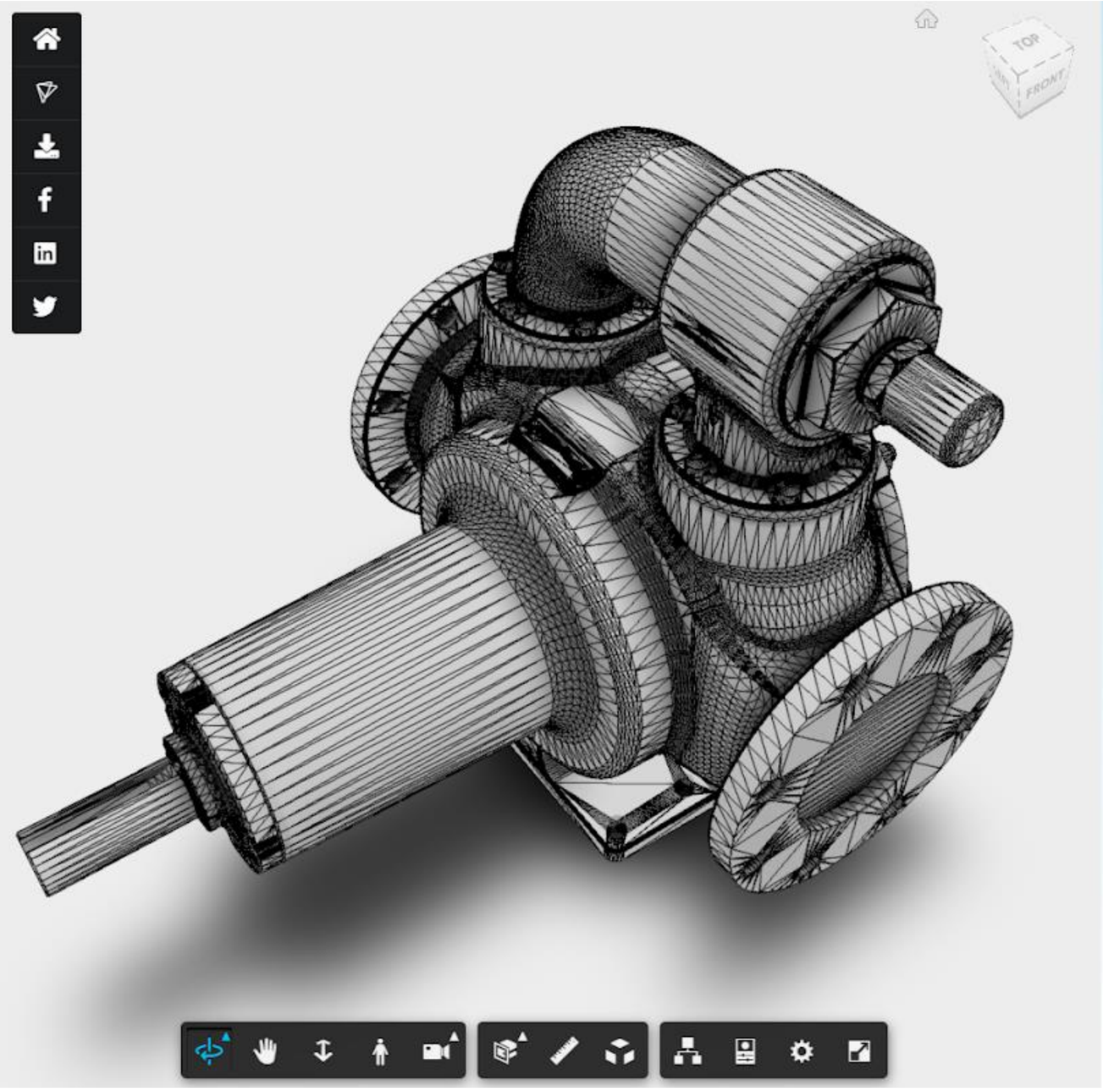


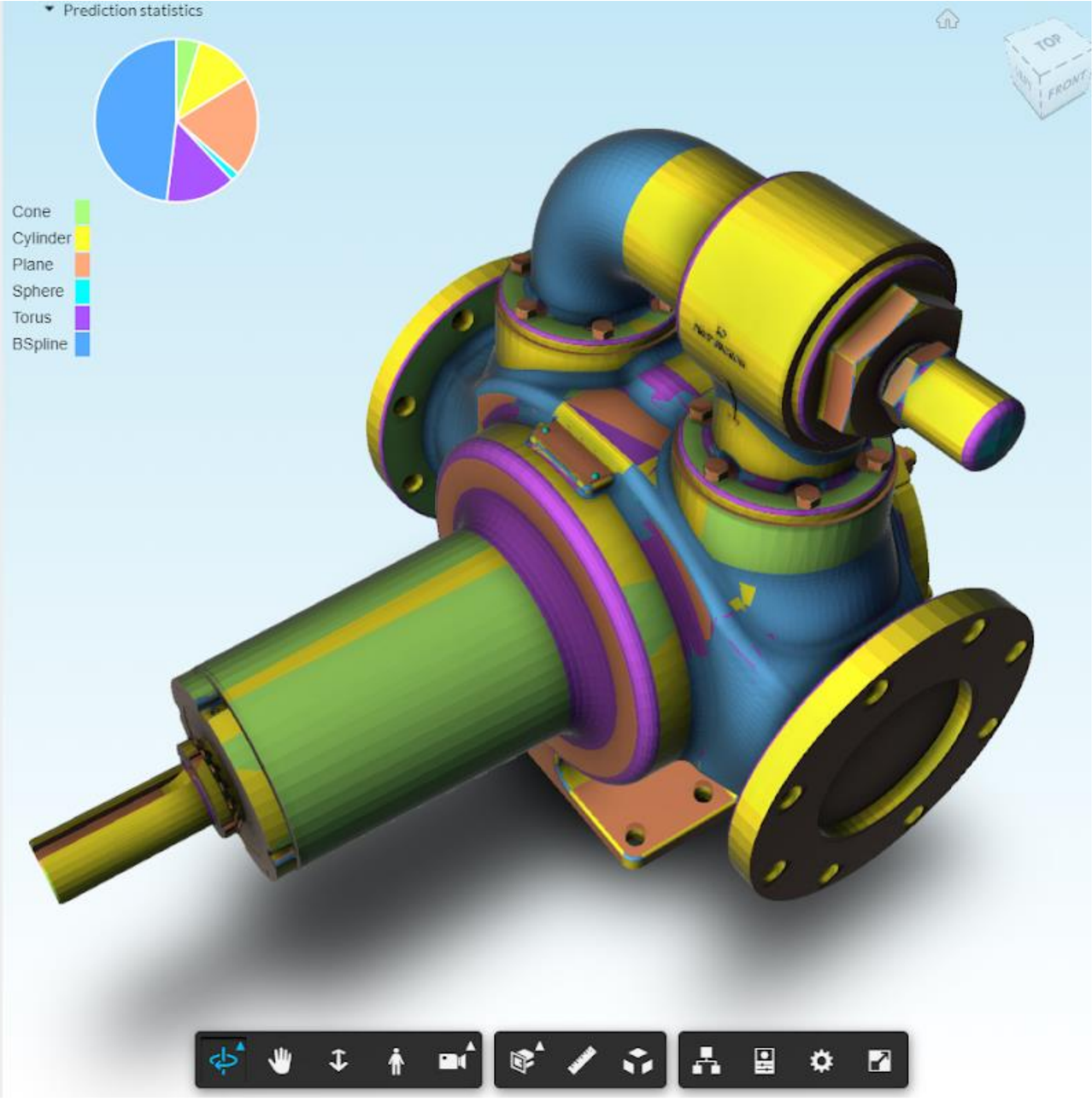
Autonomous Mesh Segmentation – Results



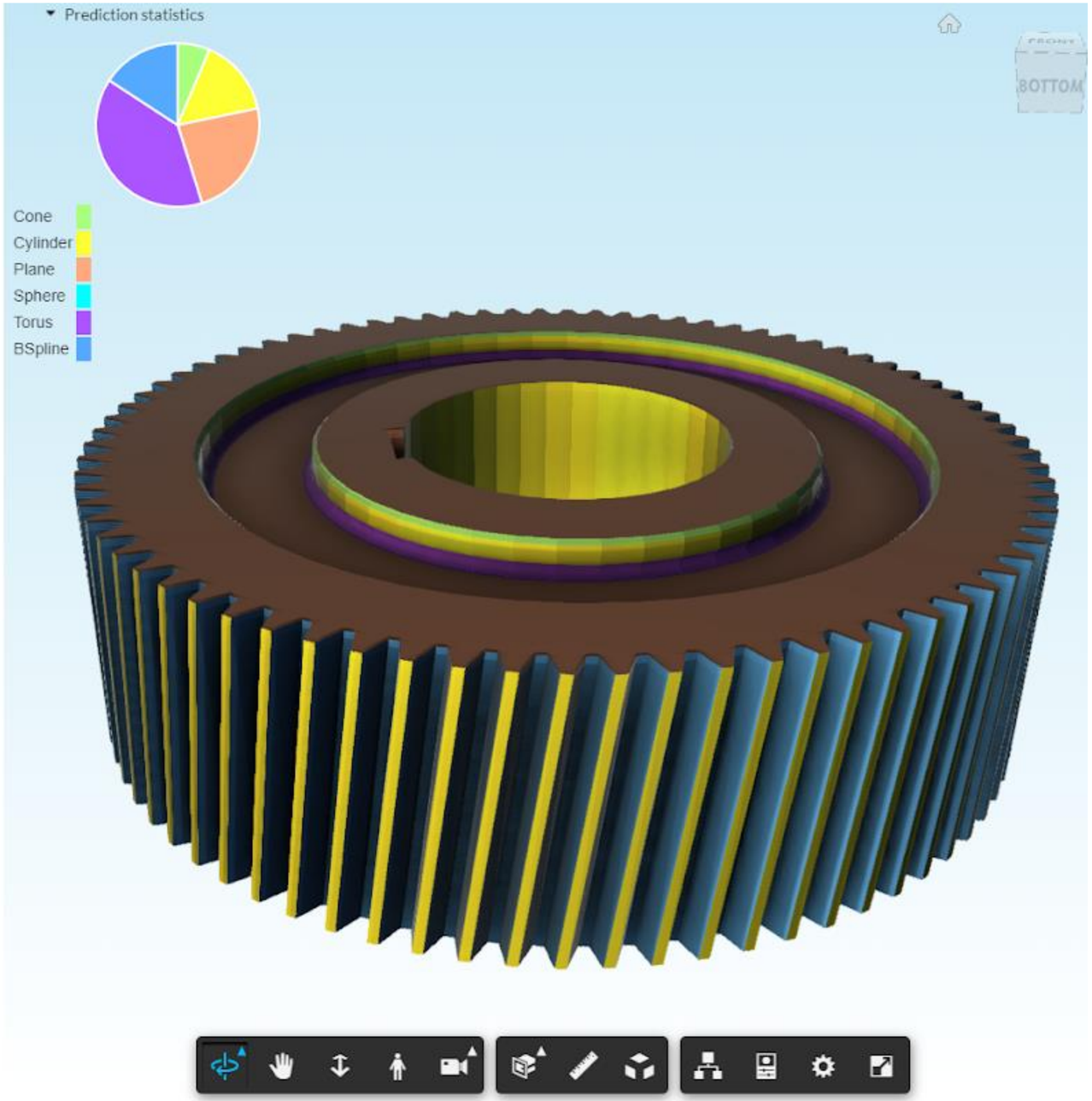


Autonomous Mesh Segmentation – Results

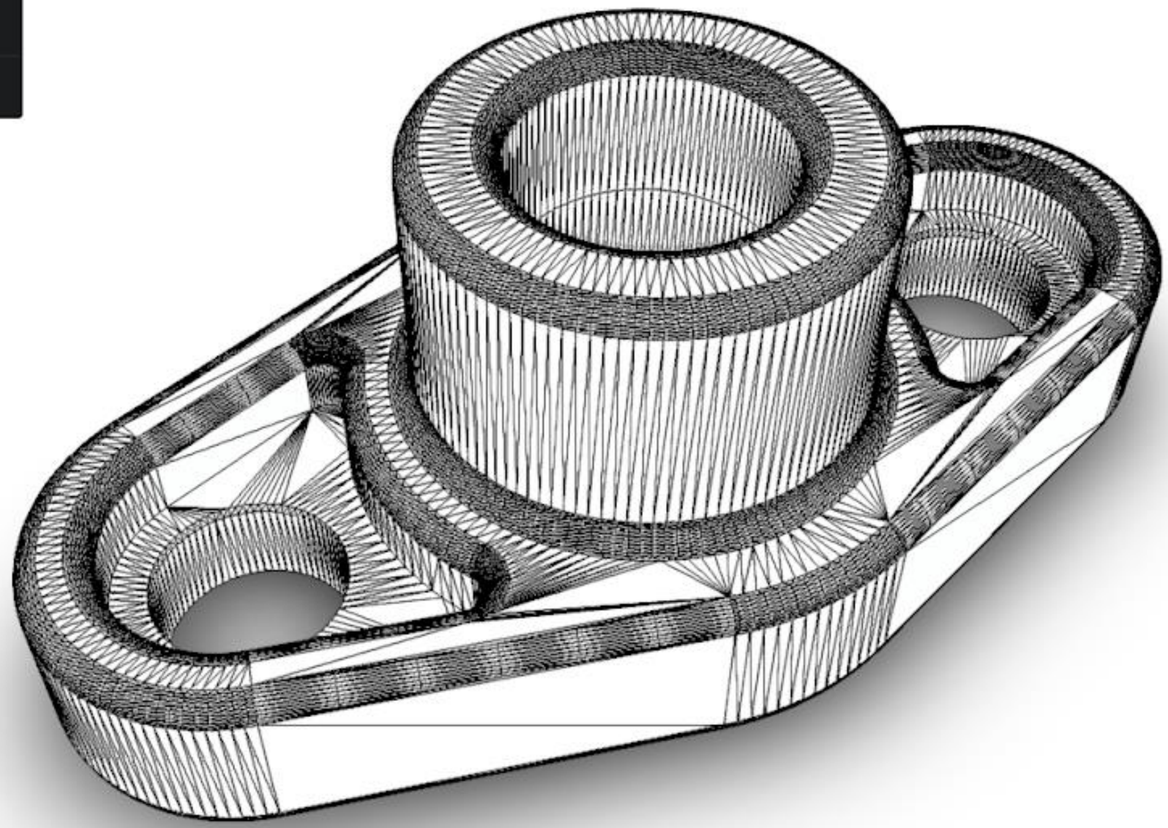


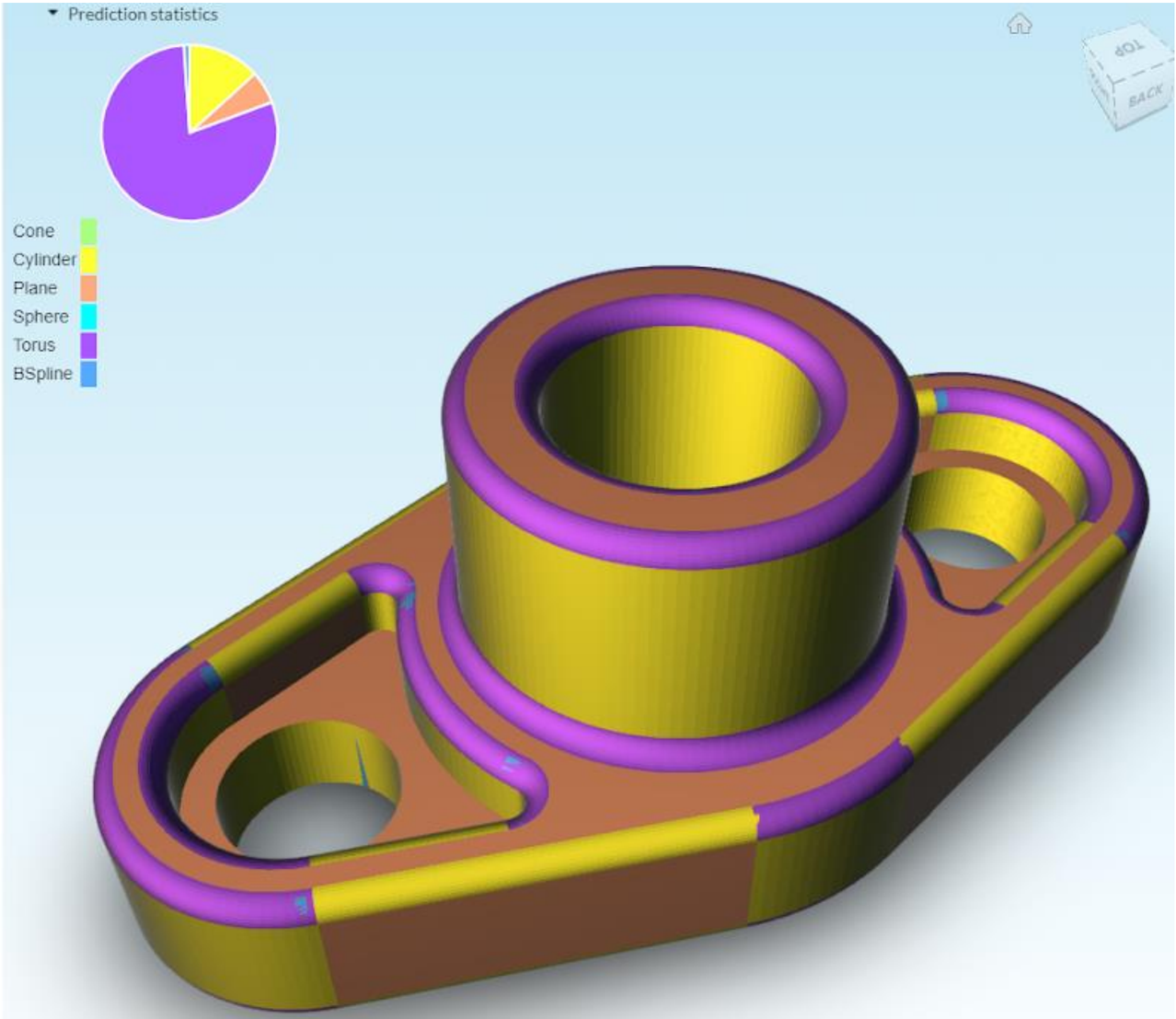


Autonomous Mesh Segmentation – Results

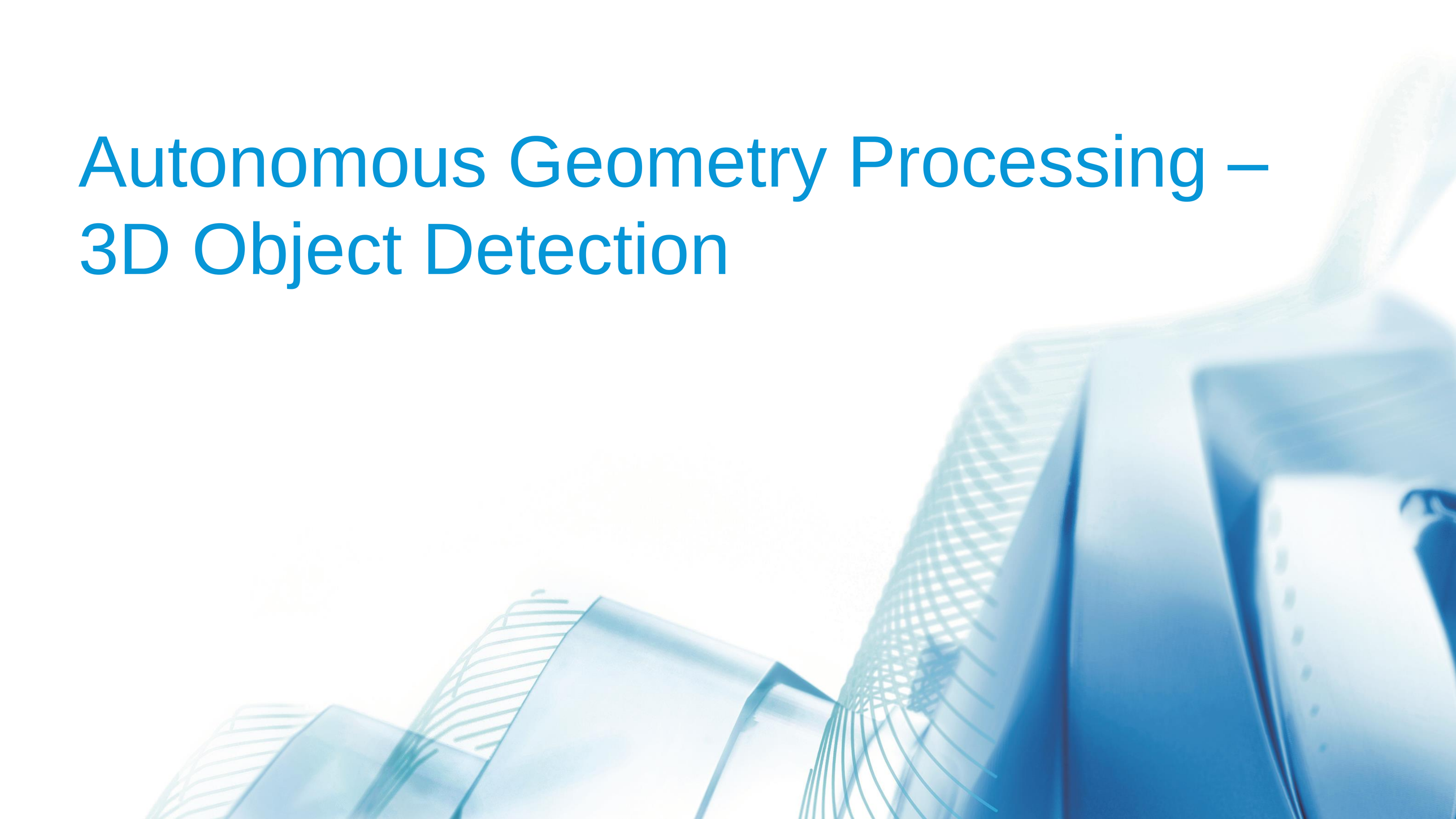


Autonomous Mesh Segmentation – Results

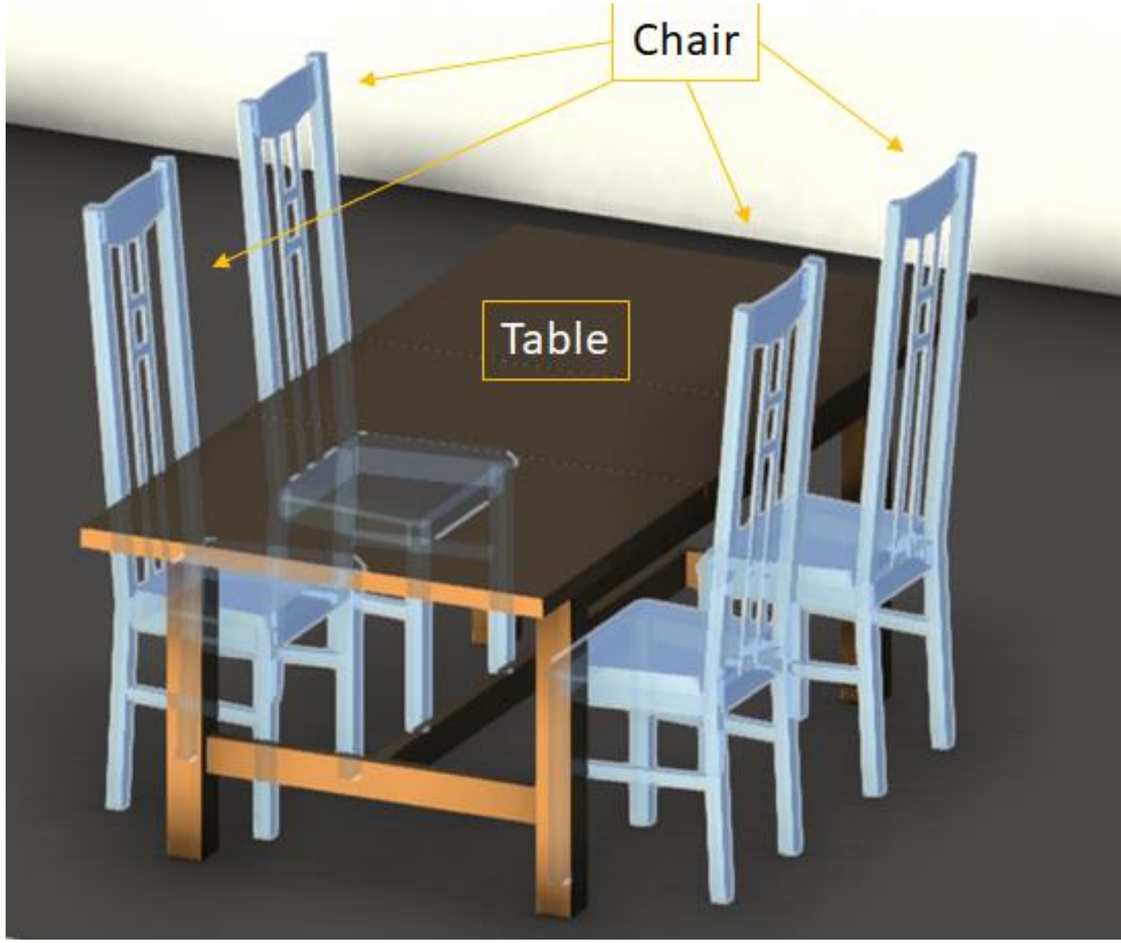




Autonomous Geometry Processing – 3D Object Detection



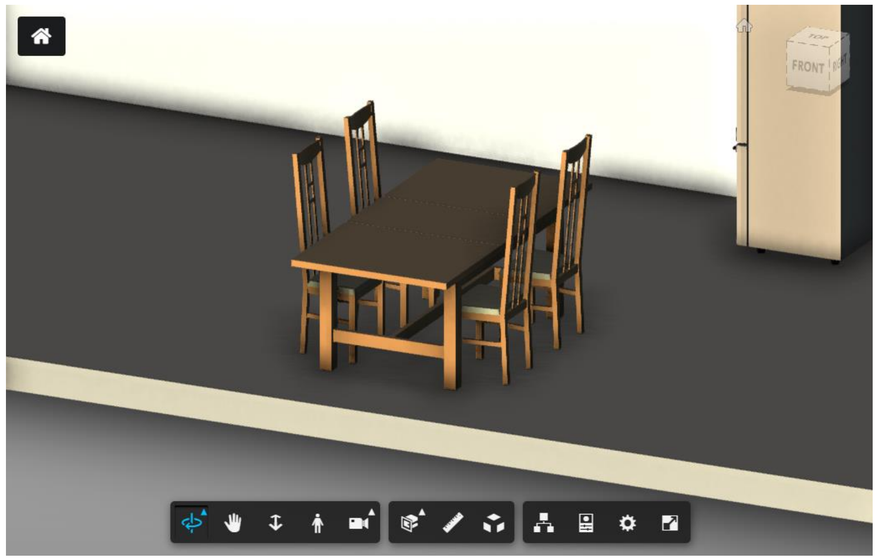
Detect the object in scene

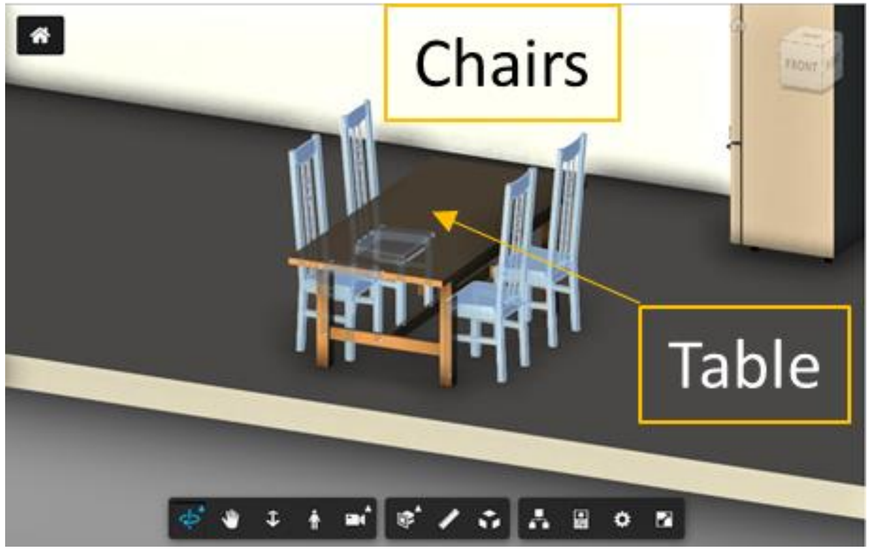


Object Detection in Images

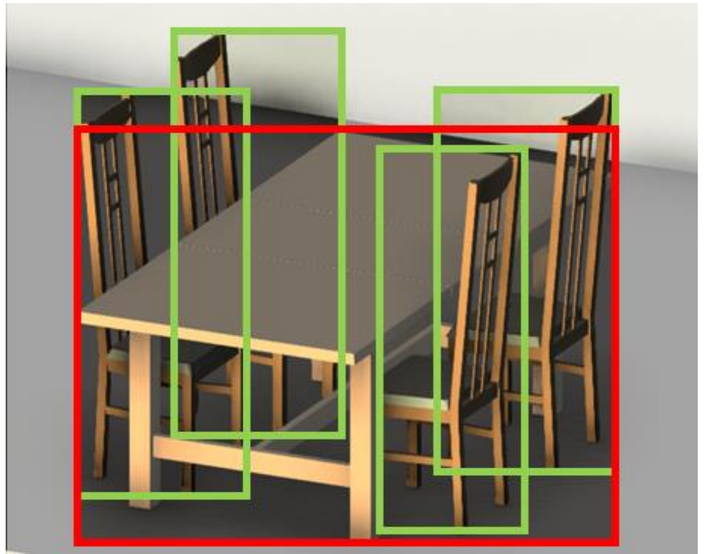
Object Detection in 3D CAD Models

3D





2D



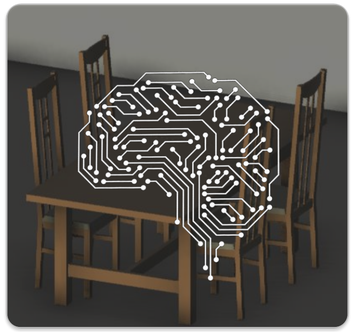
4 Step Strategy

AUTODESK FORGE VIEWER

Open 3D model in Autodesk
Forge Viewer

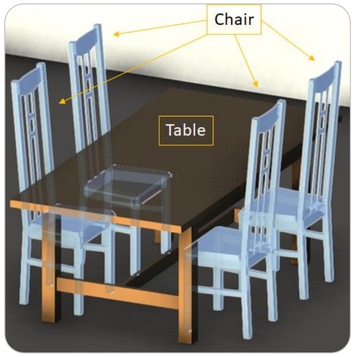
CAPTURE A SNAPSHOT

Capture a snapshot using
Forge Viewer



DETECT OBJECTS USING AI

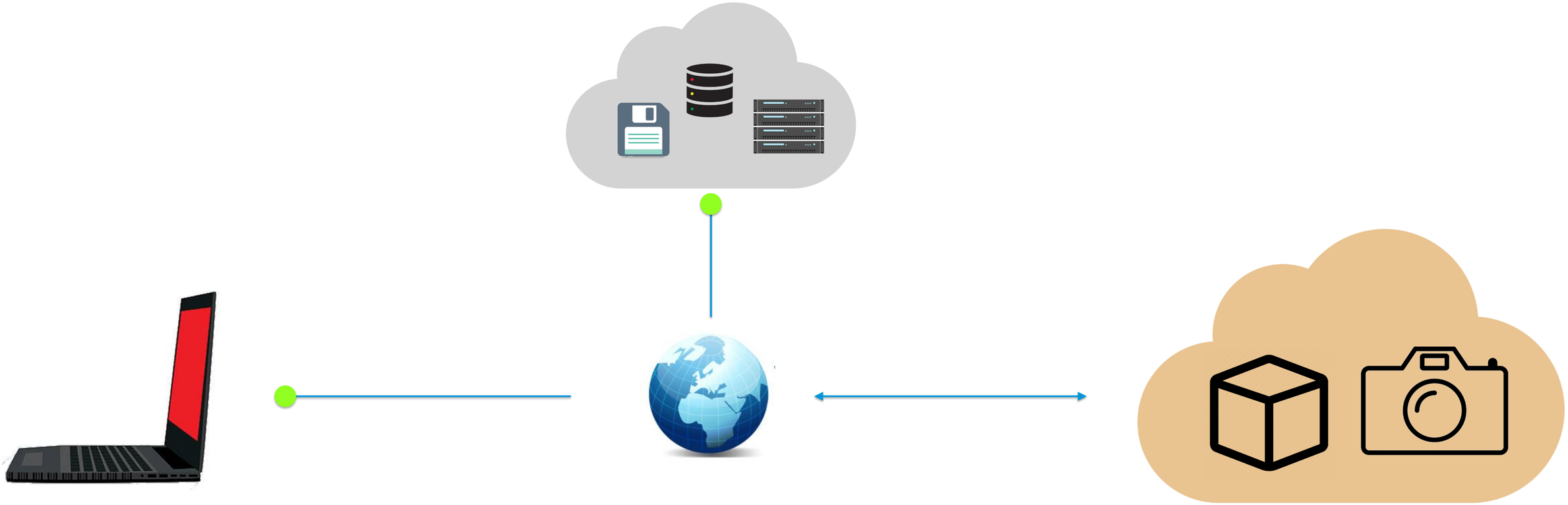
Detect objects from the
snapshot using ML



MAP OBJECTS TO 3D PARTS

Map the objects from the
snapshot to the 3D model

Micro Web Service to Capture High Res Images



Forge Access Token

Forge URN

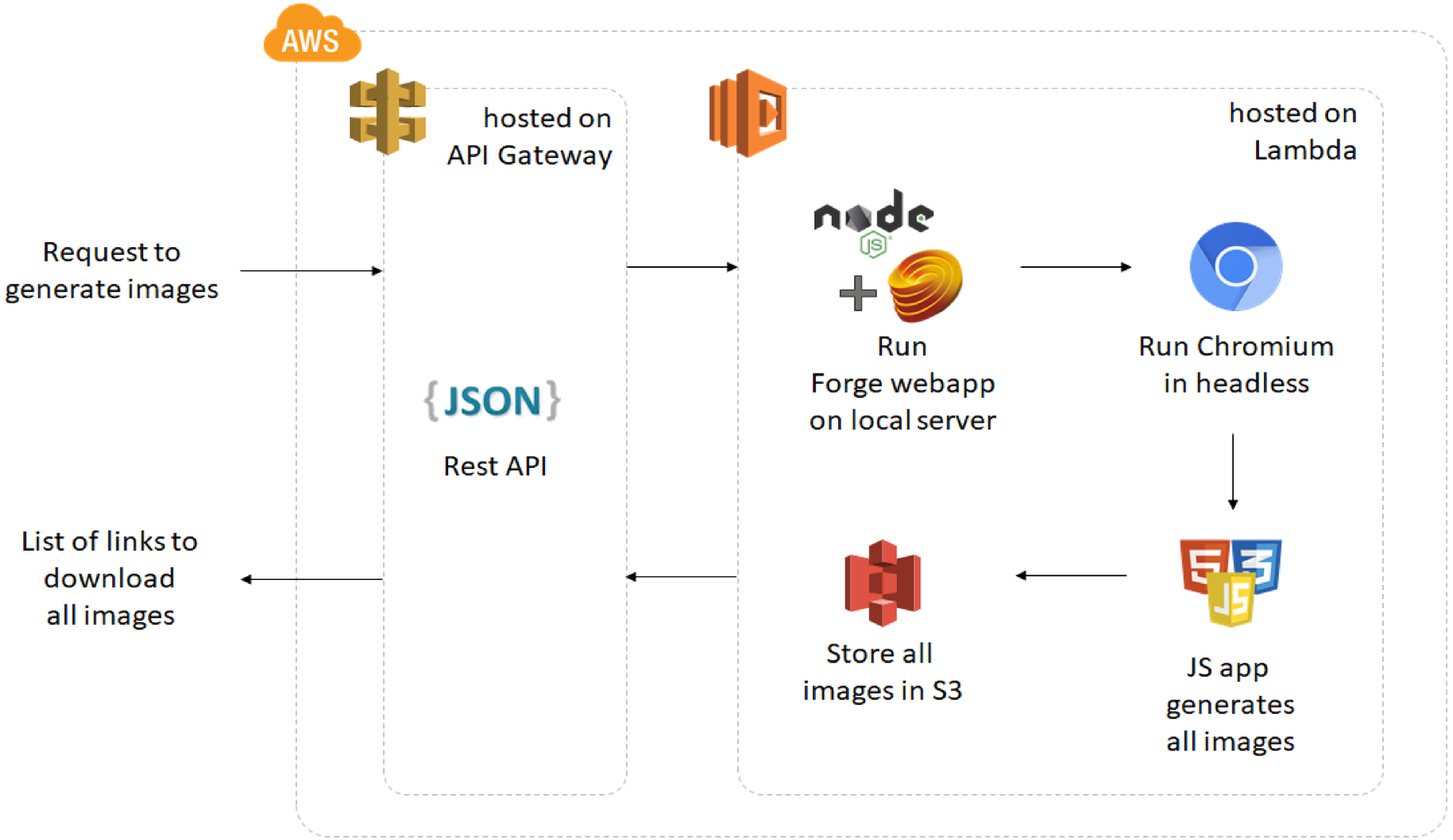
Bulk n Images Request

Link to Image 1

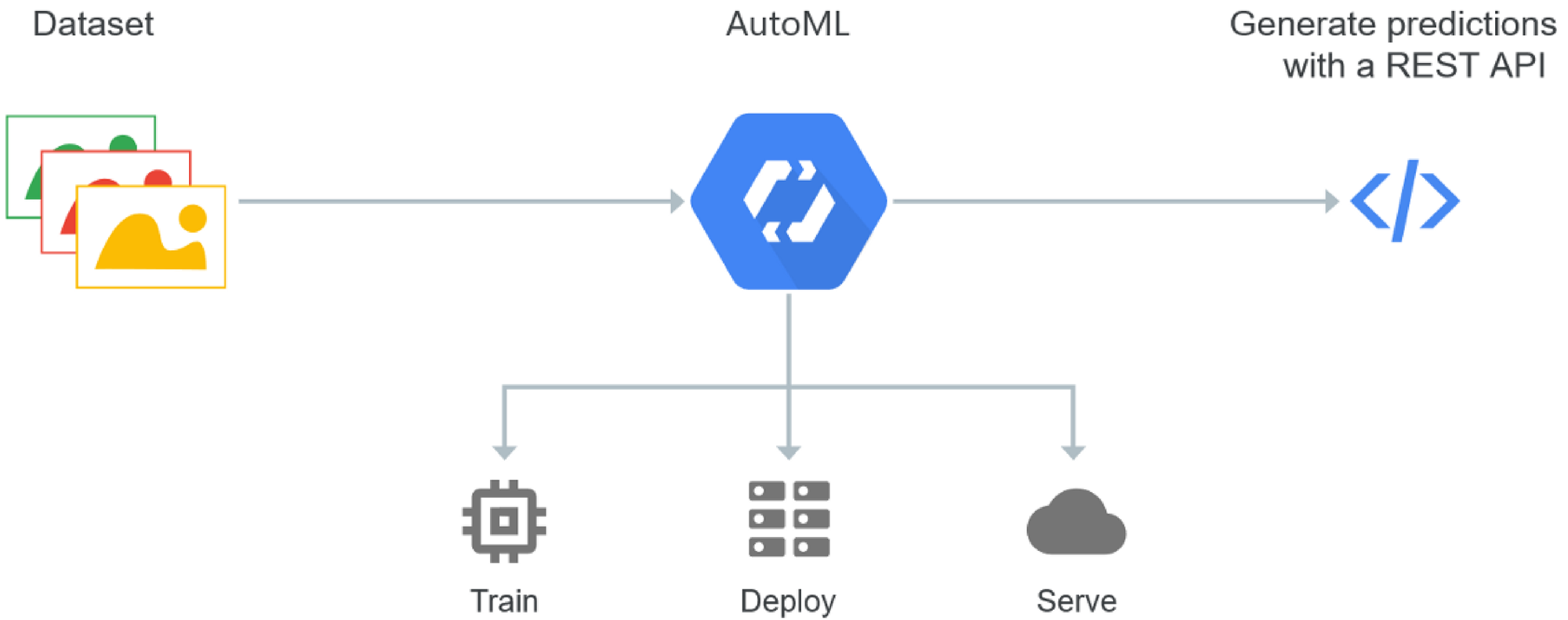
…

Link to Image *‘n’*

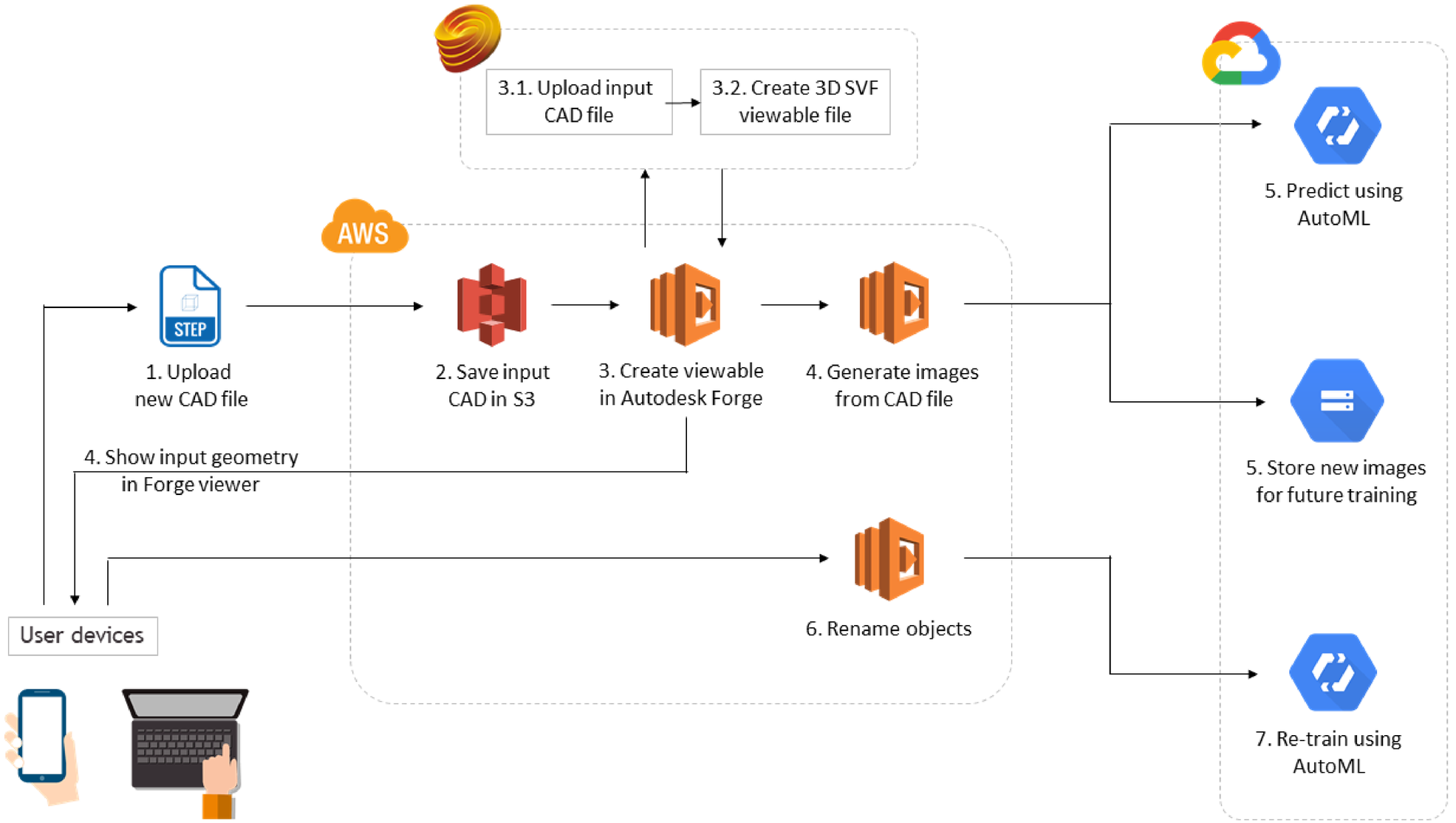
Micro Web Service to Capture High Res Images



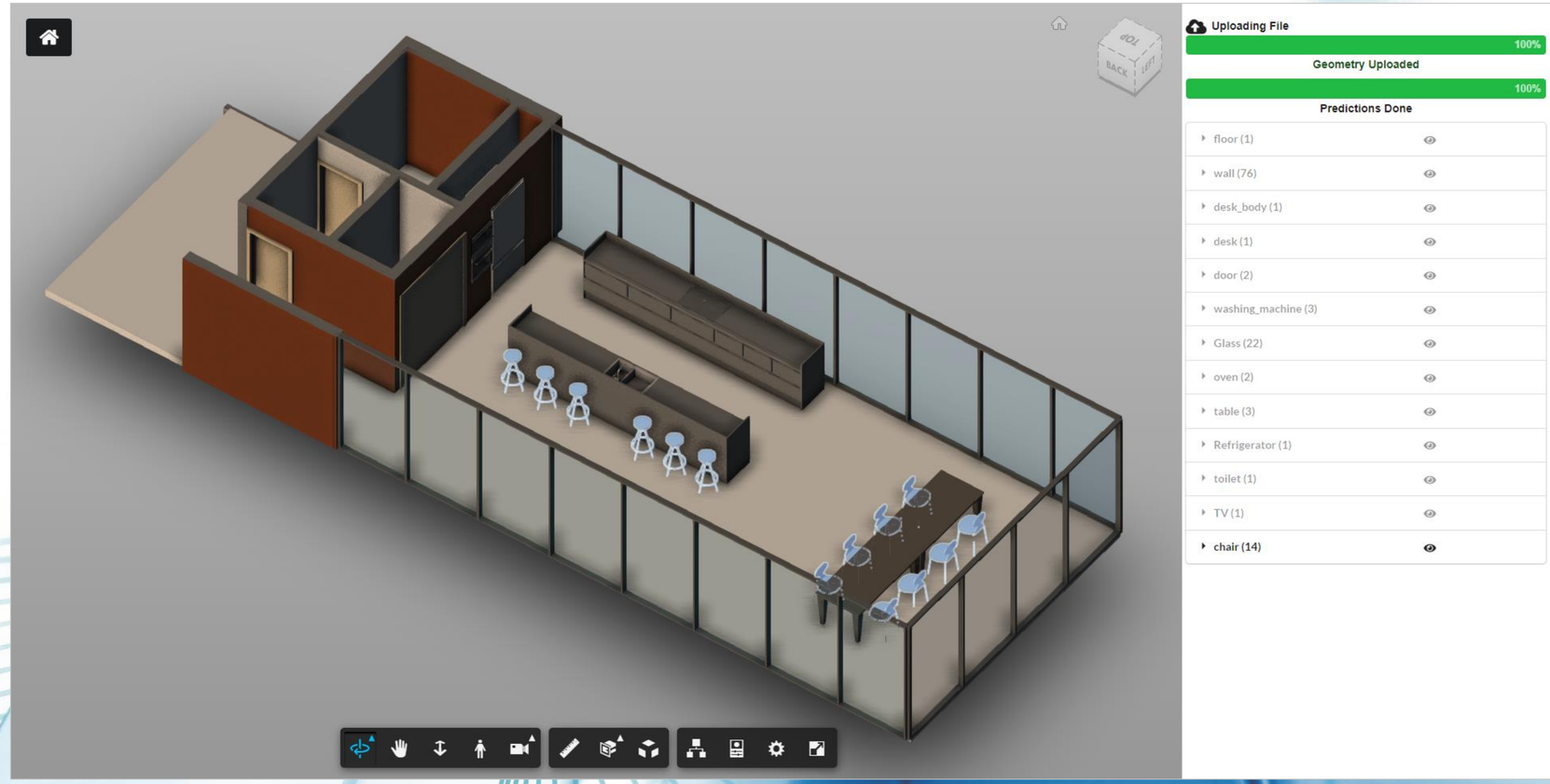
Google AutoML Cloud Service

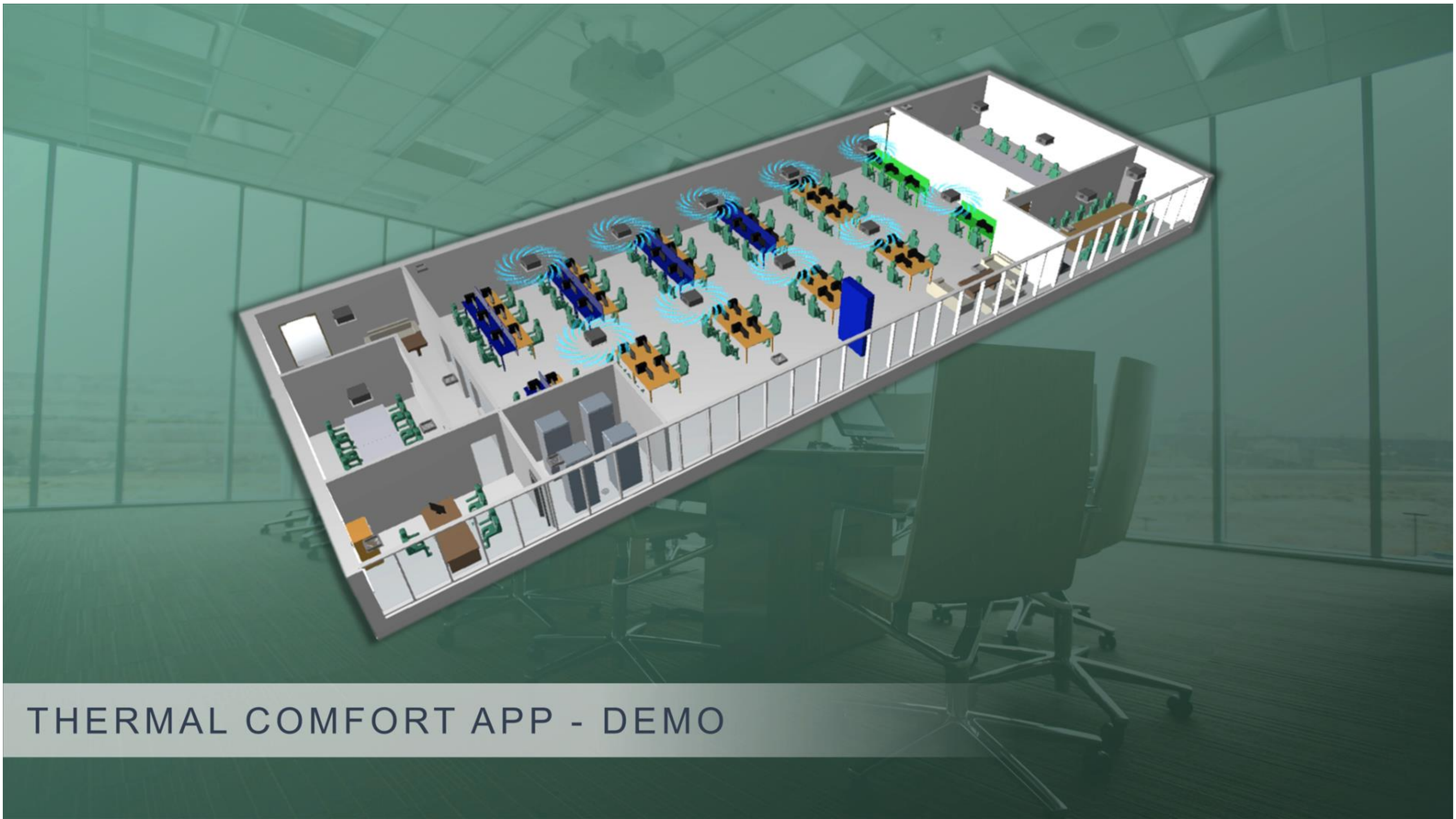


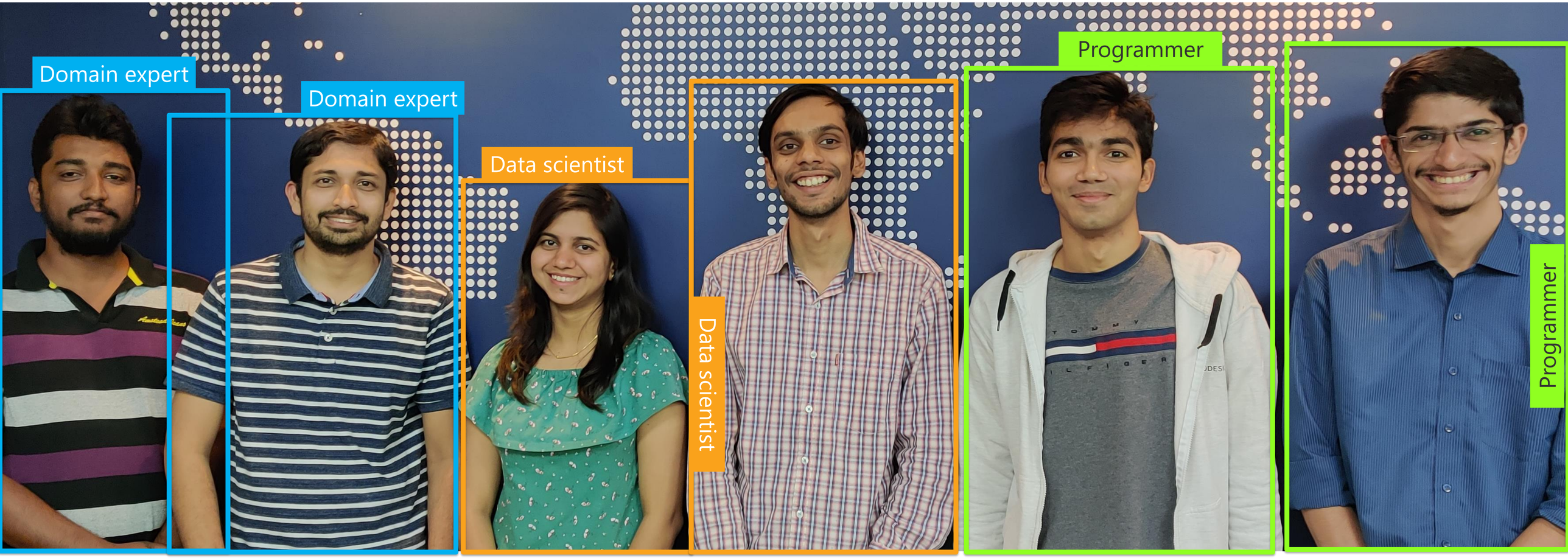
AI 3D Object Detection - Architecture



Application of technology




THERMAL COMFORT APP - DEMO



“Sometimes the little opportunities that fly at us each day can have the biggest impact”

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