# ROVISP 2016

# Density-based Denoising of Point Cloud


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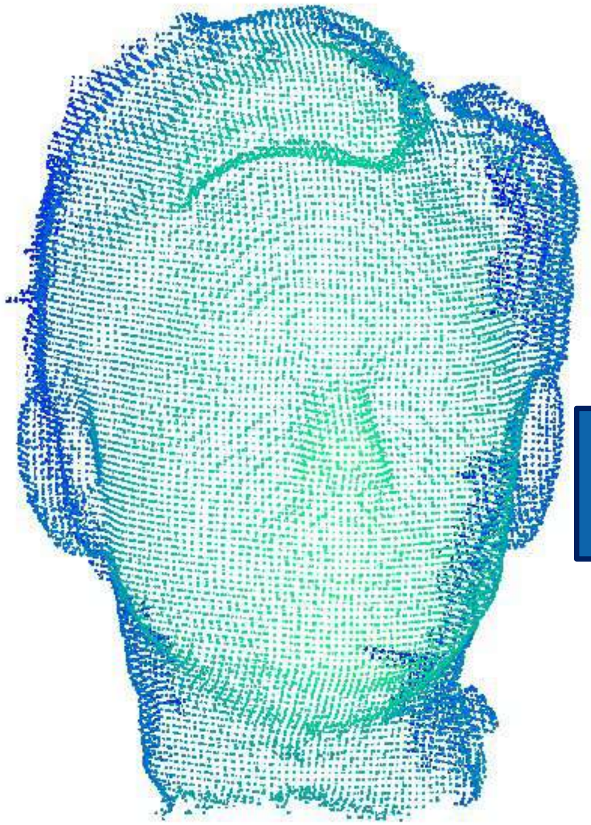
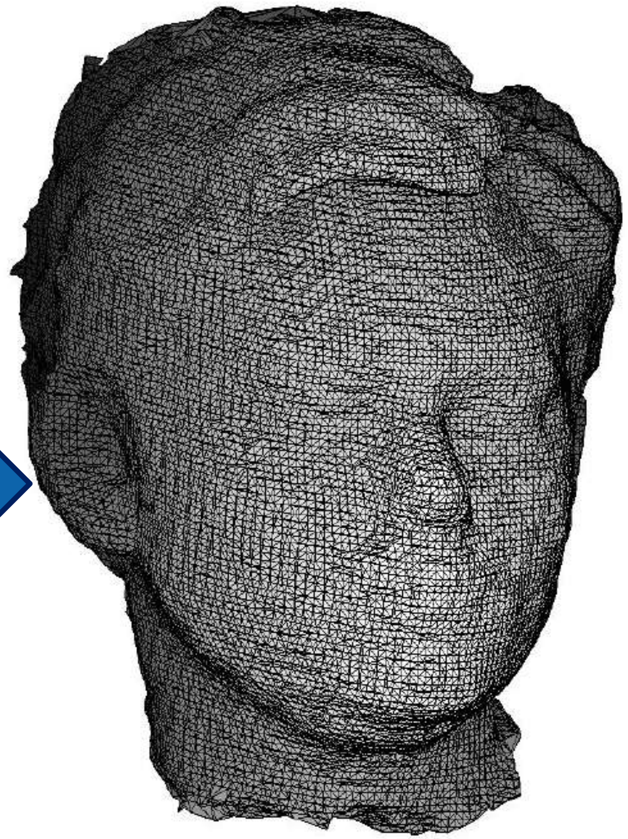
# Introduction

## What is Surface Reconstruction?

The process of producing polygonal meshes from point cloud.



SURFACE RECONSTRUCTION



**INPUT**: Point cloud from object surface

**OUTPUT**: Polygonal mesh

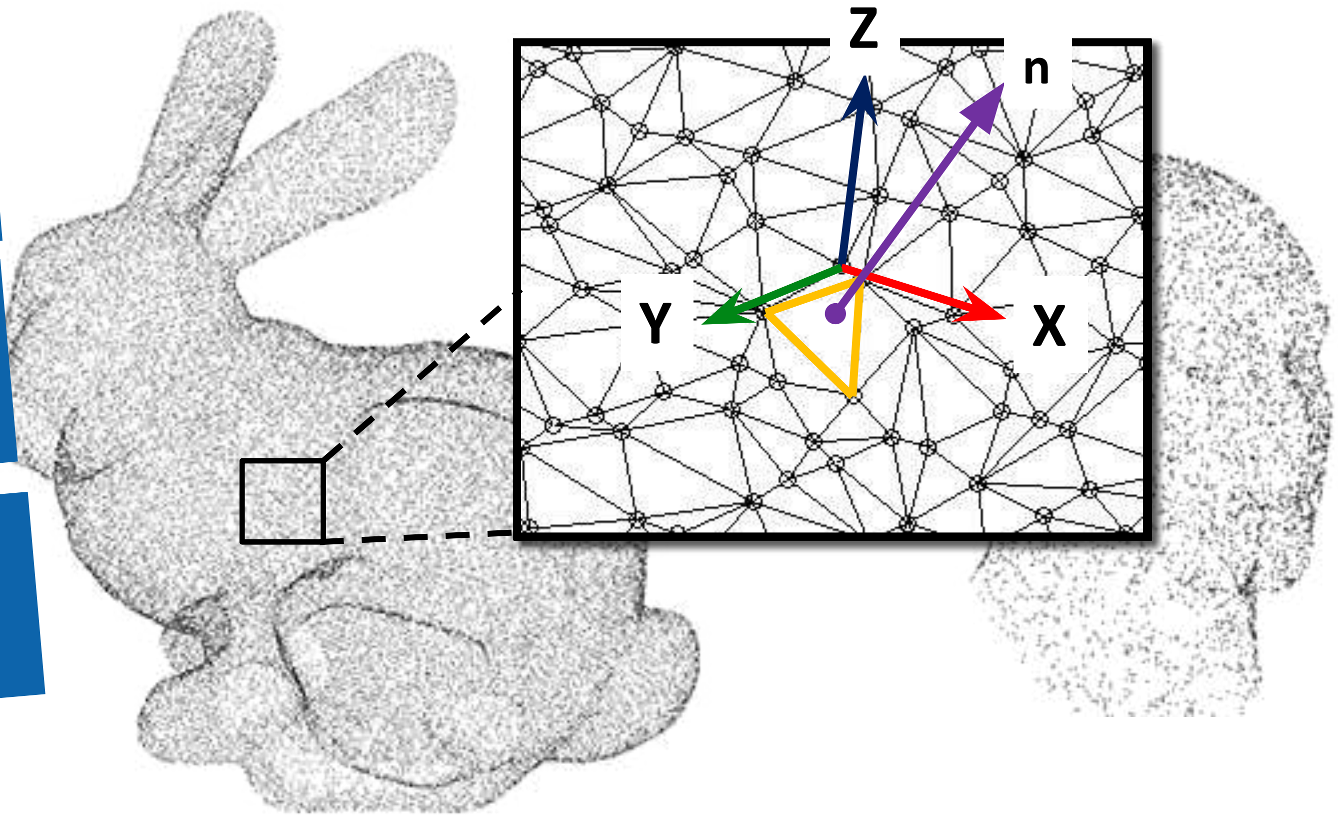
## Point Cloud

Set of points sampled from a surface.

**Location of the points**

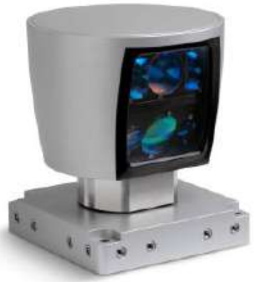
**Connectivity Information**

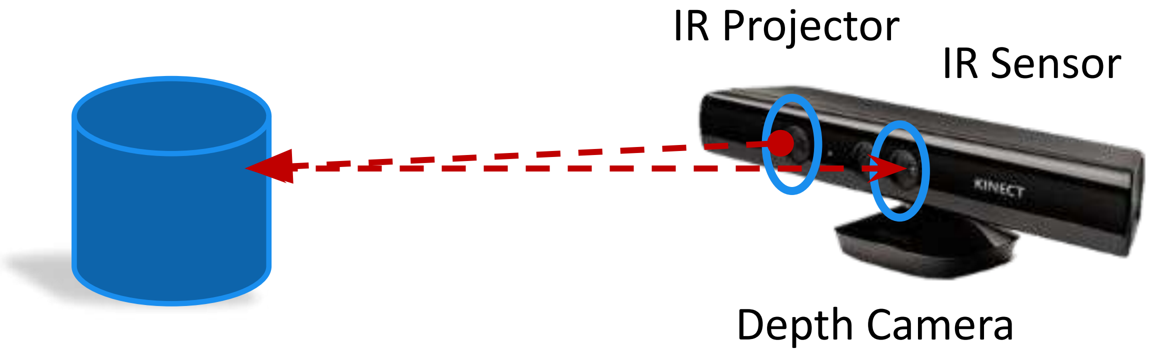
**Normal**



# Introduction

## How to get Point cloud?



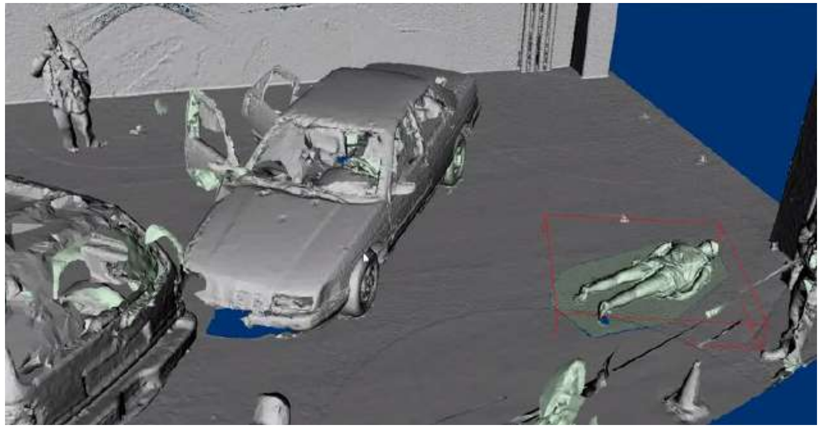



*First ever 3D-printed presidential portrait*
*by Smithsonian-led team of 3-D digital imaging specialists (Dec, 2014)*

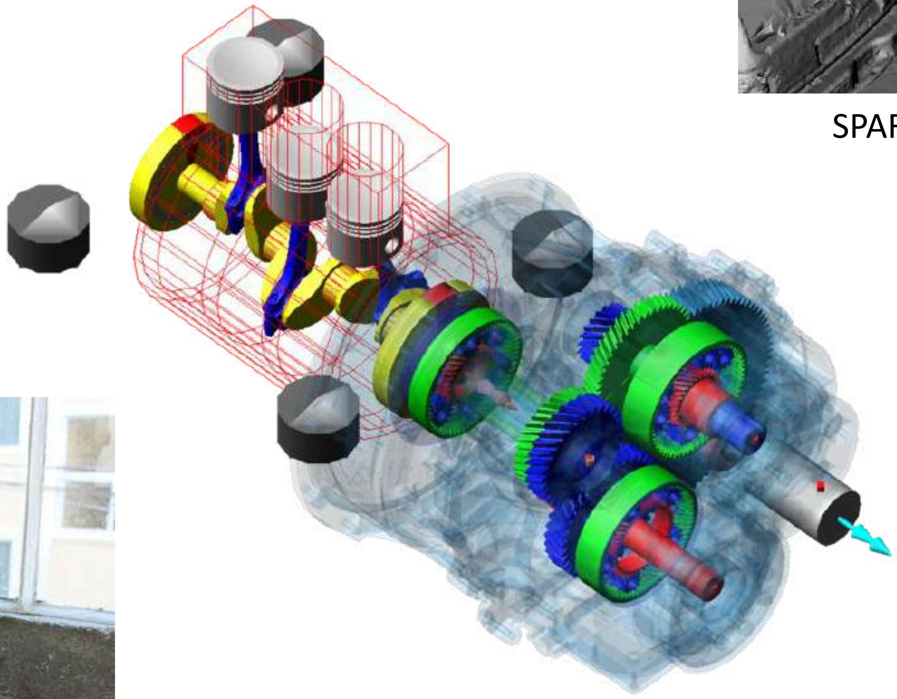
# Introduction

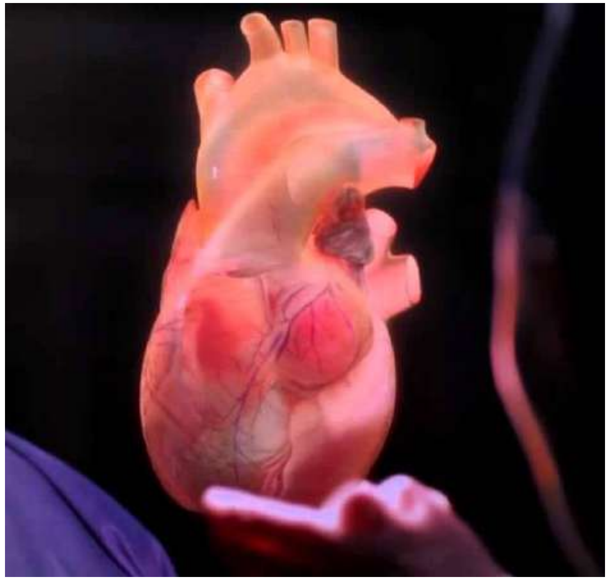
## Applications

- Crime Scene Reconstruction
- Medical Imaging
- Industrial Design
- Prototyping
- Movie Industry

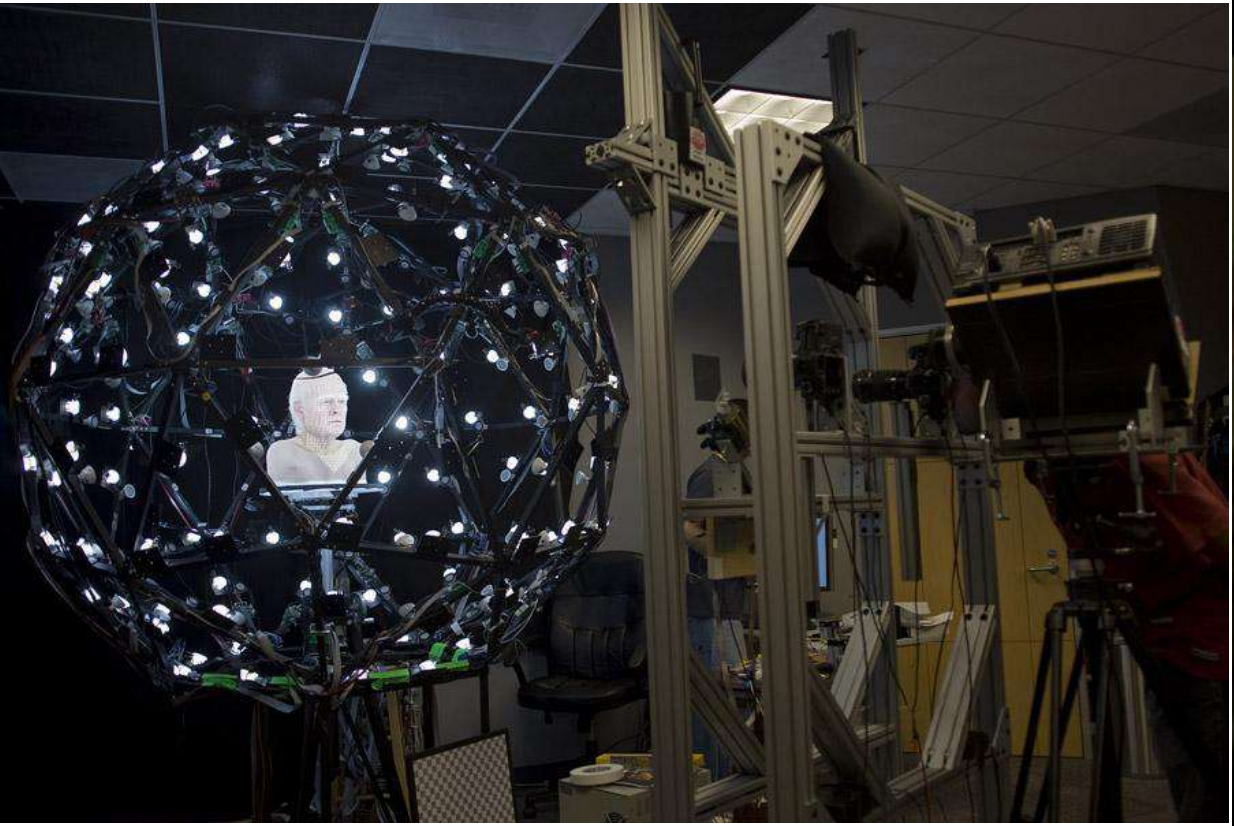


SPAR International 2014 posts Conference





RealView Imaging Ltd

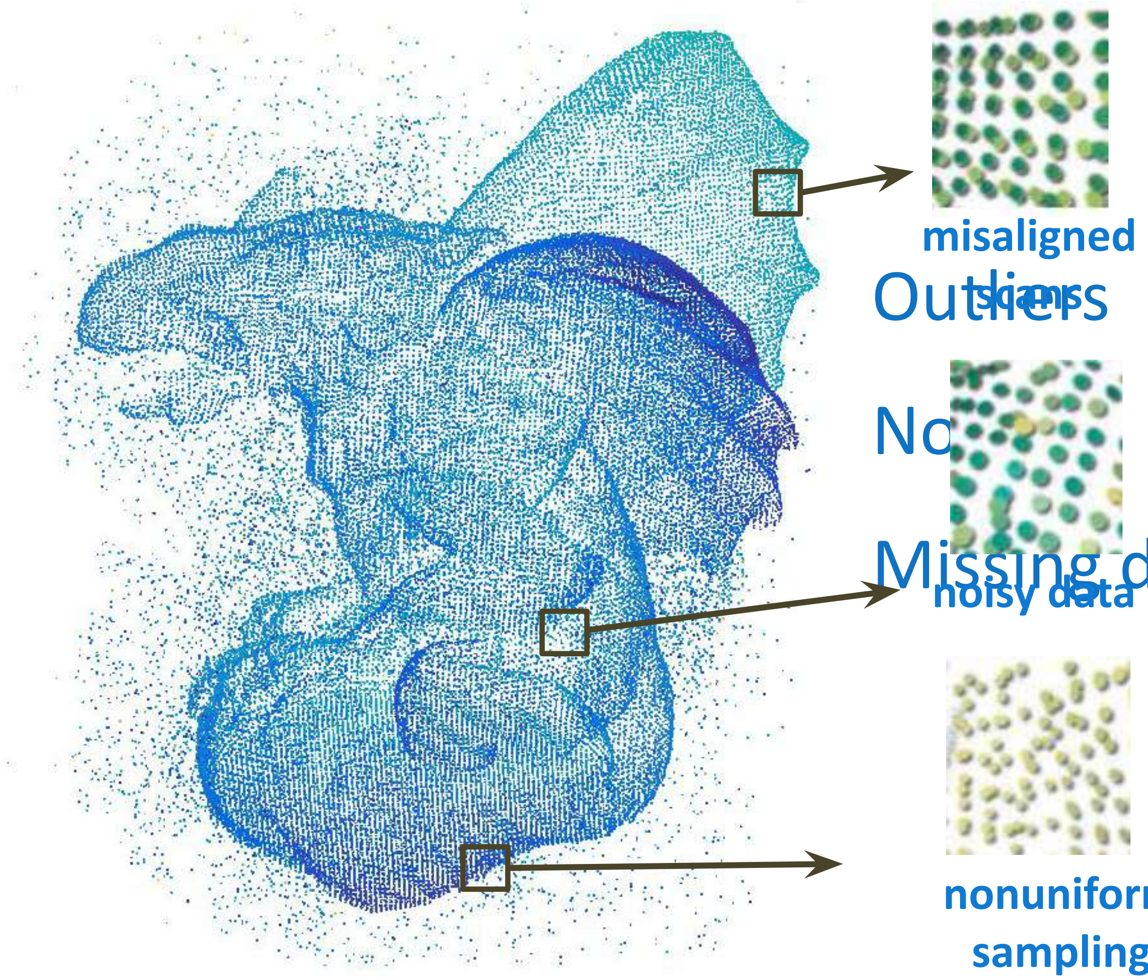


*Light Stage 5*

The Curious Case of Benjamin Button

*Technology based on: A Lighting Reproduction Approach to Live-Action Compositing*

# Challenges




Outliers

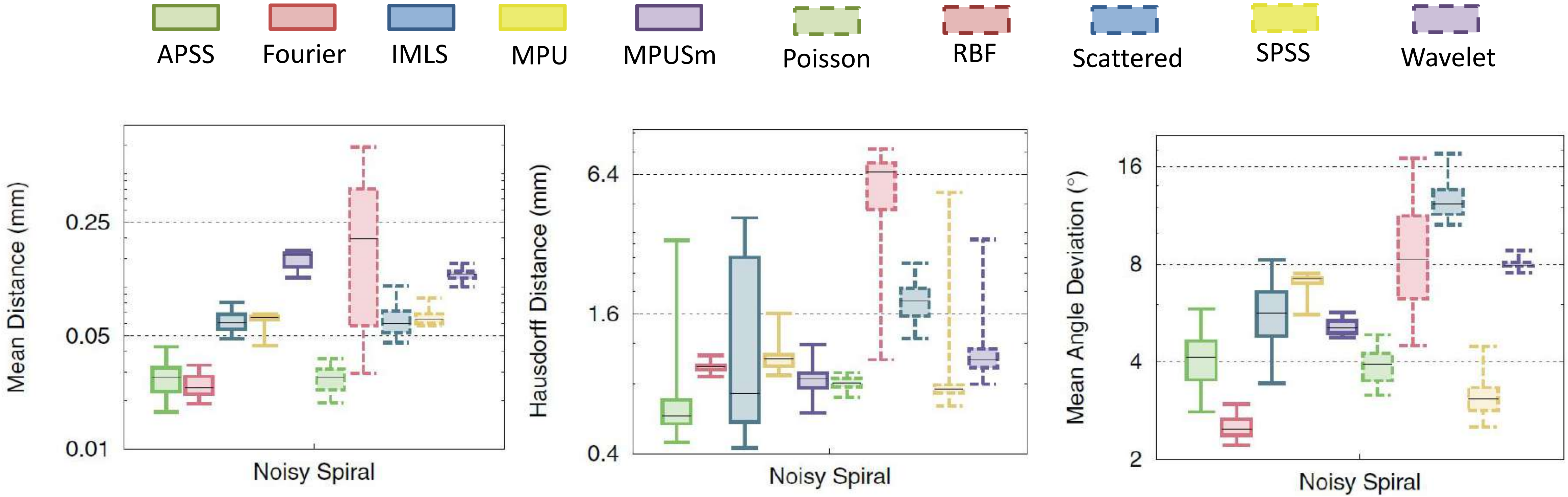
No

Missing data

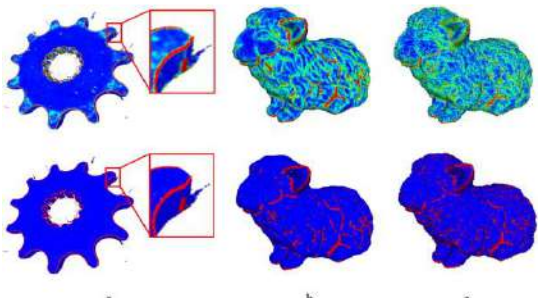
Filter out uncertain and noisy data points

# Surface Reconstruction Benchmark

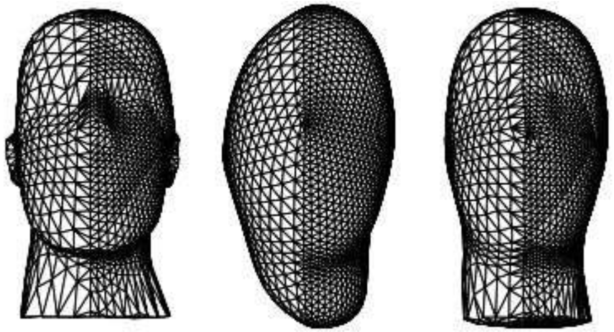
*M. Berger 2013*, created a benchmark for comparing several state-of-the-art surface reconstruction techniques



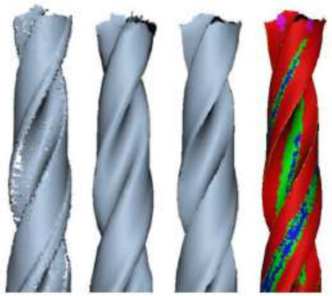

# Previous Work



Majority Voting System
*Y. Wang et al. (2015)*



Mean Curvature Flow
*Desbrun et al. (2000)*



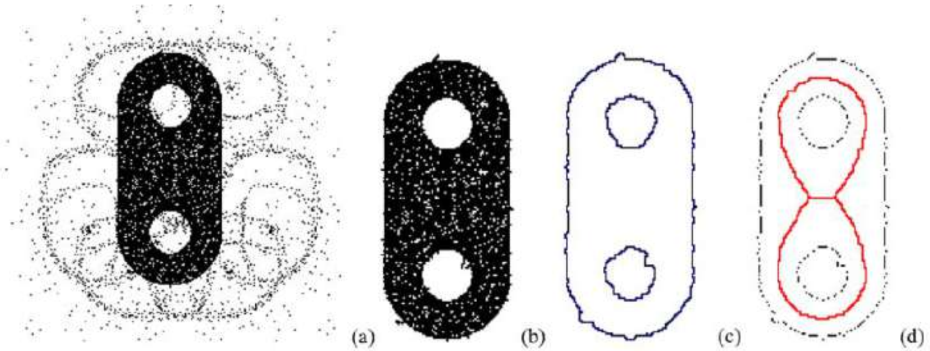
Moving Least Square
*Fleishman et al. (2005)*

high computation cost
Infeasible for large datasets

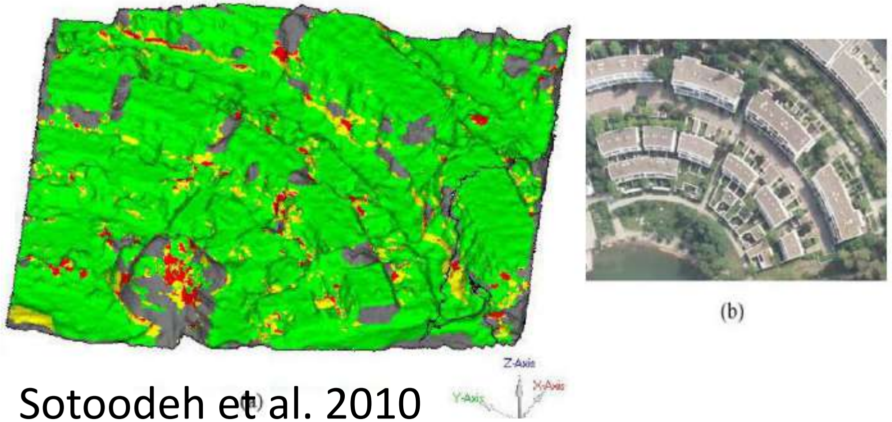
sensitive against large number of outliers
and over smooth the data points

# Previous Work

## Data Clustering




Y Song et al. 2010

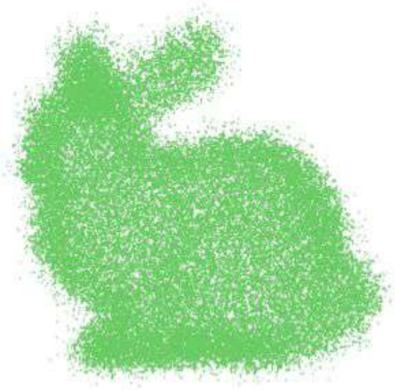



Sotoodeh et al. 2010

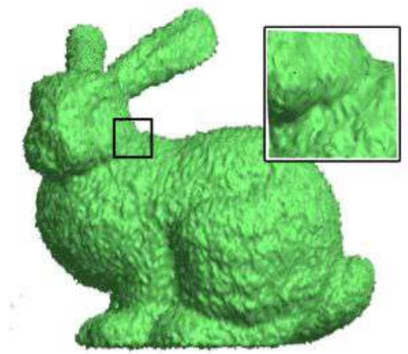
require prior knowledge about the input objects

# The Density-based Method

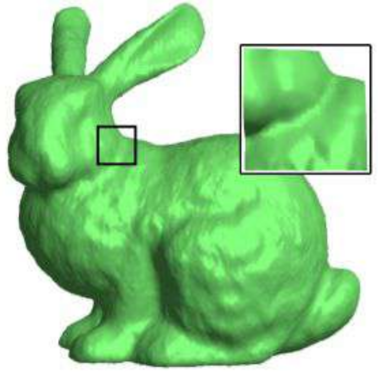
- We propose a method to find the optimal bandwidth of Kernel Density Estimation using PSO.



- Mean-shift based clustering technique is used to remove outliers through a thresholding scheme.



- Bilateral mesh filtering is applied to smooth the remaining points.



# Kernel Density Estimation

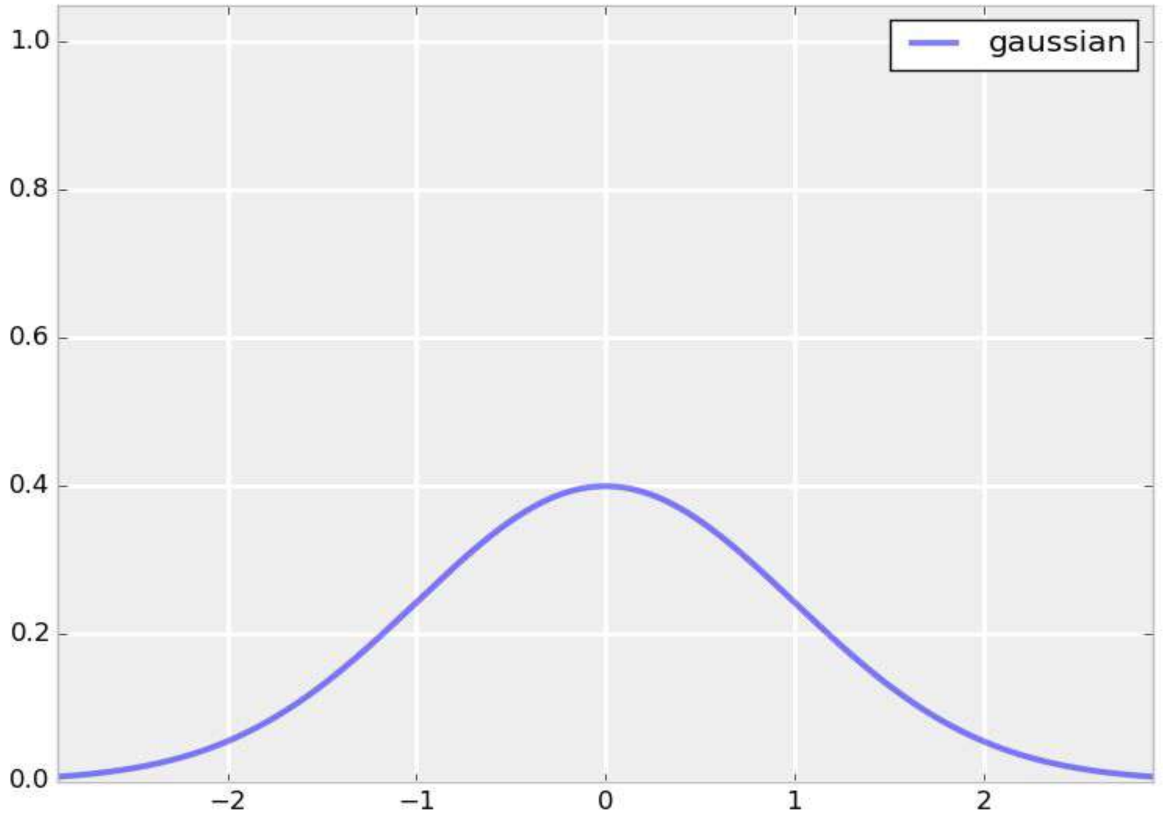
$$\boldsymbol{X} = (x_1, x_2, \ldots\ldots, x_N)^{\boldsymbol{T}}$$

$$\hat{f}_H(x) = n^{-1} \sum_{i=1}^{N} K_H(x - X_i)$$

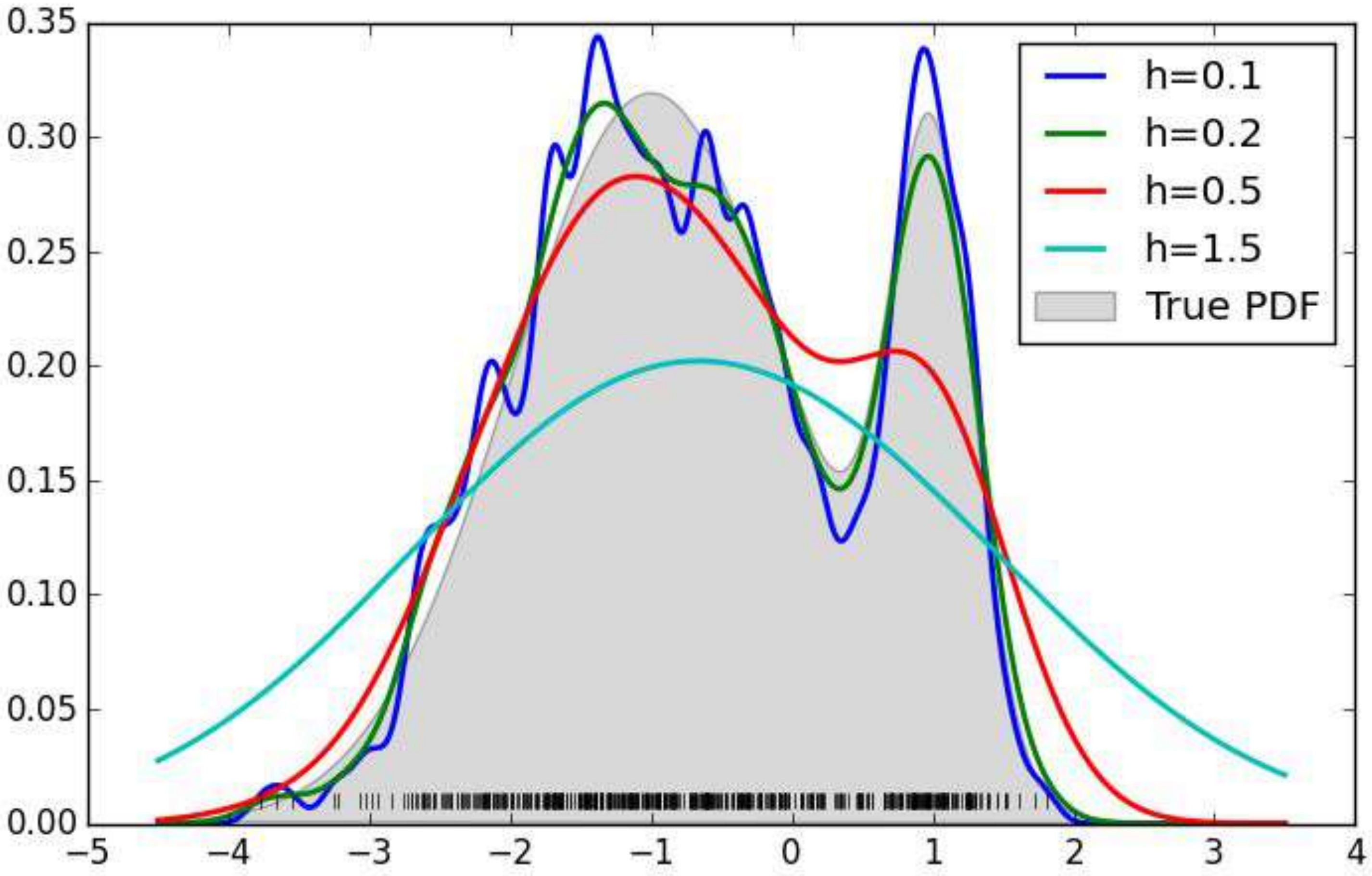
kernel function

$$\hat{f}(x) = n^{-1} \sum_{i=1}^{N} h^{-1} K\left(\frac{x - X_i}{h}\right)$$

Smoothing parameter

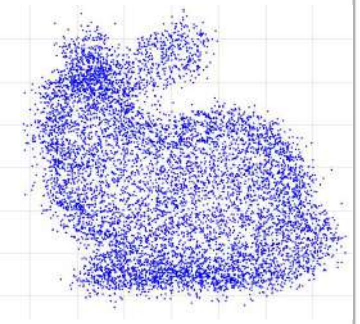


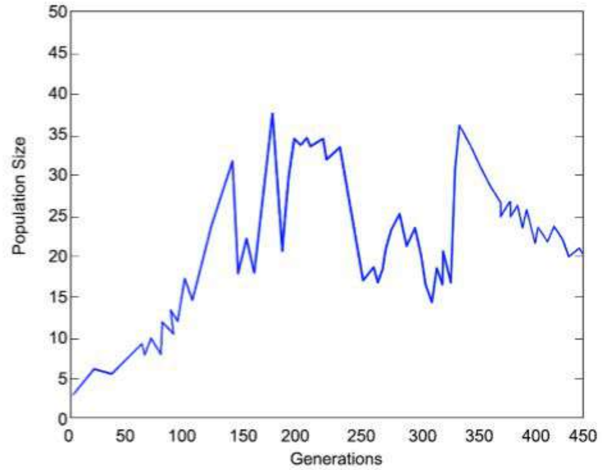
# Influence of Bandwidth (h)



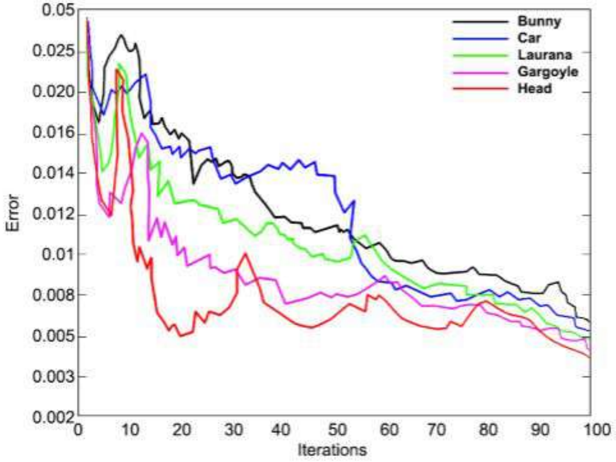
# Proposed Pipeline

**Proposed optimal bandwidth selection criterion using PSO**

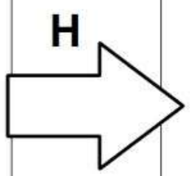


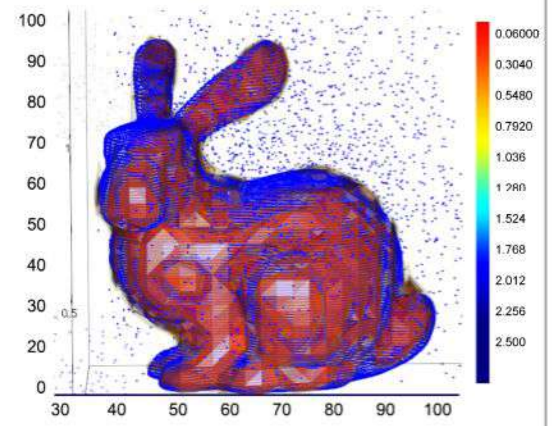



**Adjusting particle size using population manager**




**Bandwidth estimation performance for different models**




**Results of kernel density estimation using optimal bandwidth**

# Optimal $H$

## Error Criteria:

– Minimize the error between

$\hat{f}_H(x)$ (estimated density) and $f(x)$ (true density)

$$MISE(h) = E\left\{\int [\hat{f}(x) - f(x)]^2 dx\right\}$$

Mean Integrated Square Error

$$ISE(h) = \int [\hat{f}(x) - f(x)]^2 dx$$

Integrated Square Error

# Cross-Validation Methods

- Leave-One-Out Cross-Validation (LOOCV)
  – LOOCV to estimate the risk function $R(\hat{f}(x), f(x))$

$$L(H) = \frac{1}{n}\sum_{i=1}^{n} \log \hat{f}_{H,i}(x_i)$$

The optimal smoothing parameter:

$$H^* = \arg\max \frac{1}{n} L(H)$$

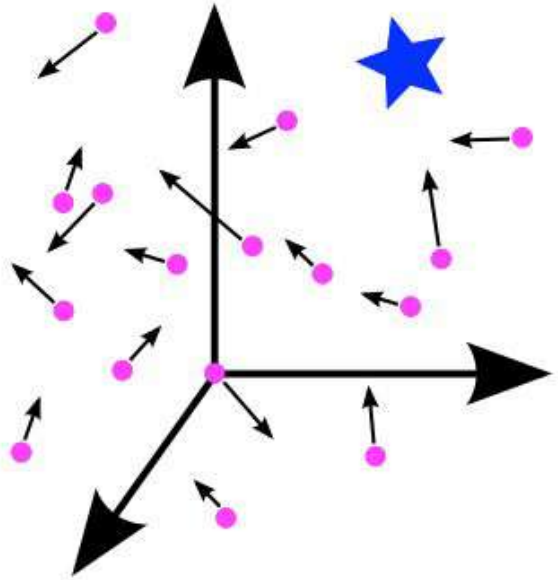
More details in paper!

# PSO for Optimal Bandwidth Selection

$$v_{id} = \omega v_{id} + C_c U[0,1](x_{id} - p_{id}) + C_s U[0,1](x_{id} - p_{gd})$$

$$x_{id} = x_{id} + v_{id}$$

$$x_{id} = \min(\max(B_{ld}, x_{id}), B_{ud})$$





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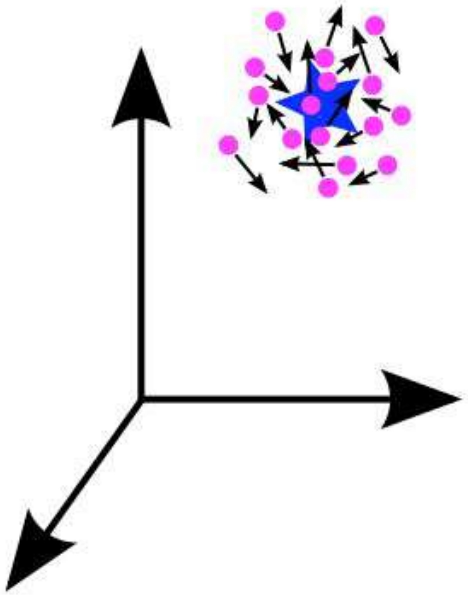
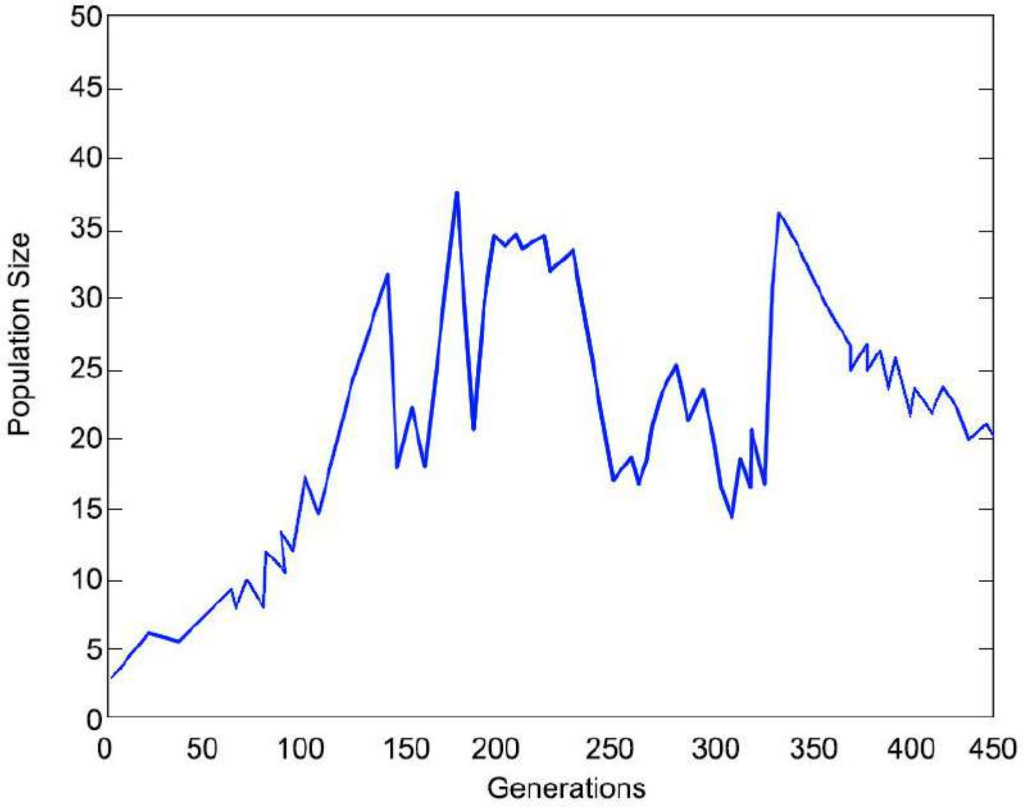
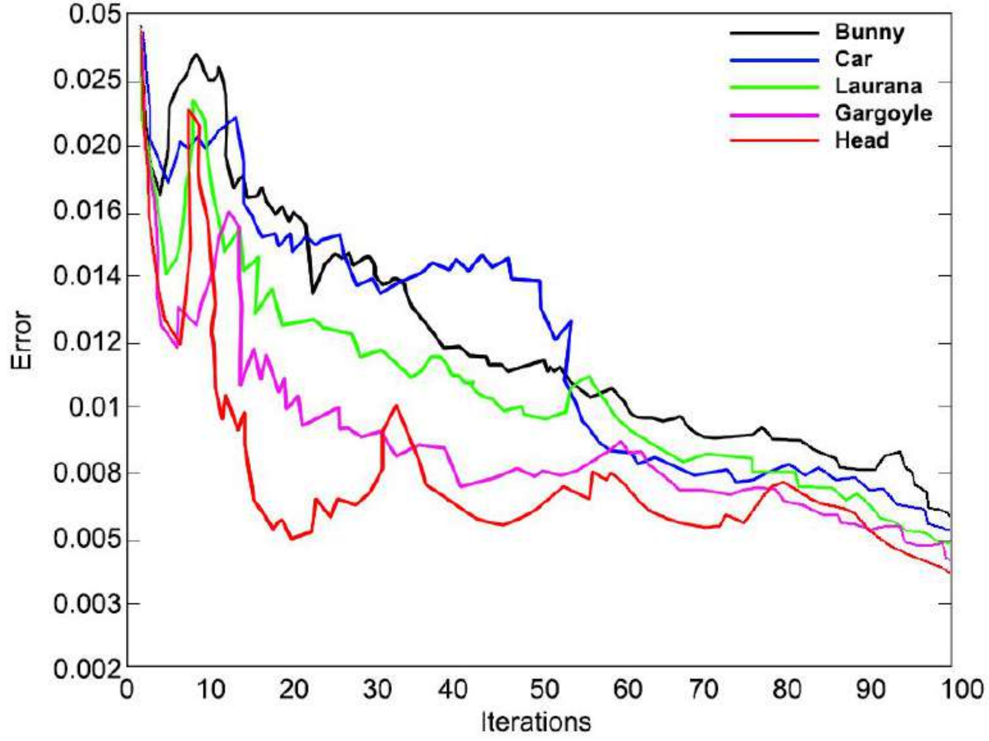


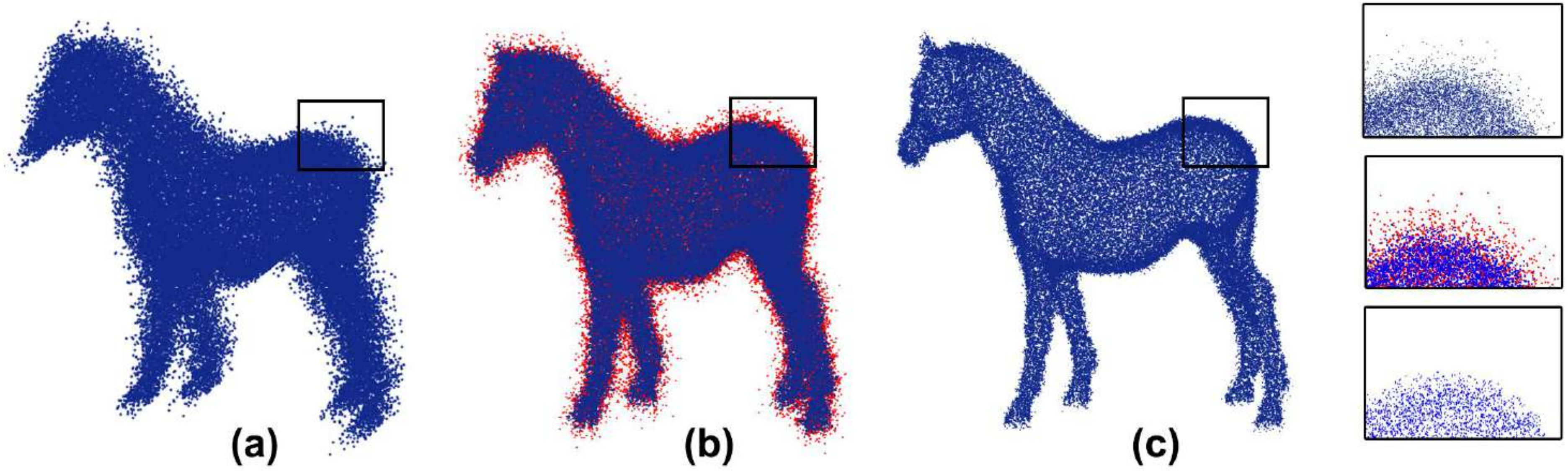
# Particle Selection

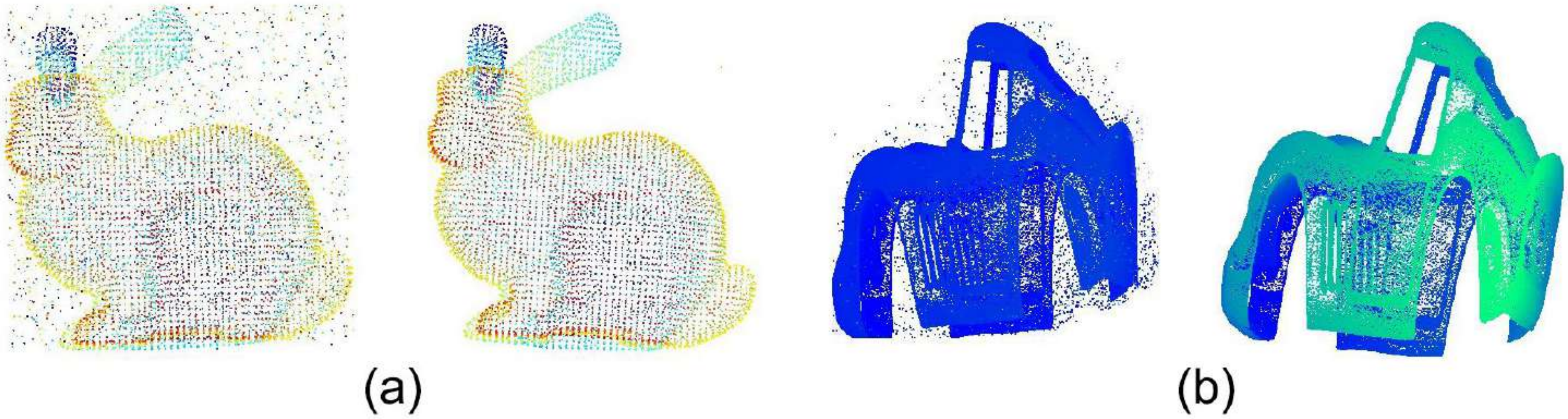
- Efficient Population Utilization Strategy for PSO (EPUS-PSO)
  - adopting population manager to significantly improve the efficiency of PSO *[ST Hsieh 2009]*



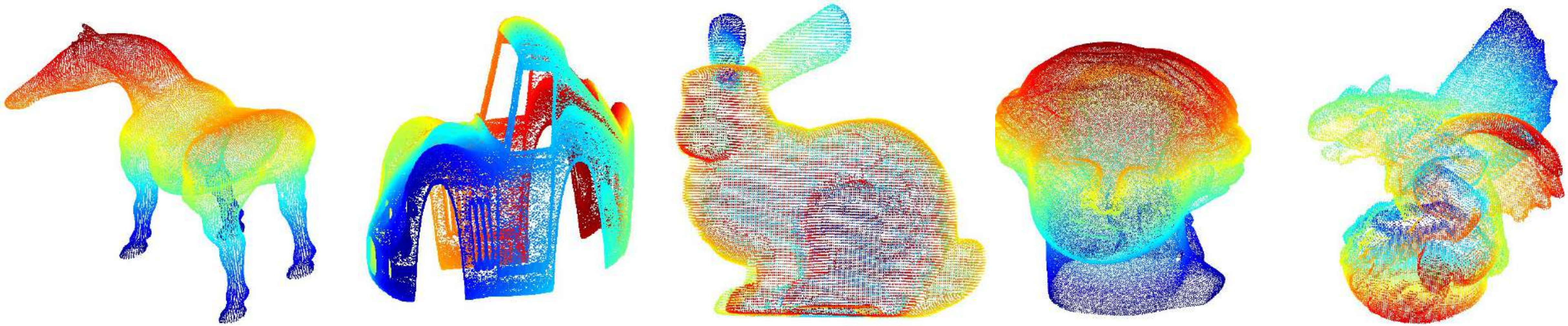
# Results



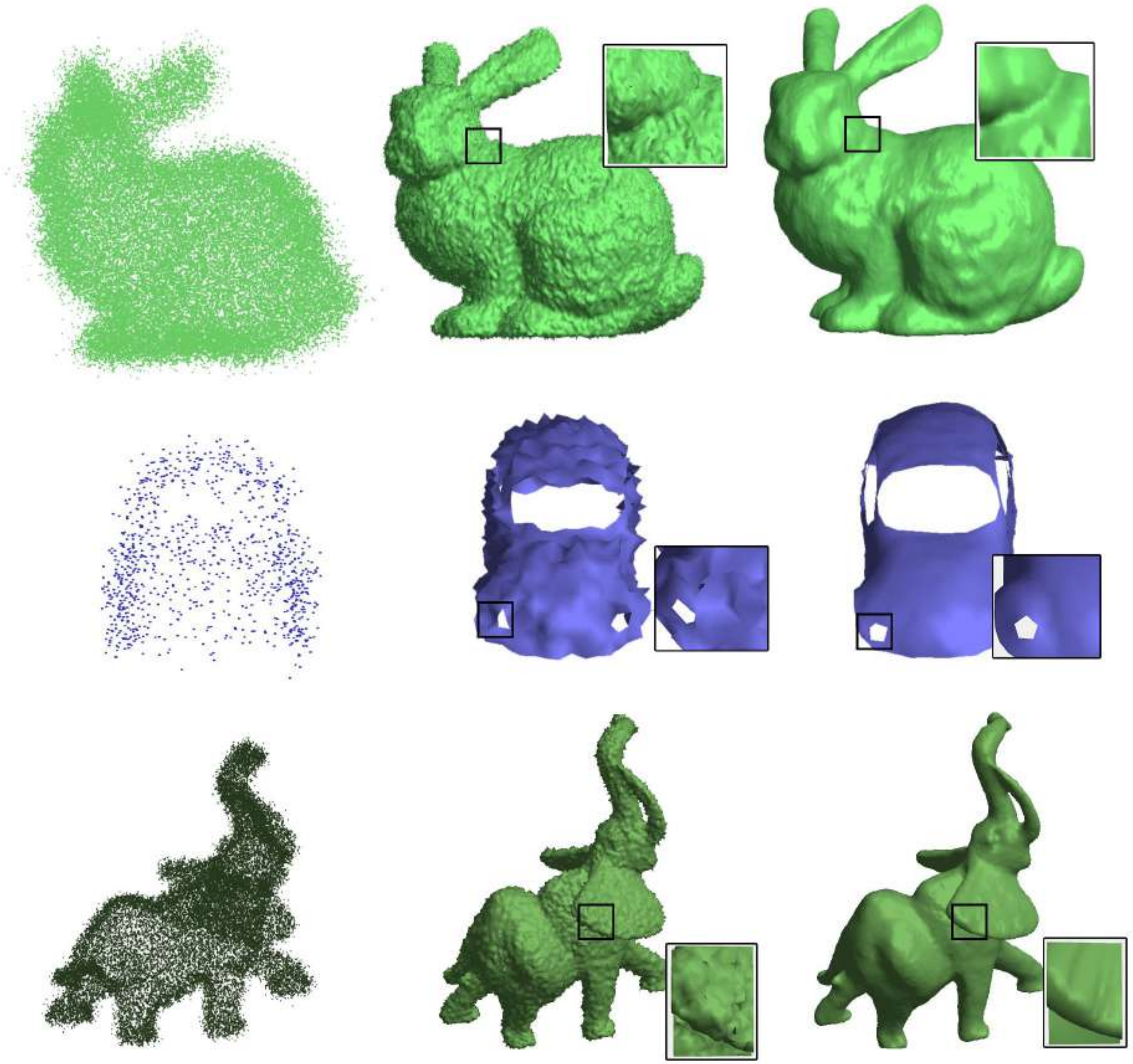



# Performance

| Data | | | | |
|---:|---|---|---|---|
| Bunny | 330 K | 324 K | 29 s | 30 s |
| Car | 720 K | 600 K | 1 m 45 s | 1 m 25 s |
| Horse | 364 K | 214 K | 44.43 s | 18 m 45 s |
| Gargoyle | 2.1 M | 796 K | 3 m 2 s | 4 m 44 s |
| Head | 1.9 M | 1.2 M | 2 m 5 s | 3 m 25 s |



# Bilateral Mesh Denoising



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# Thanks!

Any Questions

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