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State of the Art in Surface Reconstruction from Point Clouds

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Introduction

Longstanding Goal in Computer Graphics

Model The World Around Us

Need to first acquire the world

Acquisition

Desktop Scanners

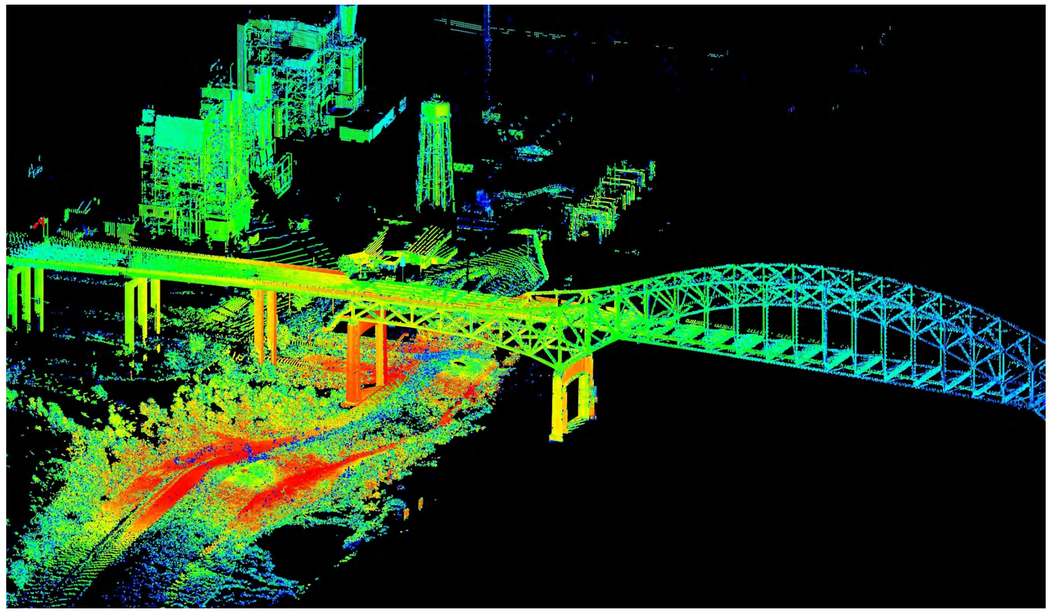
- Single object
- Fine-grained control
- Controlled setting

[Lanman & Taubin 09]

Acquisition

Terrestrial LiDAR

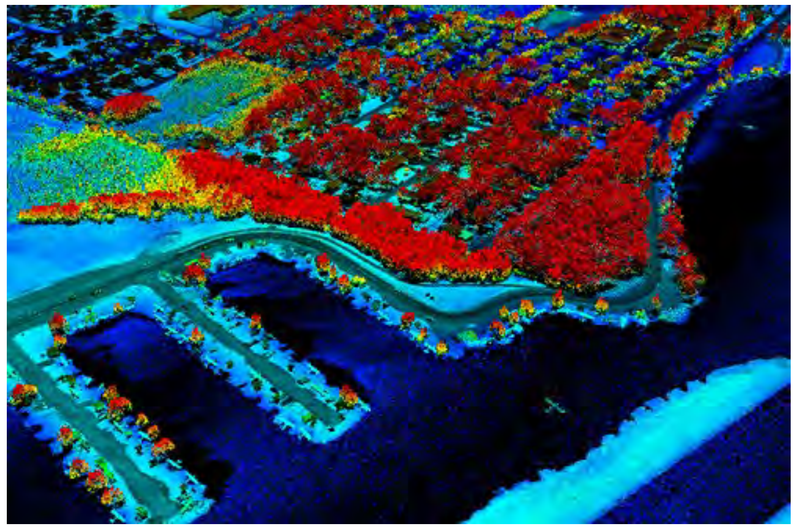
- Large scenes
- Low control
- Occlusion

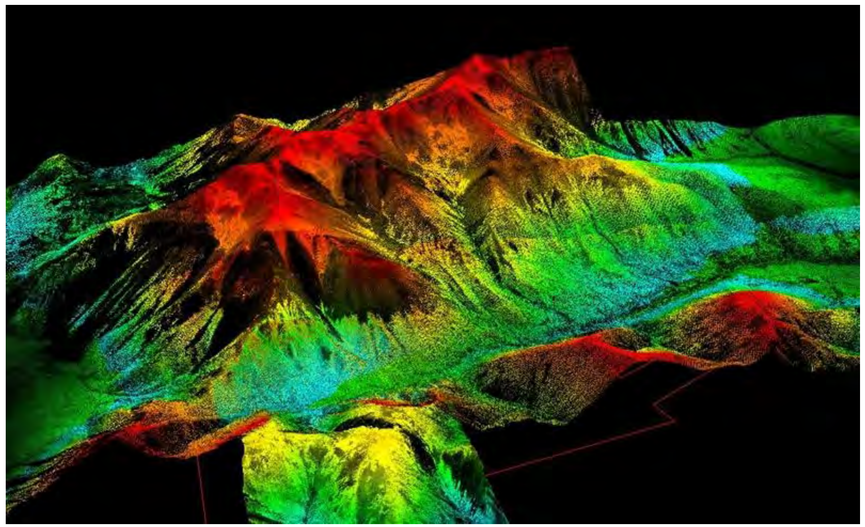


Acquisition

Aerial LiDAR

- Large environments
- Top-down perspective
- Lower resolution

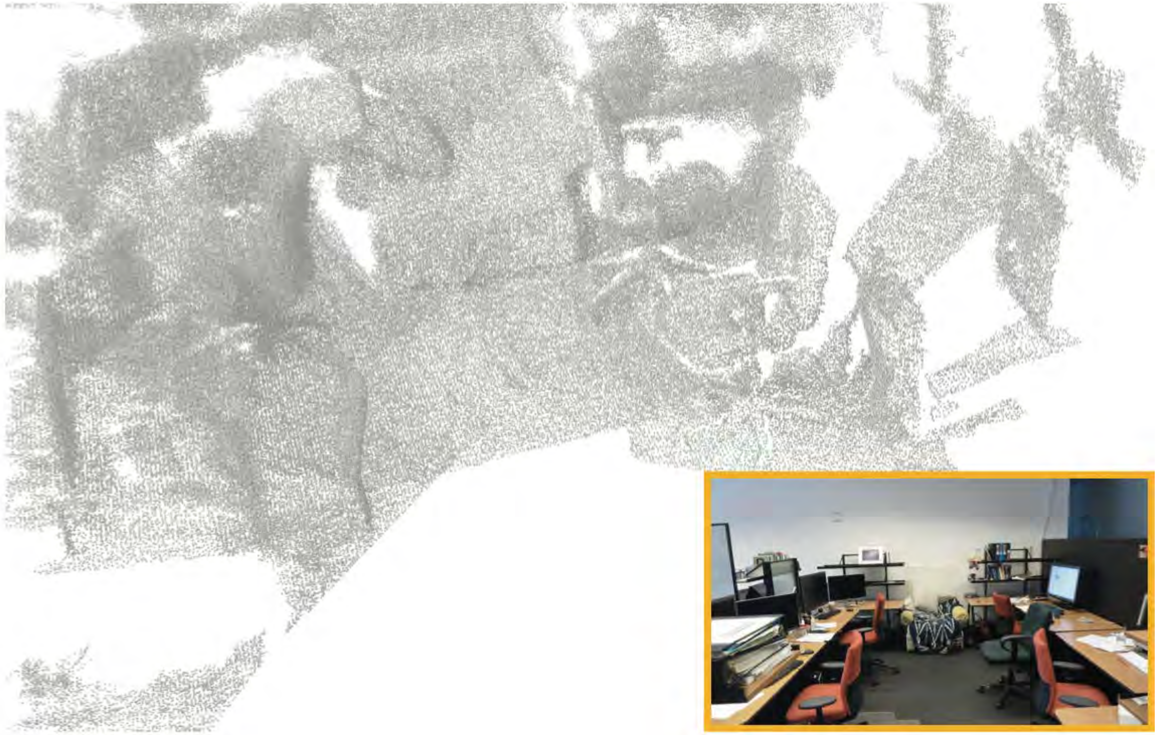




Acquisition

Compact Real-time Scanning

- Fine-grained detail
- Small scenes
- Easy and cheap to use



[Kim et al. SIGA'12]

General Pipeline

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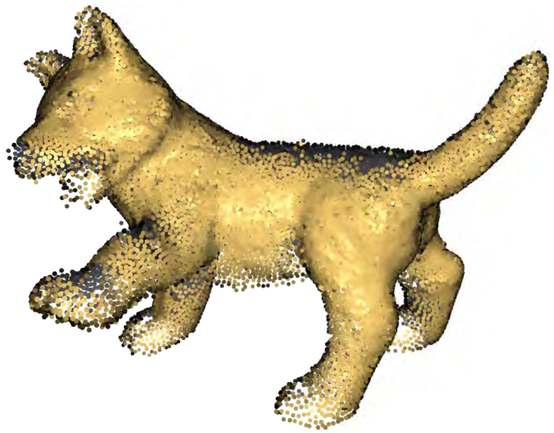

General Pipeline

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Surface Reconstruction from Point Clouds!

General Pipeline

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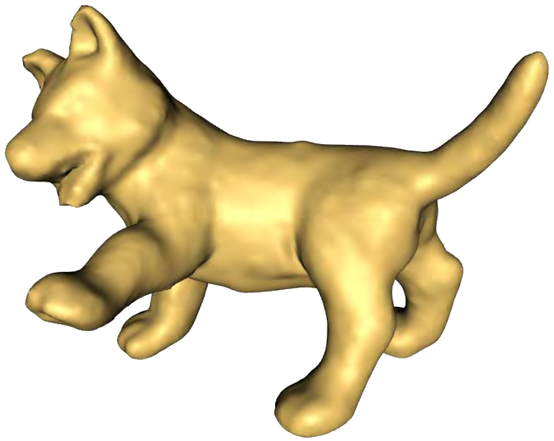

Surface Reconstruction from Point Clouds!

Why Reconstruction?

- Captured point cloud unsuitable for many geometry processing tasks
- Noisy, incomplete
- Topology not well-defined
- Does not define continuous representation

Why Reconstruction?

Raw Point Cloud Not Enough!

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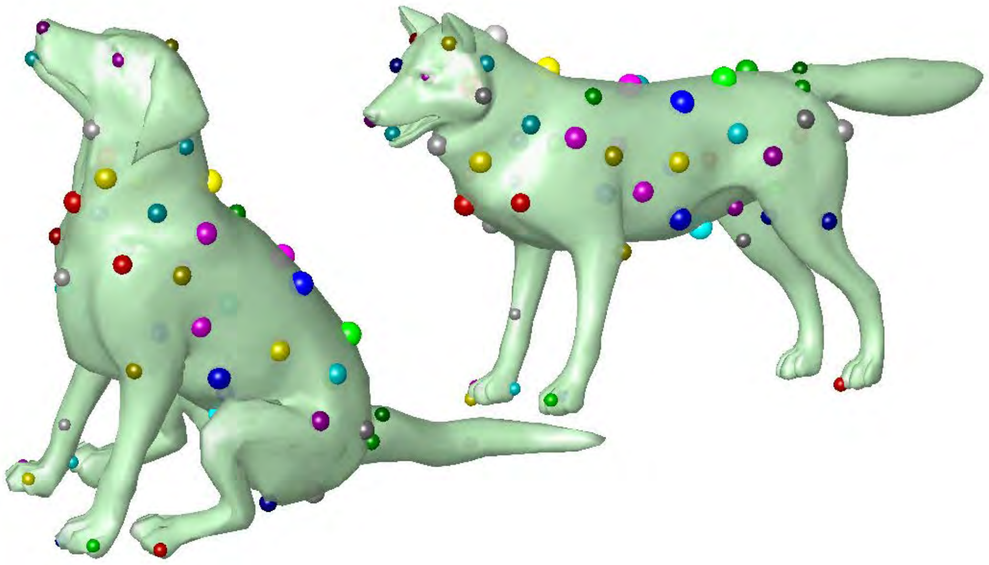

[Lipman & Funkhouser SIG'09]

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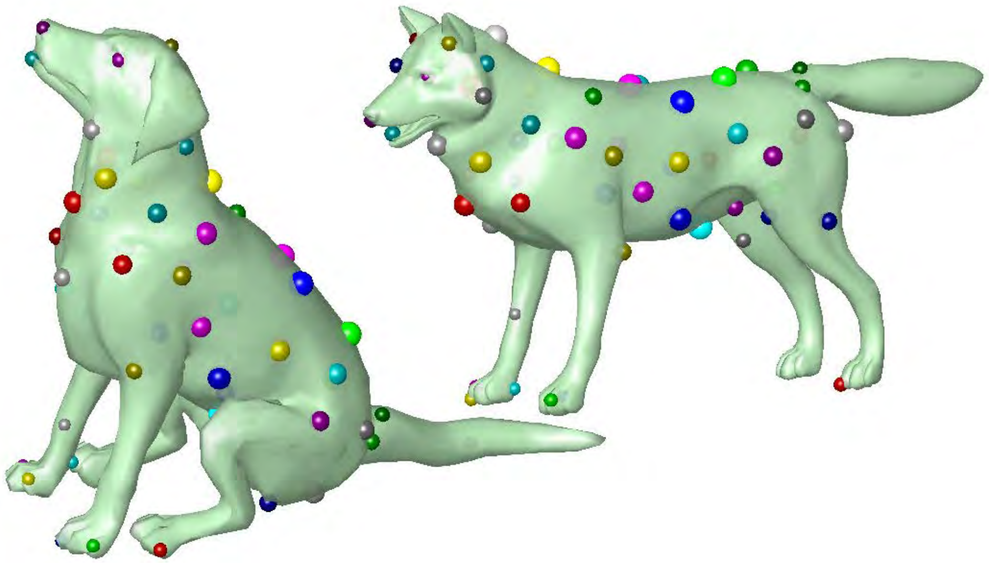

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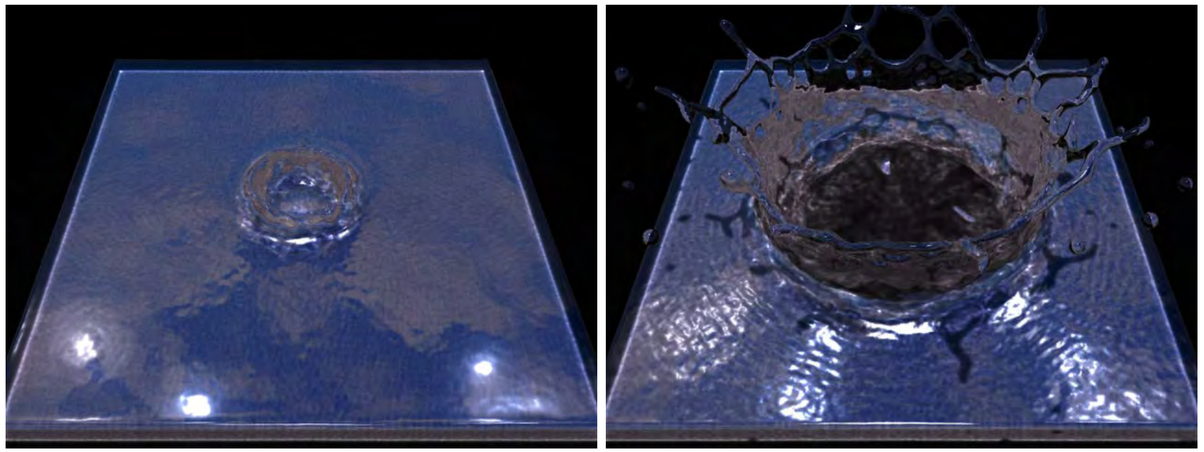

[Yu et al. EG'12]

Traditional Reconstruction

- Take point cloud as input
- Output: continuous representation
- Assumption: output should be smooth

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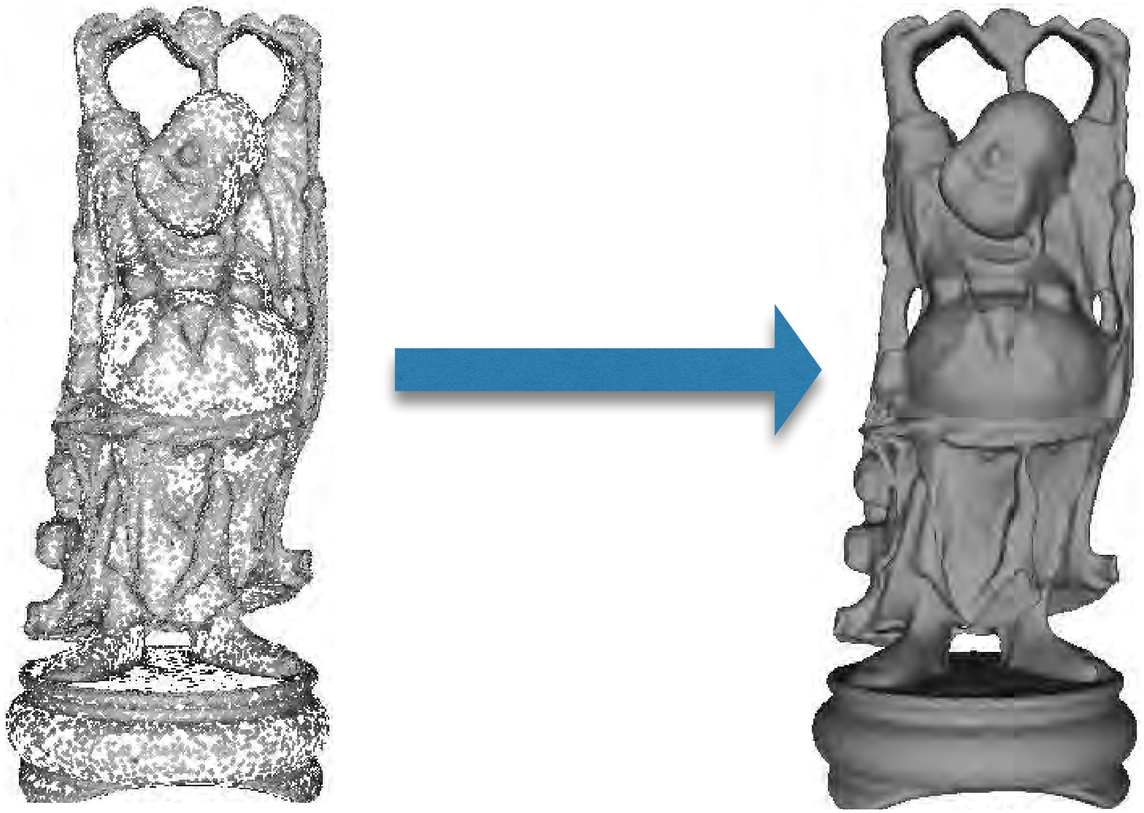


[Kazhdan SGP'05]

Departure from Traditional

How do we handle substantial artifacts in the point cloud?

Priors!

- Priors on the scanned shape
- Priors on the acquisition
- Priors on the interaction

Priors

Volume Smoothness

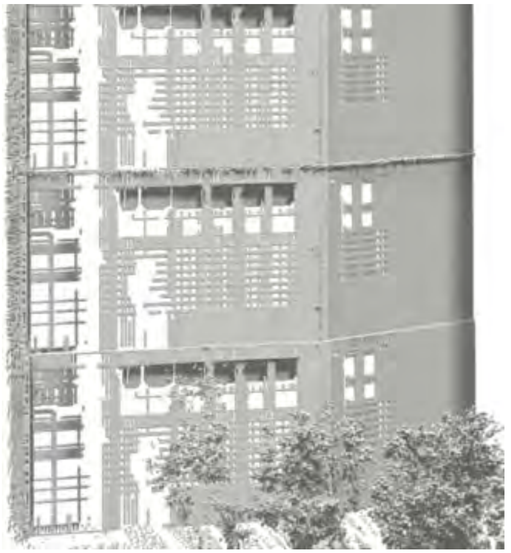


[Tagliasacchi et al. SIG'09]

Priors

Global Regularity

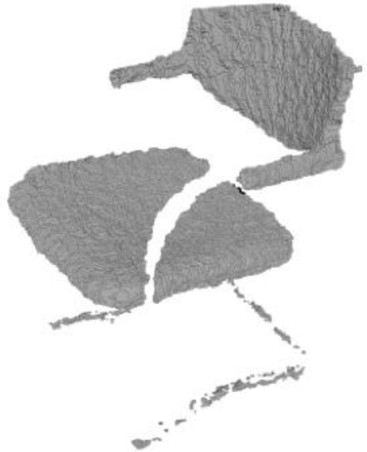
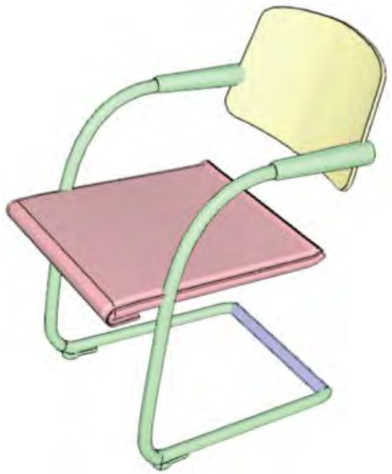




[Zheng et al. SIG'10]

Priors

Data-Driven

[Shen et al. SIGA'12]

Outline

Present survey of surface reconstruction from the perspective of priors

- Characterization of surface reconstruction
- Surface smoothness methods
- Specialized priors
  - visibility, volume smoothness, primitives, global regularity, data-driven, interactive
- Where surface reconstruction is headed

Characterization

- Point Cloud Artifacts
- Point Cloud Input
- Shape Class

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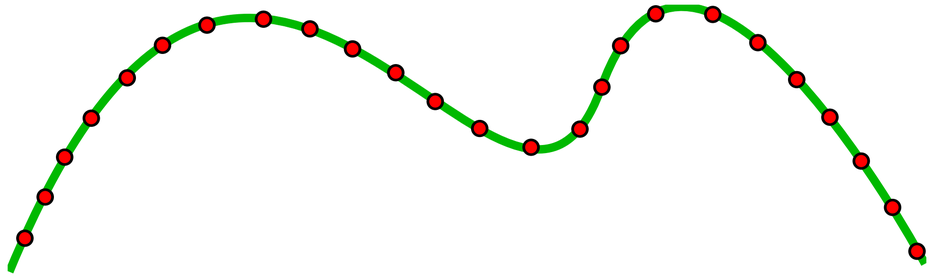

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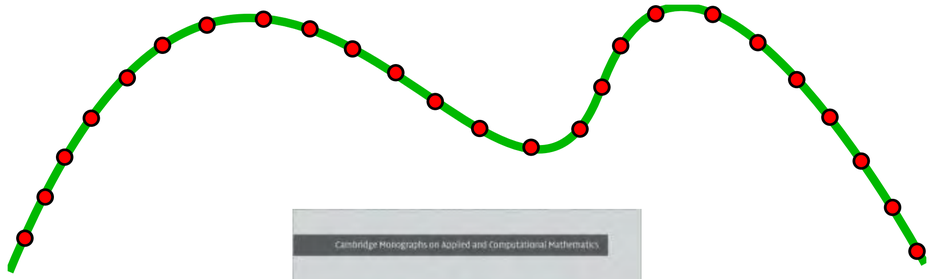
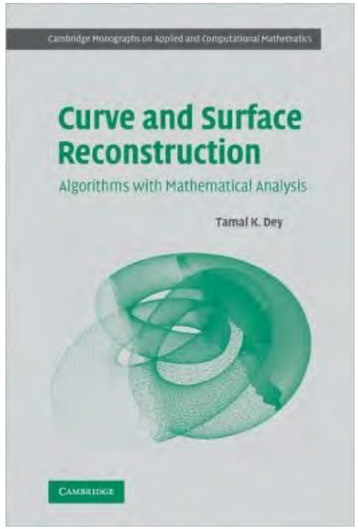
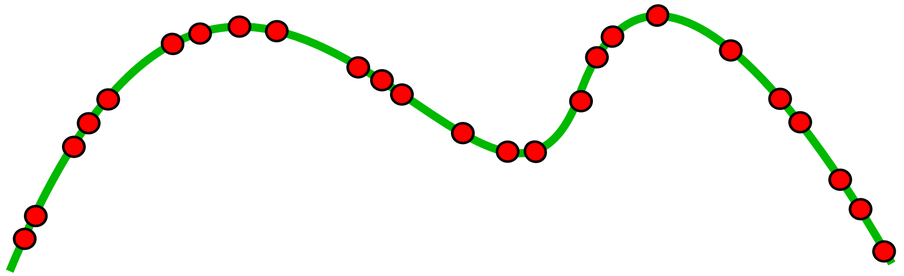




Artifacts

Sampling Density

- Distribution of sampled points
- Useful in computing many surface quantities
- Challenge: *nonuniform*



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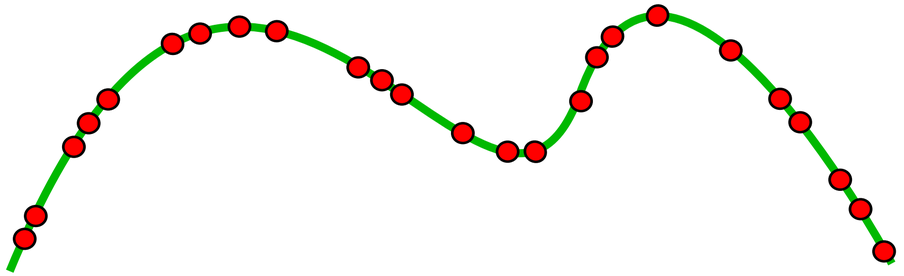

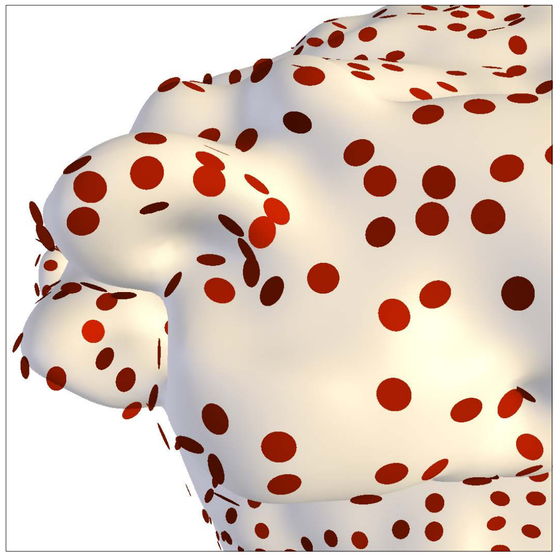

[Guennebaud et al. SIG'07]

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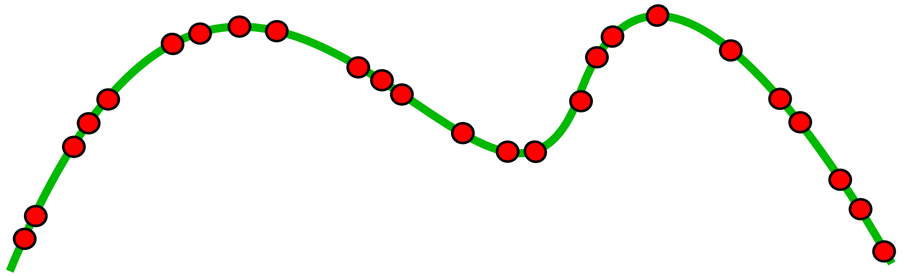

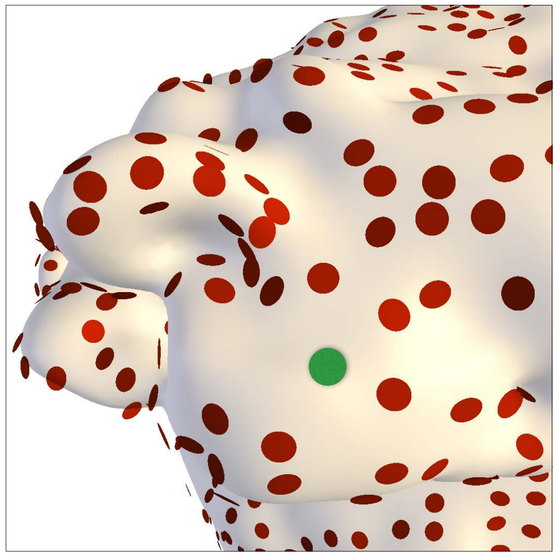

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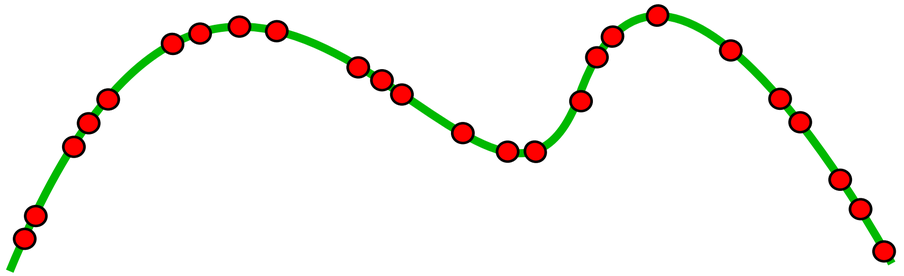
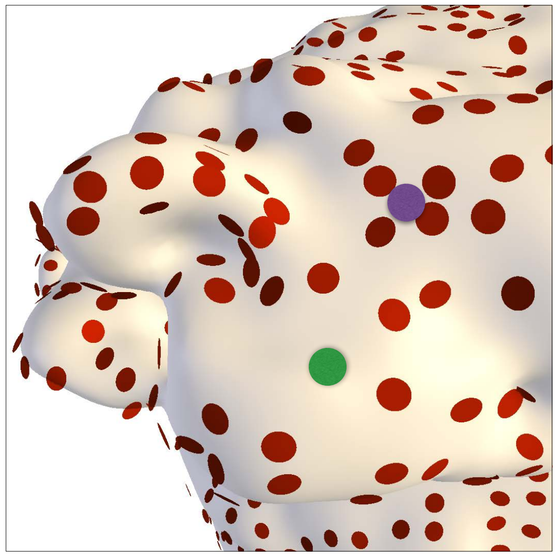


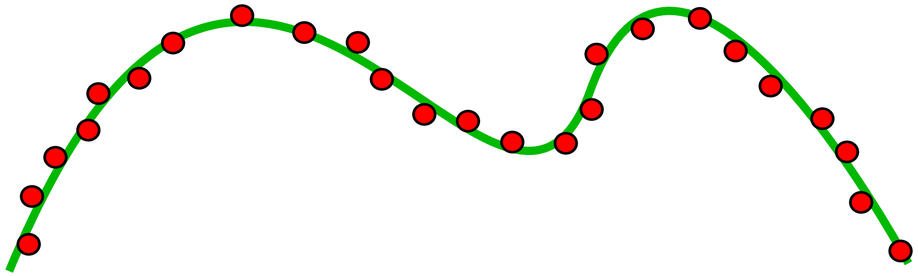


[Guennebaud et al. SIG'07]

Artifacts

Noise

- Points randomly distributed near the surface
  - Basic assumption: noise distribution is zero mean



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  - Sensor noise, depth quantization, surface material properties
- May also be spatially-varying

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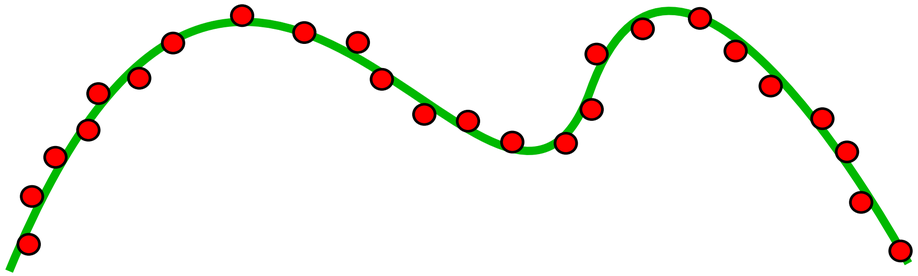

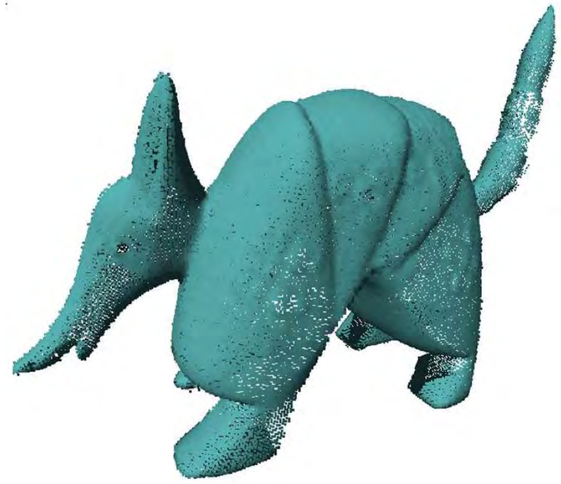

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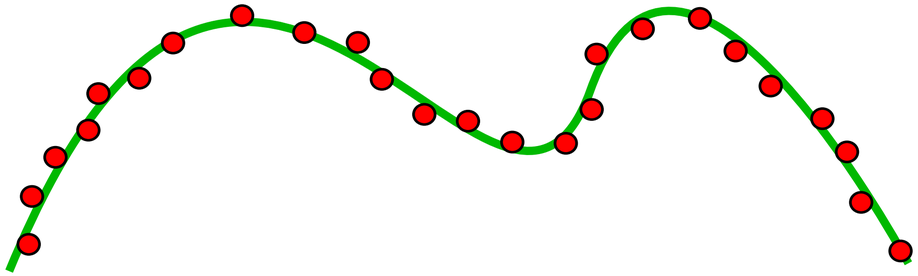

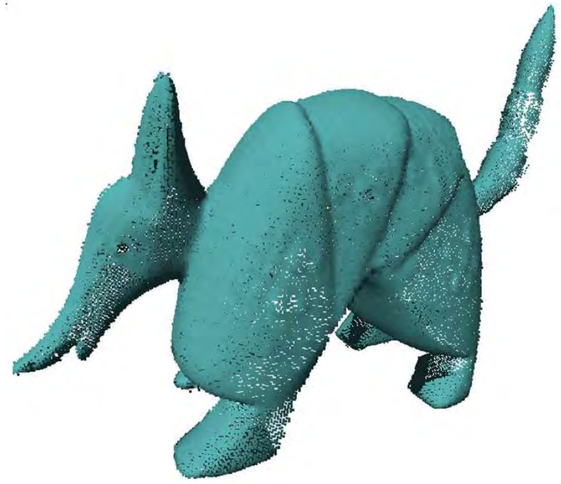

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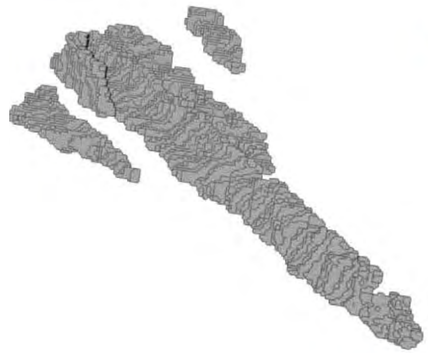


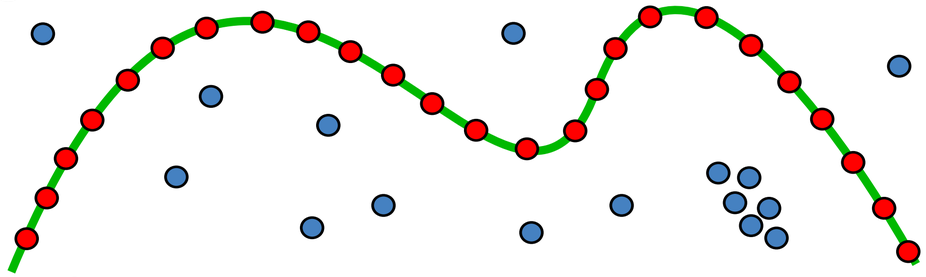
[Shen et al. SIGA'12]

- May also be spatially-varying

Artifacts

Outliers

- Points far from the surface
- Structural artifacts in acquisition
- Can be randomly distributed in the volume
- But can also be highly structured



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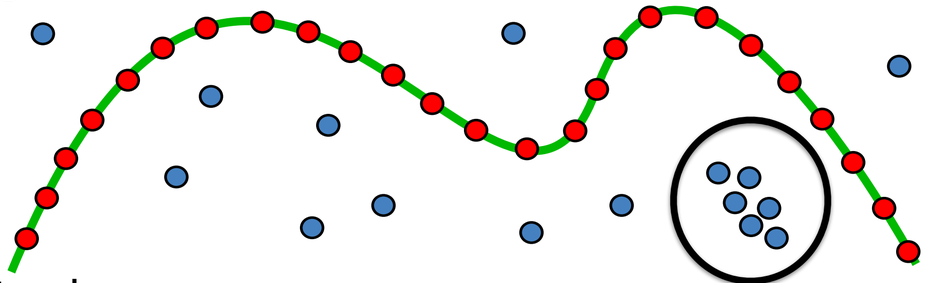

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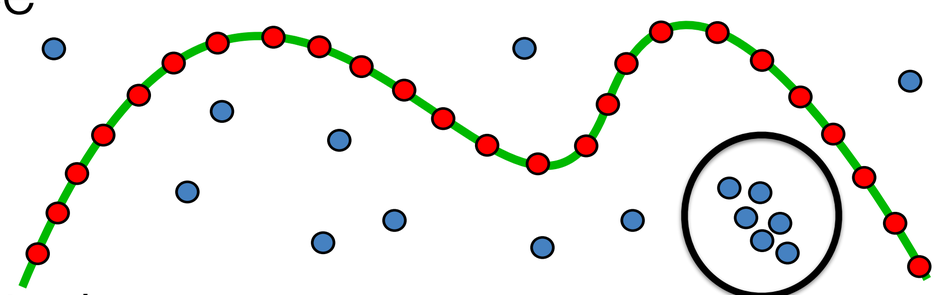
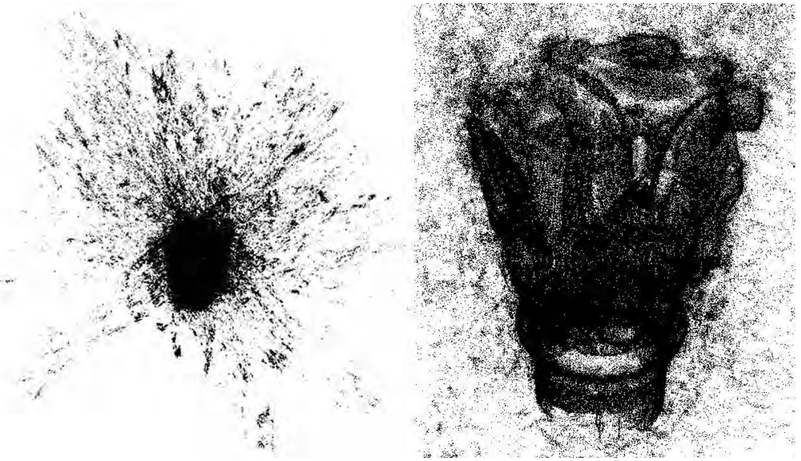


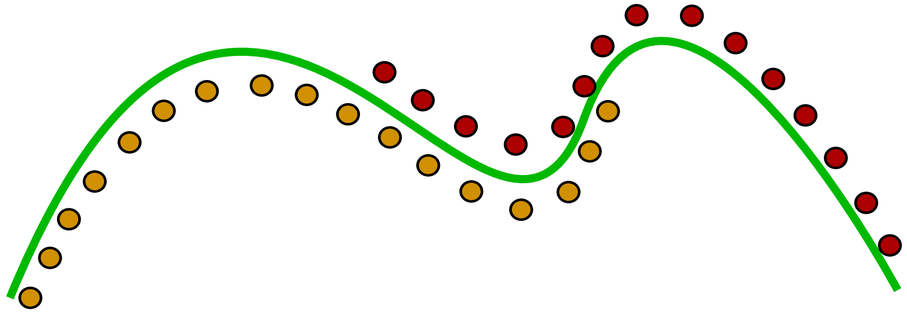


[Giraudot et al. SGP'13]

Artifacts

Misalignment

- Imperfect registration of range scans
- Introduces highly structured noise



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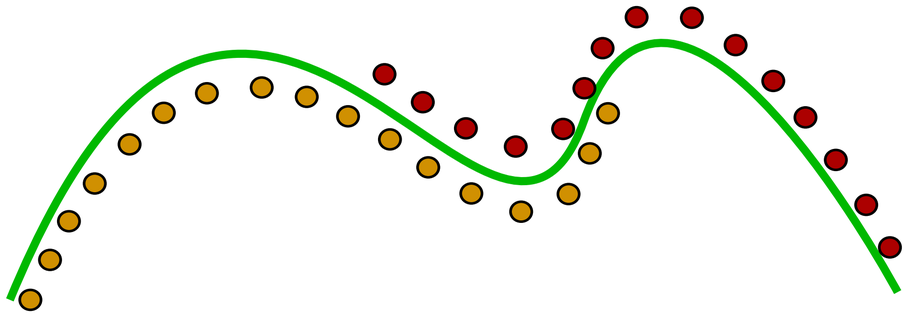
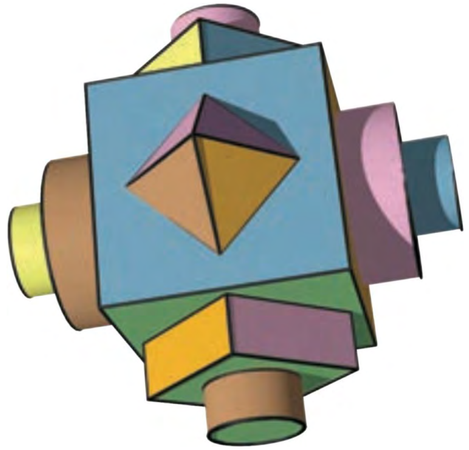


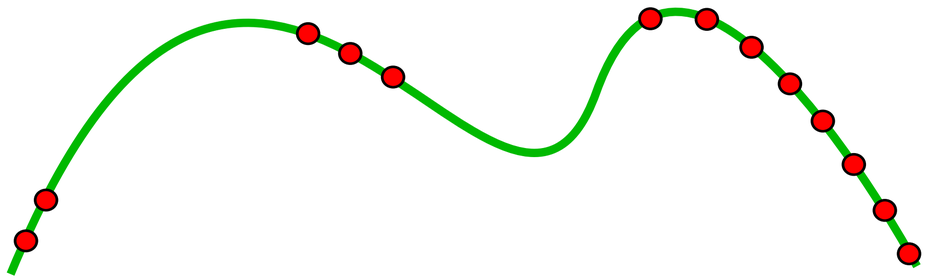


[Li et al. SIG'11]

Artifacts

Missing Data

- Regions of zero sampling density
- Different ways to handle missing data
  - Watertightness
  - Reconstruct higher-level information in lieu of the original shape



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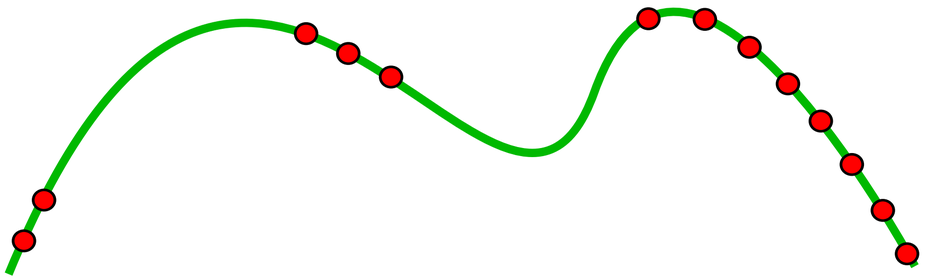

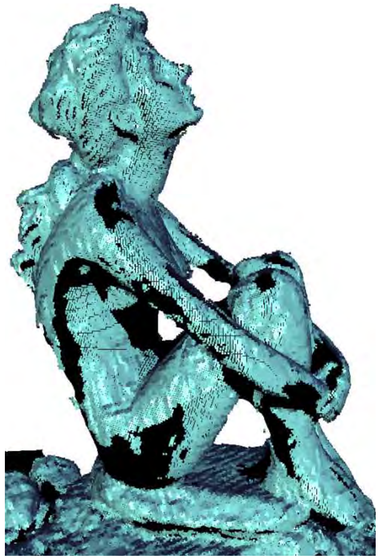

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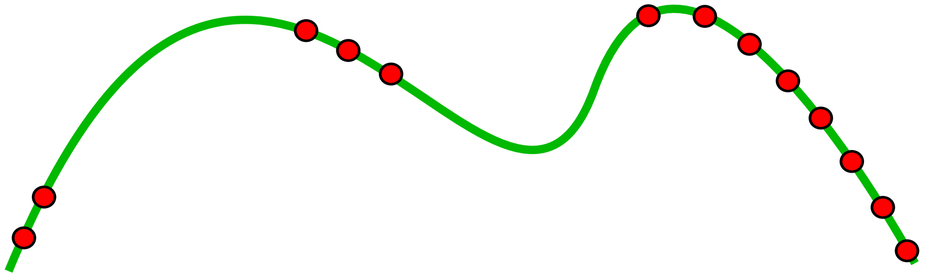

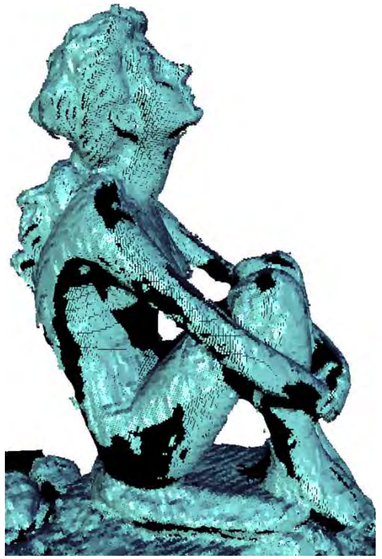

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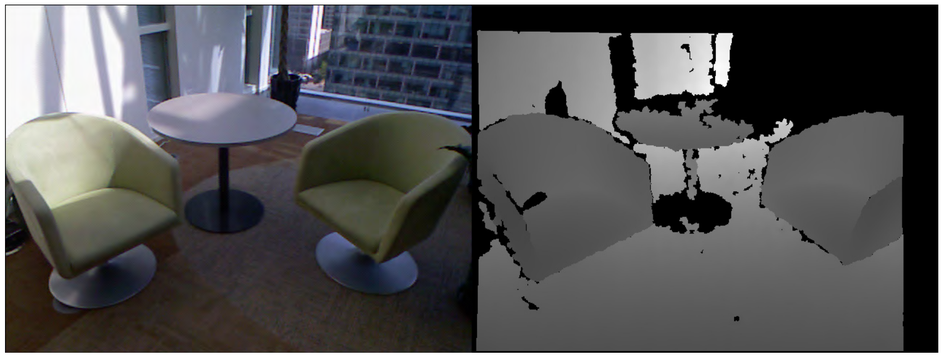


[Shao et al. SIGA'12]

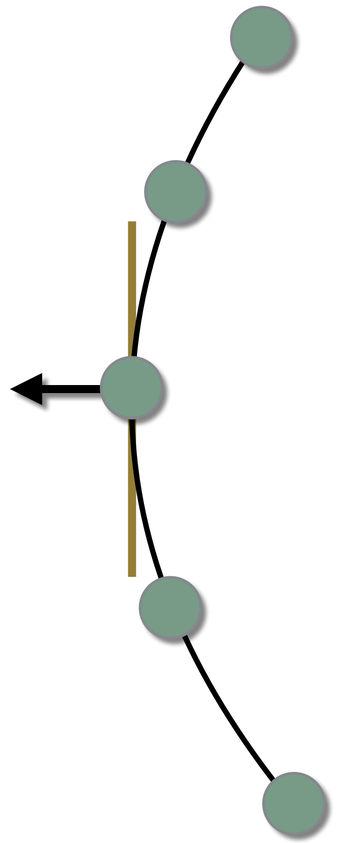
Characterization

- Point Cloud Artifacts
- Point Cloud Input
- Shape Class

Inputs

Normals

- The direction perpendicular to the tangent space at each point
- Represents a localized approximation to the surface
- Orientation: all normals are consistently pointing inside/outside of the surface



Inputs

Normal Orientation

- Provides useful cues about the surface
- Distinguish thin sheets from a single sheet
- Challenging research problem in its own right: [Hoppe et al. SIG'92, Huang et al. SIGA'09, Liu & Wang SMI'10]

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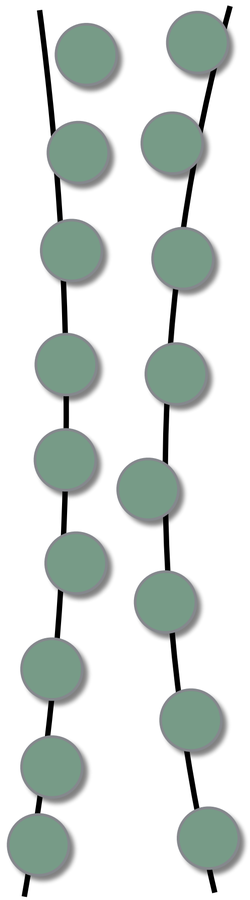

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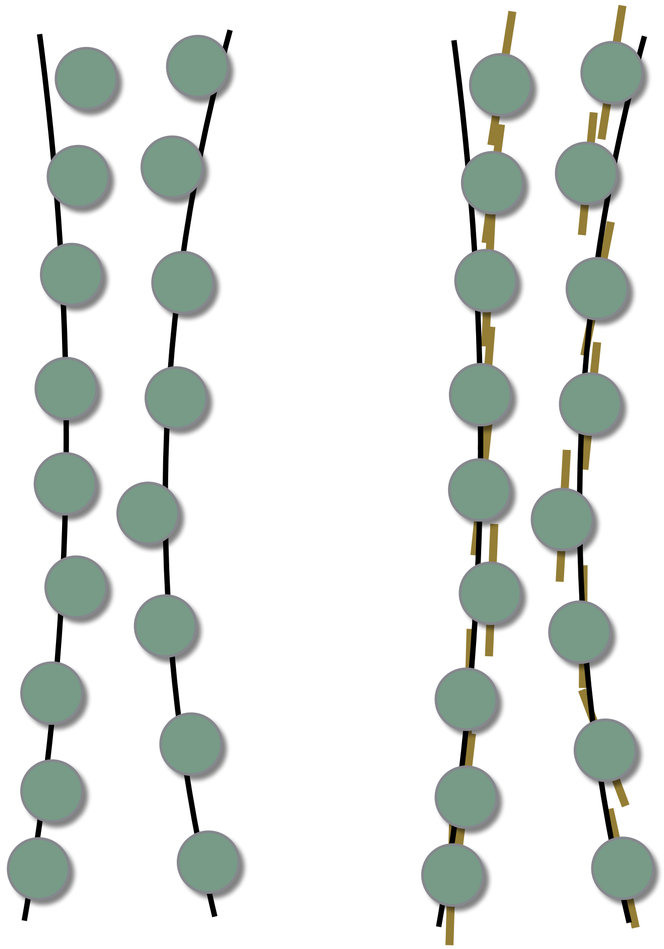

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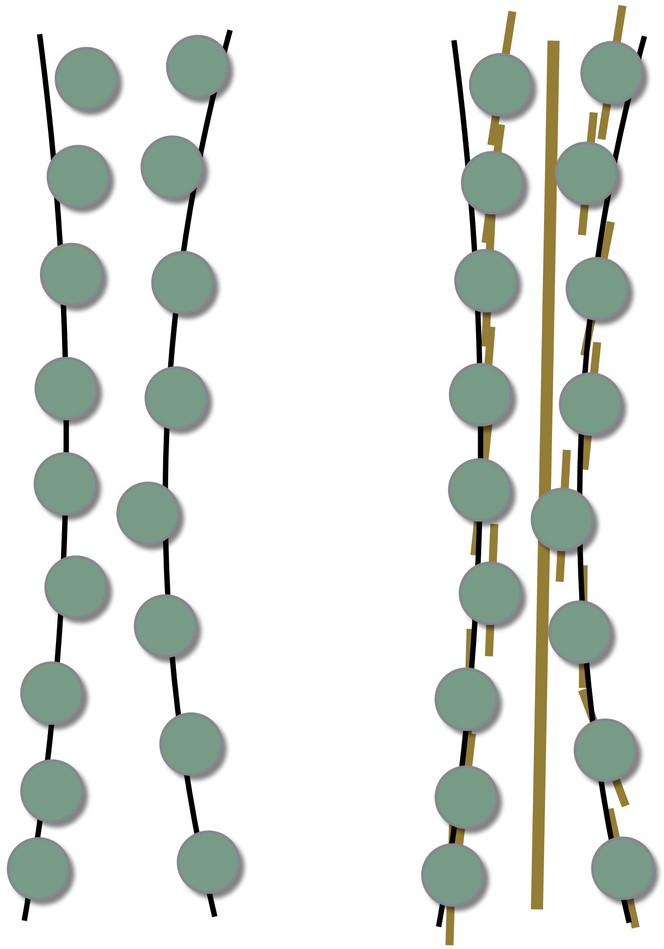

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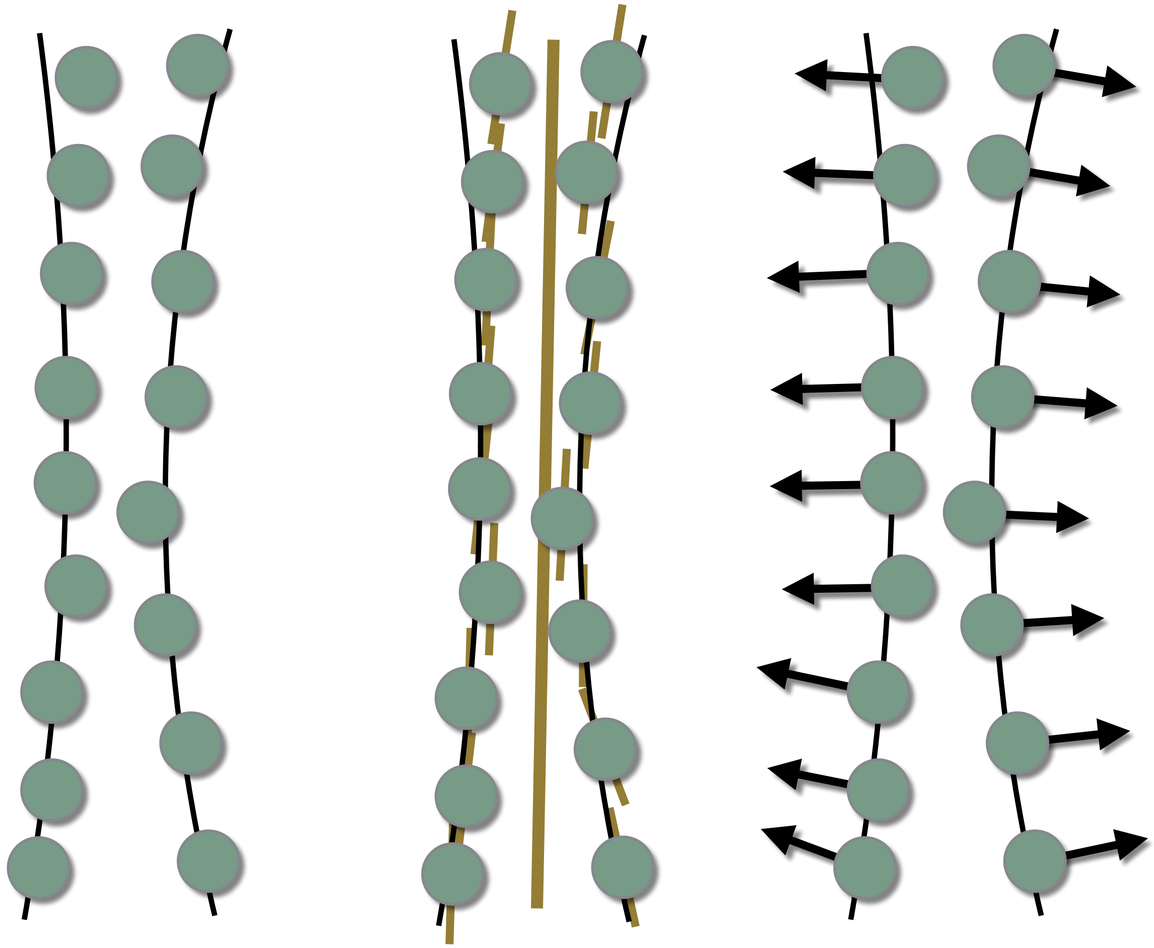
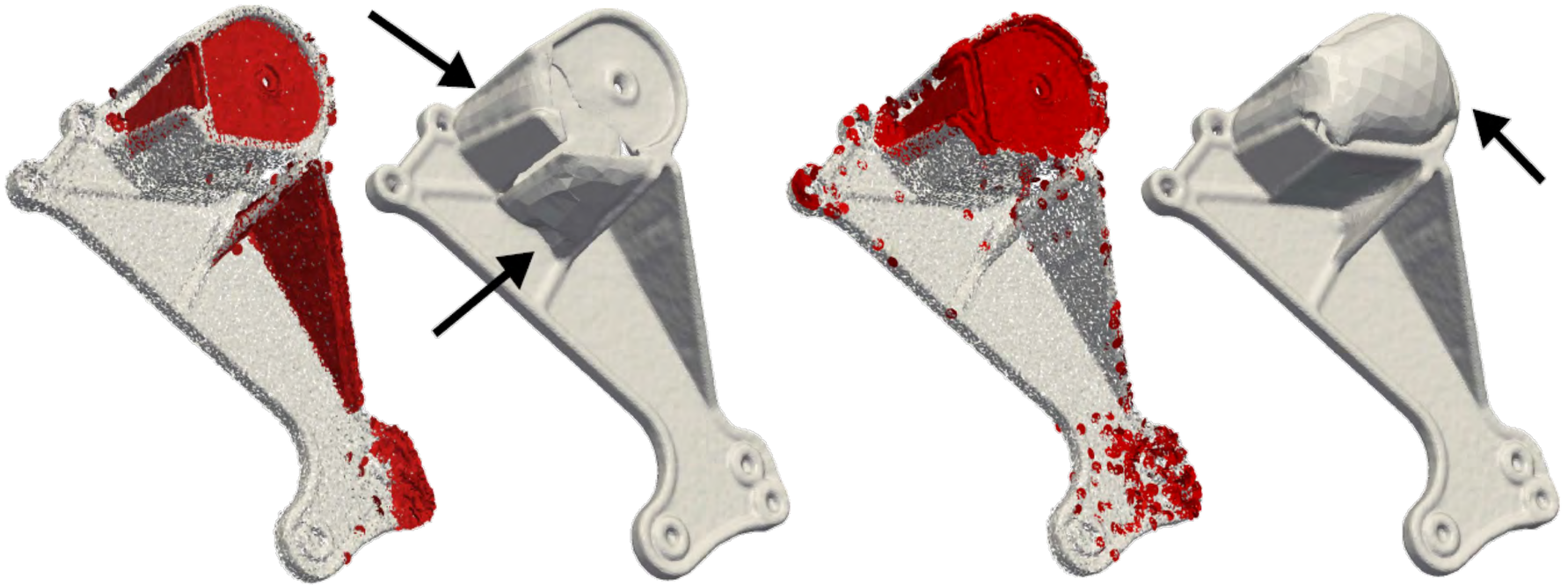


Inputs

Sensitivity to Normal Orientation



[Hoppe et al. SIG'92] [Kazhdan et al. SGP'06] [Liu & Wang SMI'10] [Kazhdan et al. SGP'06]

Inputs

Scanner Information

- Provides a variety of useful information
- 2D lattice structure
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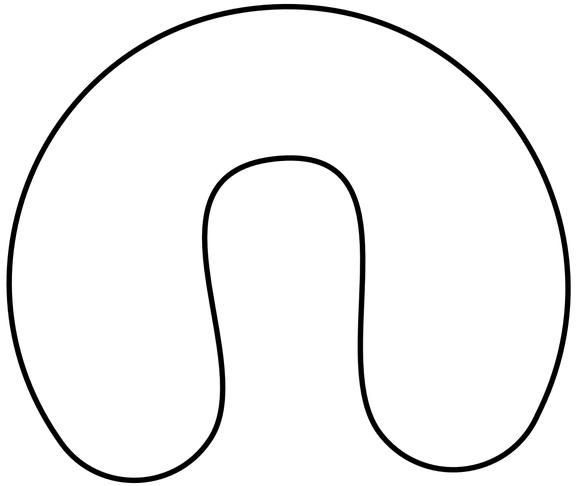

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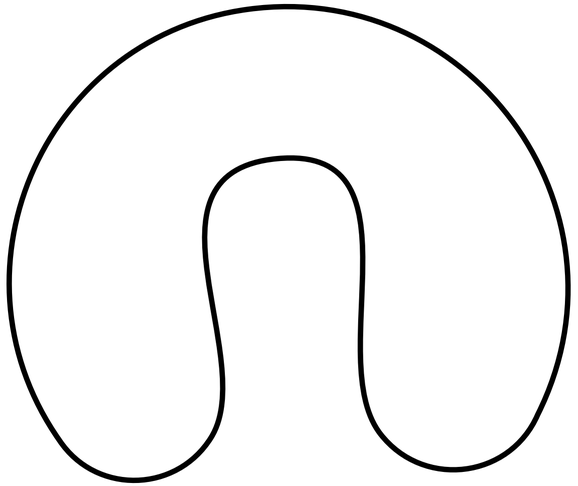

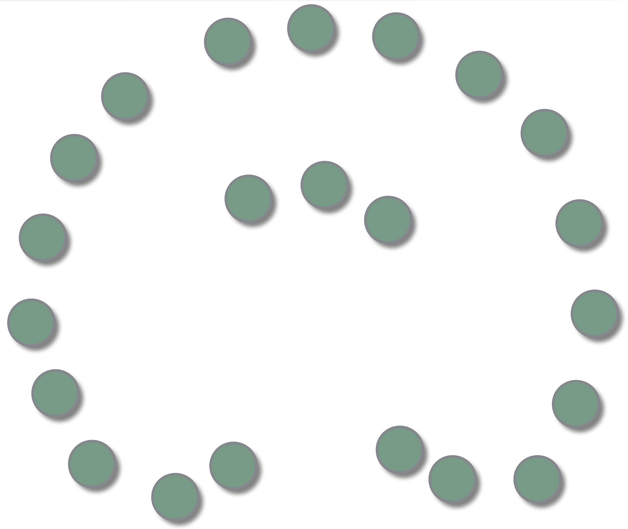

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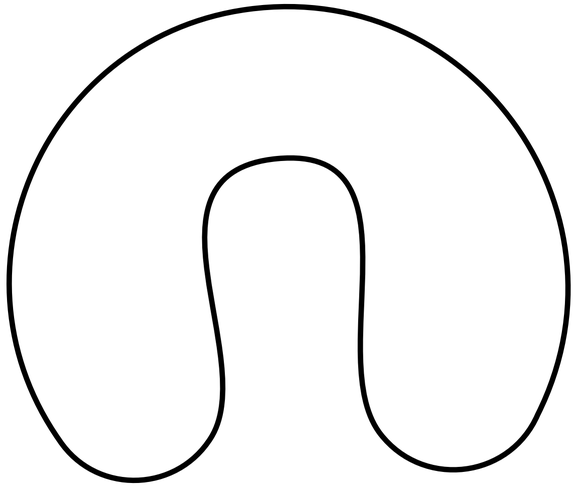

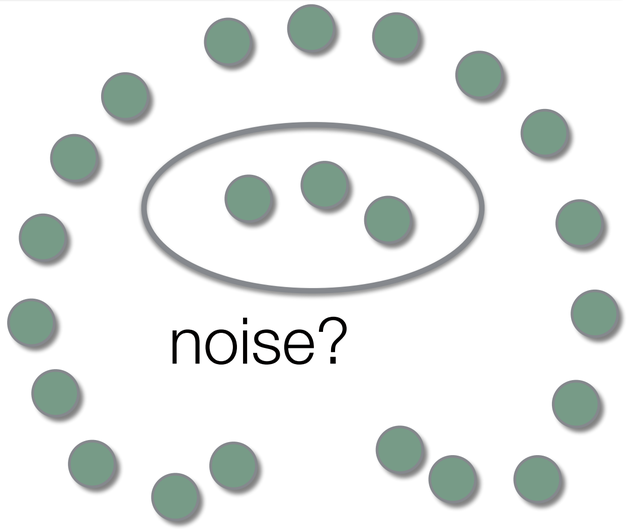

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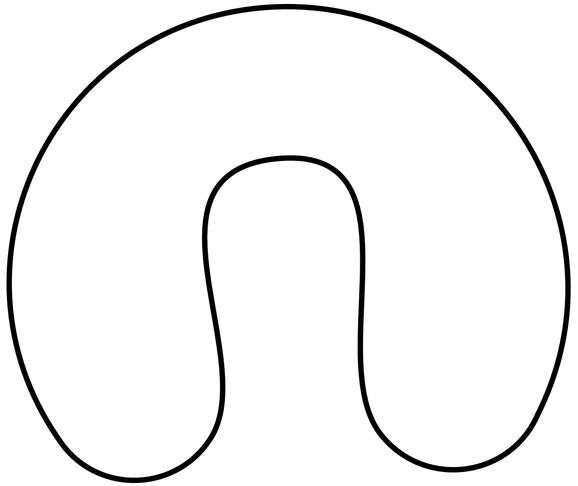

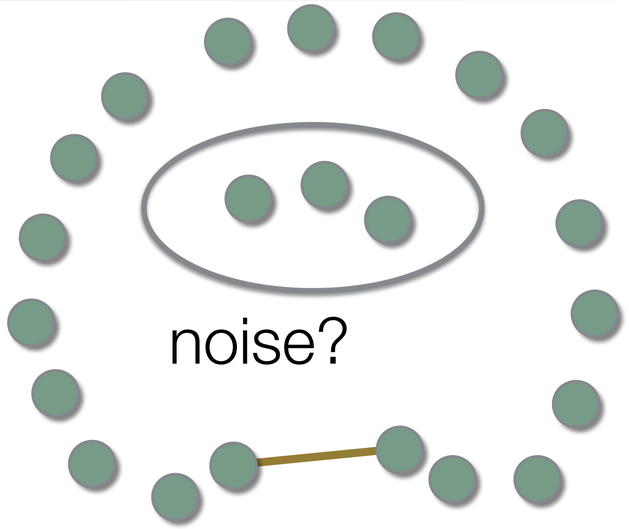

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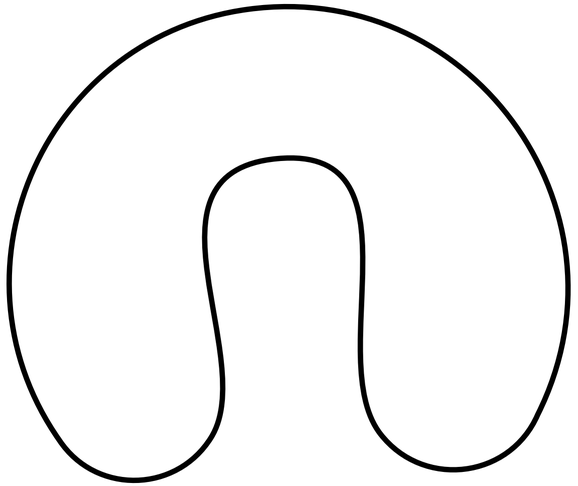

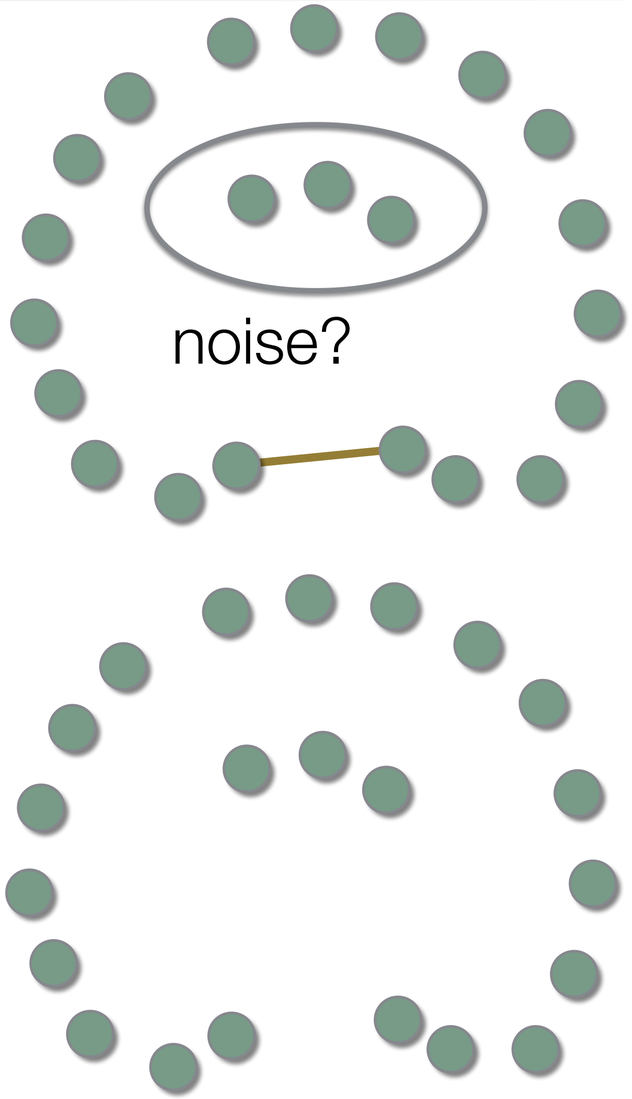

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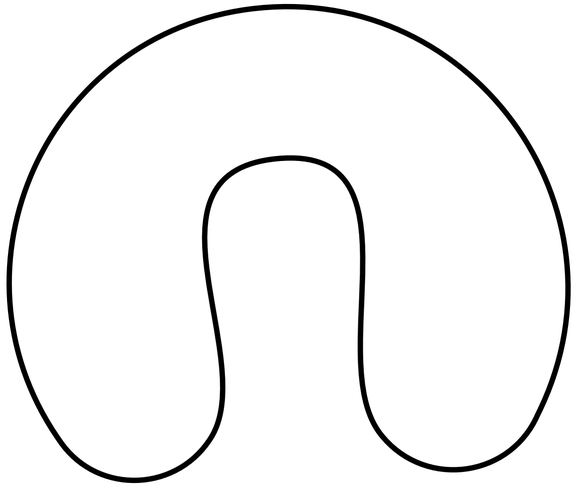

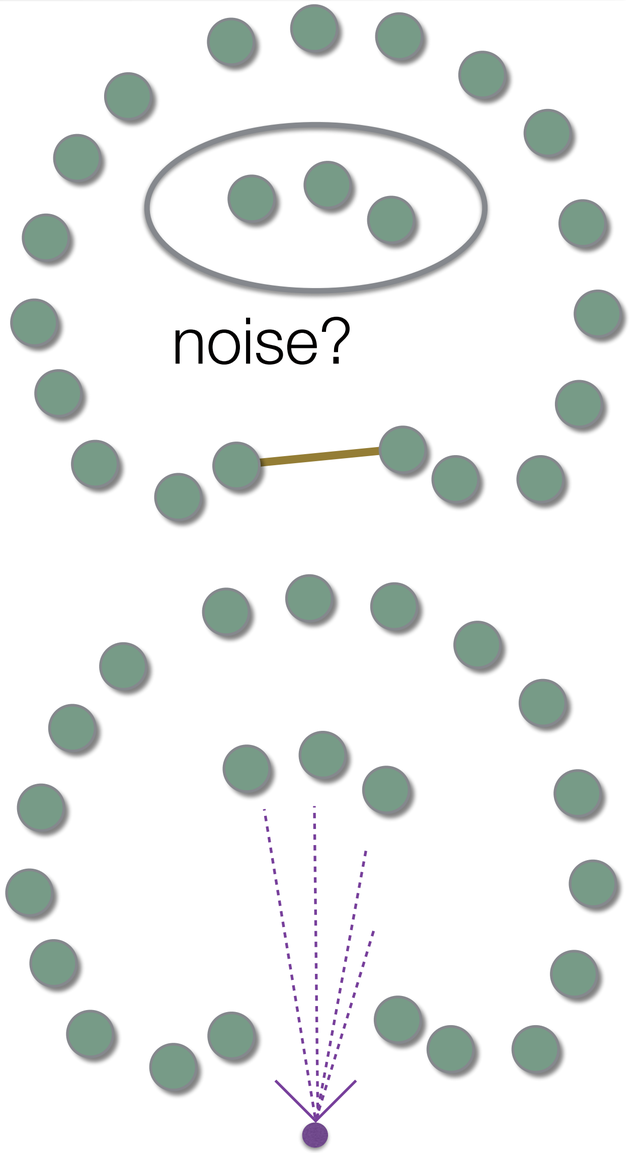

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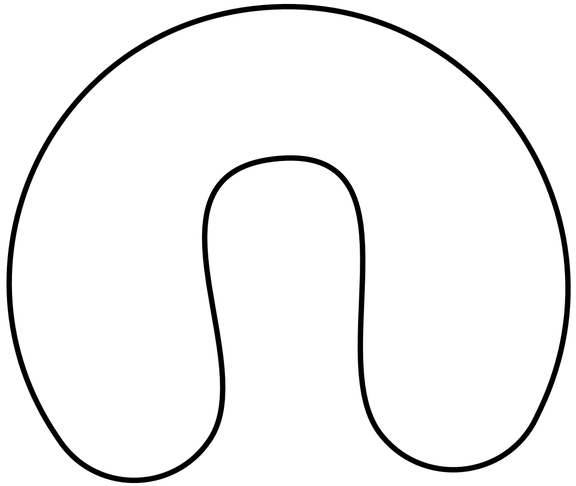

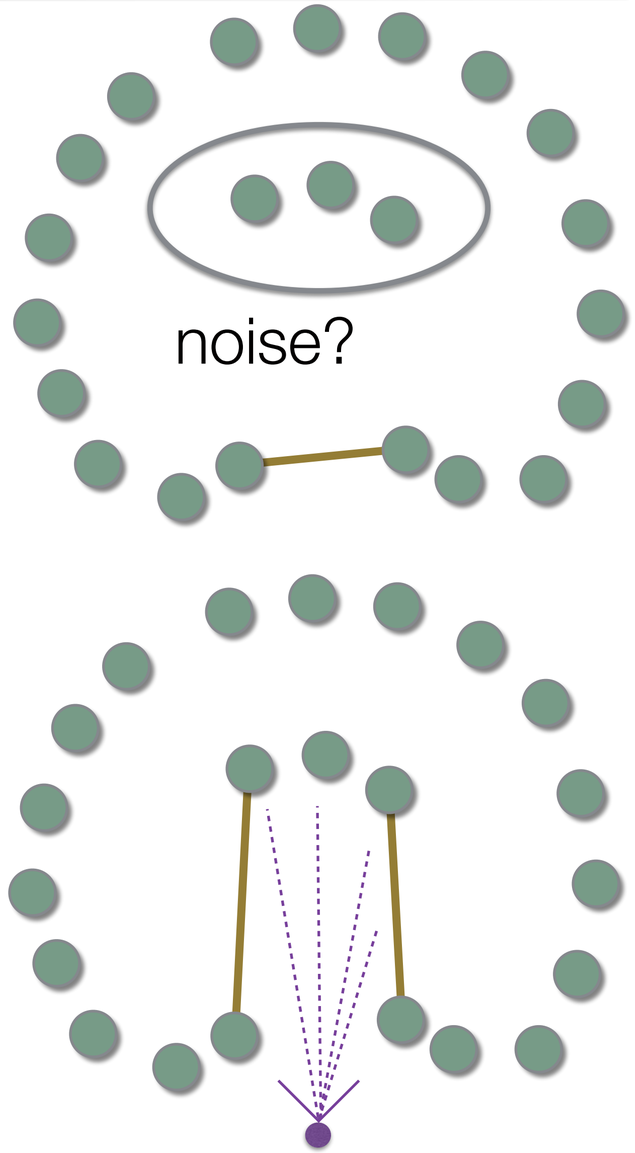

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RGB Imagery

- Complements depth capture, particularly when data is missing
- Fuse features between the depth and RGB image

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[Shen et al. SIGA'12]

Characterization

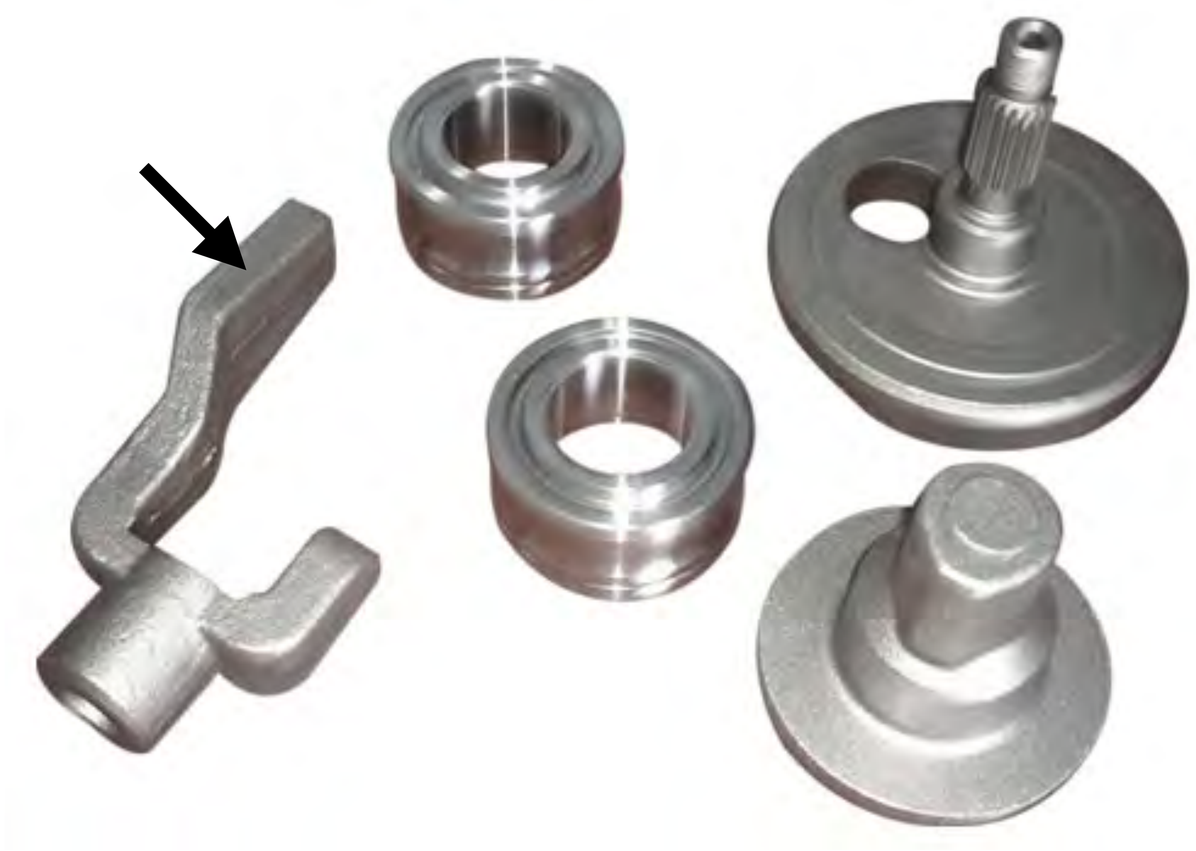
- Point Cloud Artifacts
- Point Cloud Input
- Shape Class

Shape Class

CAD Models

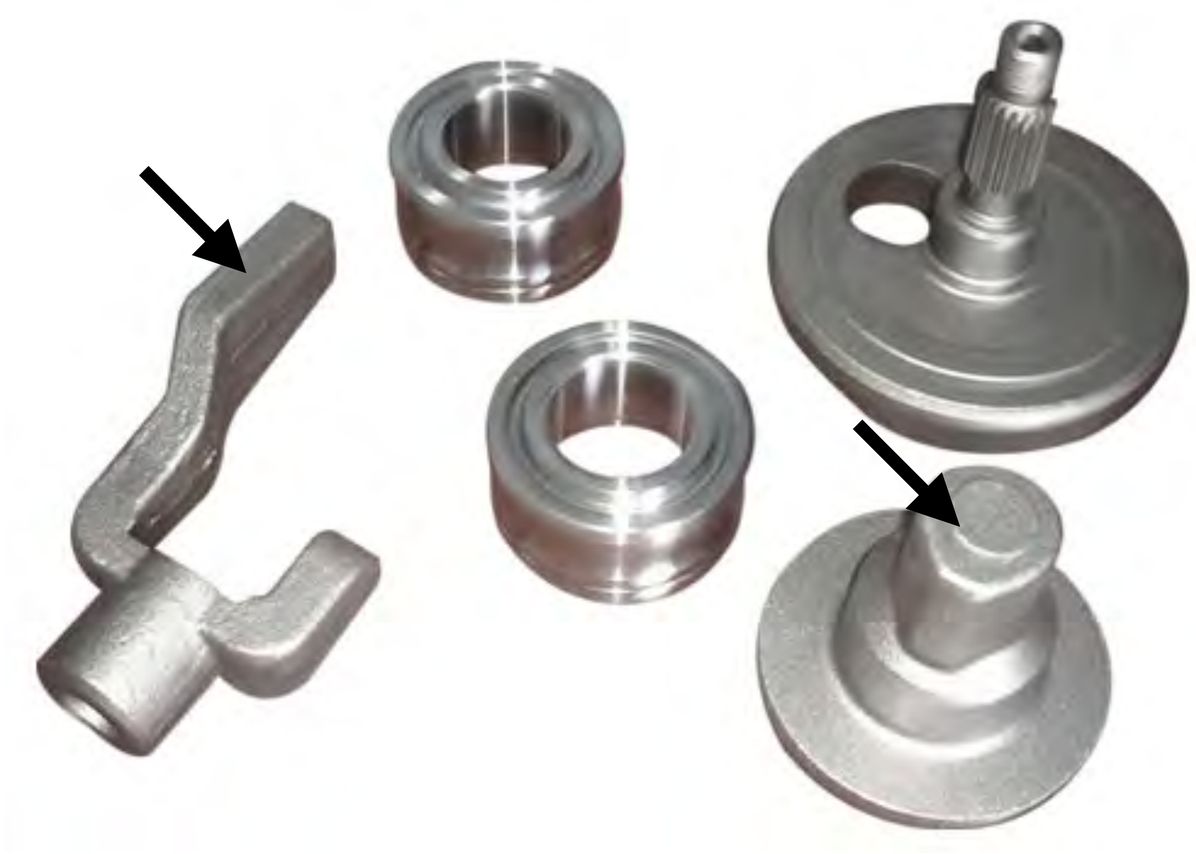
Shape Class

CAD Models



Shape Class

CAD Models



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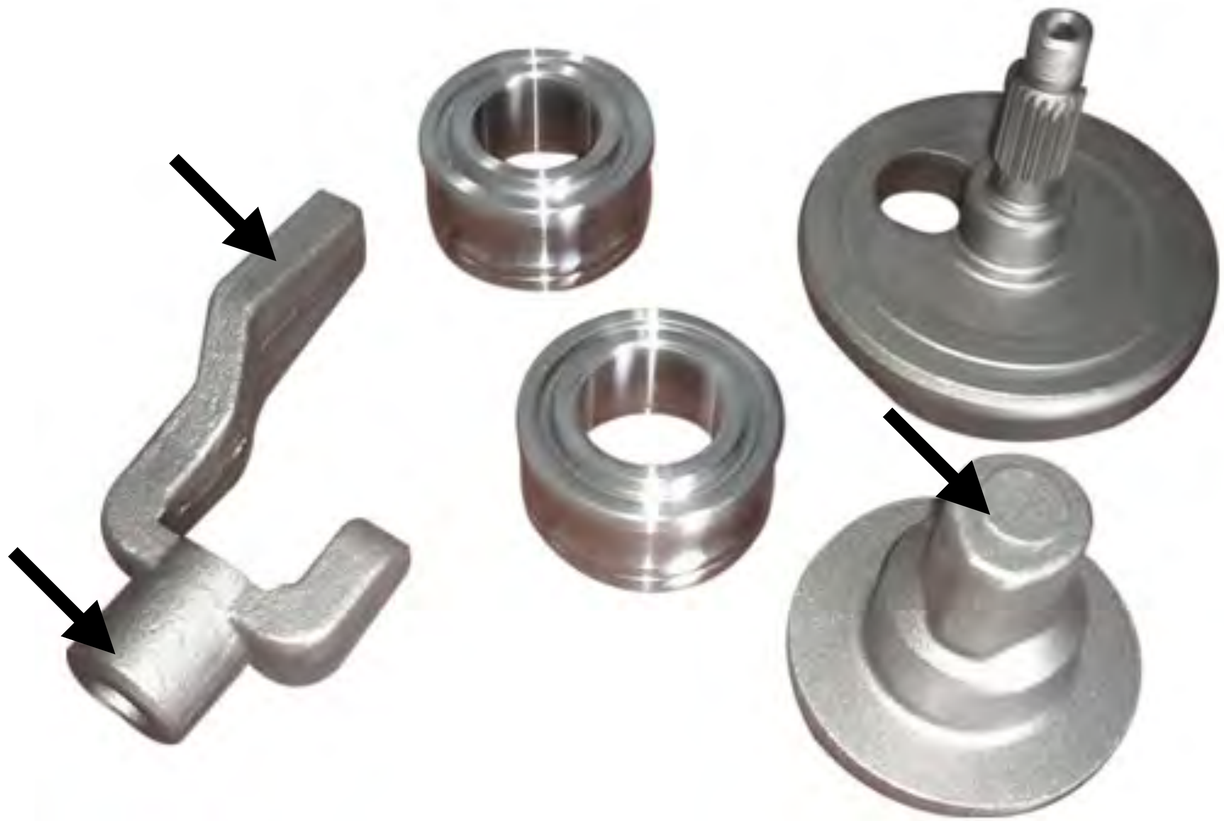

Shape Class

Man-made shapes

Shape Class

Man-made shapes

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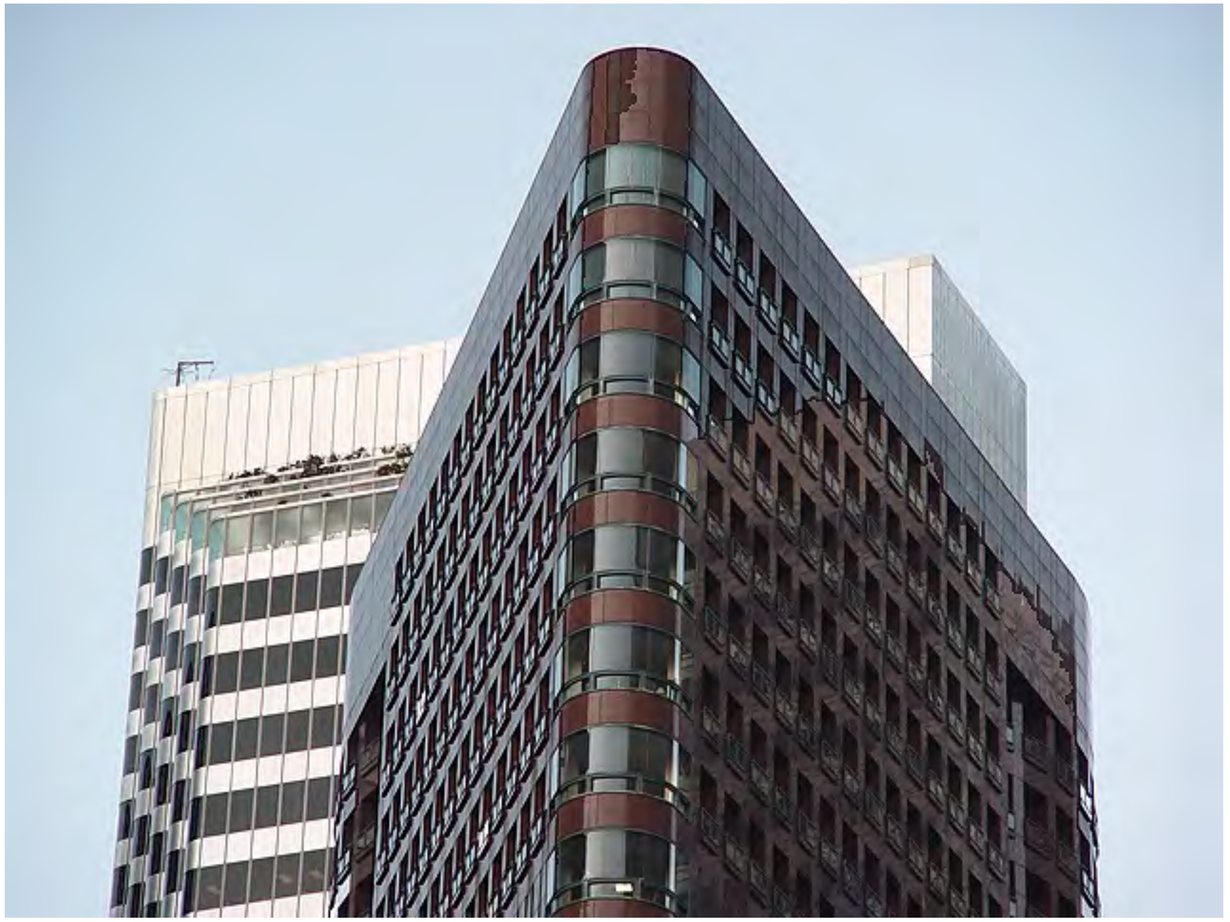
Shape Class

Organic shapes

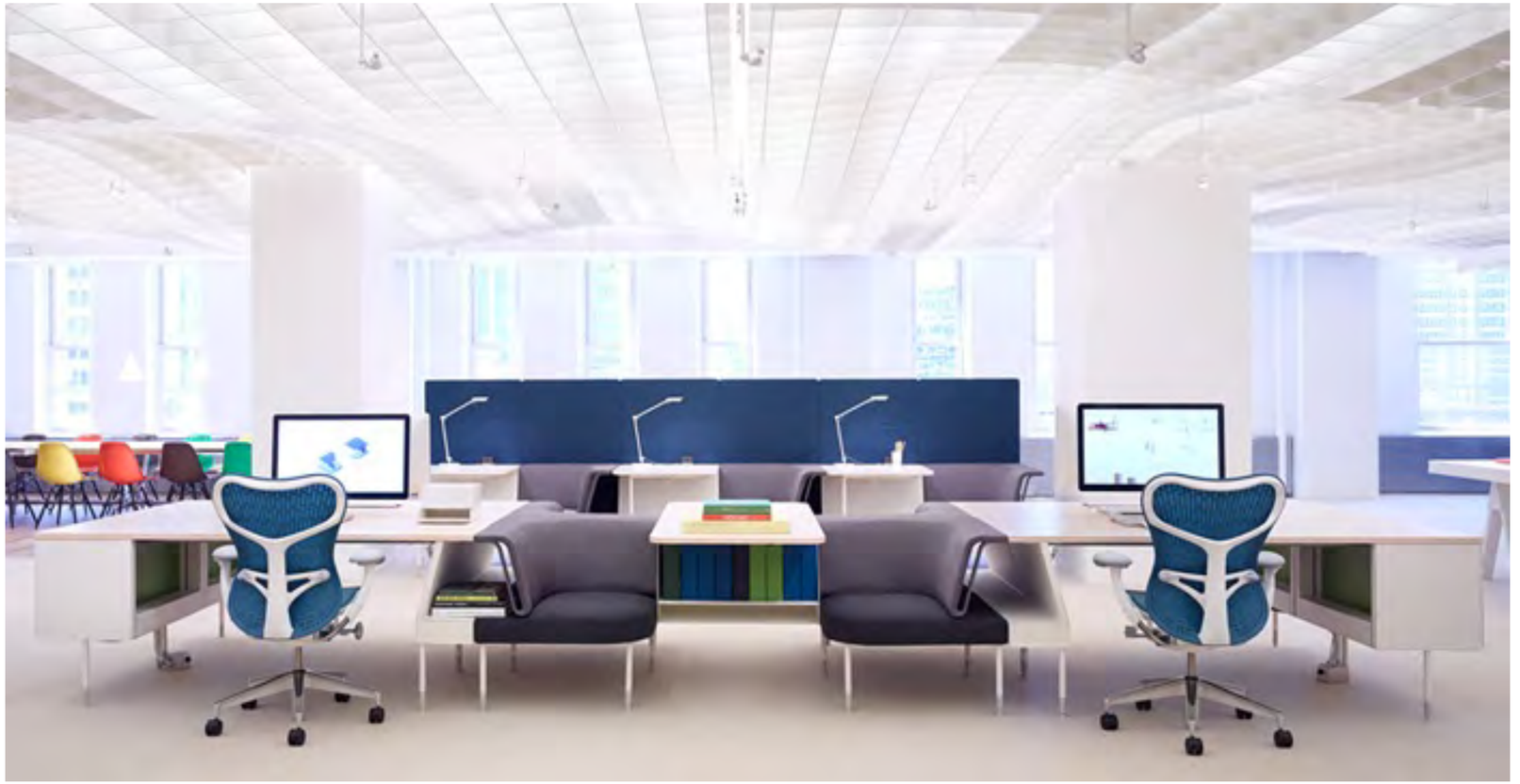
Shape Class

Architectural shapes



Shape Class

Indoor environments



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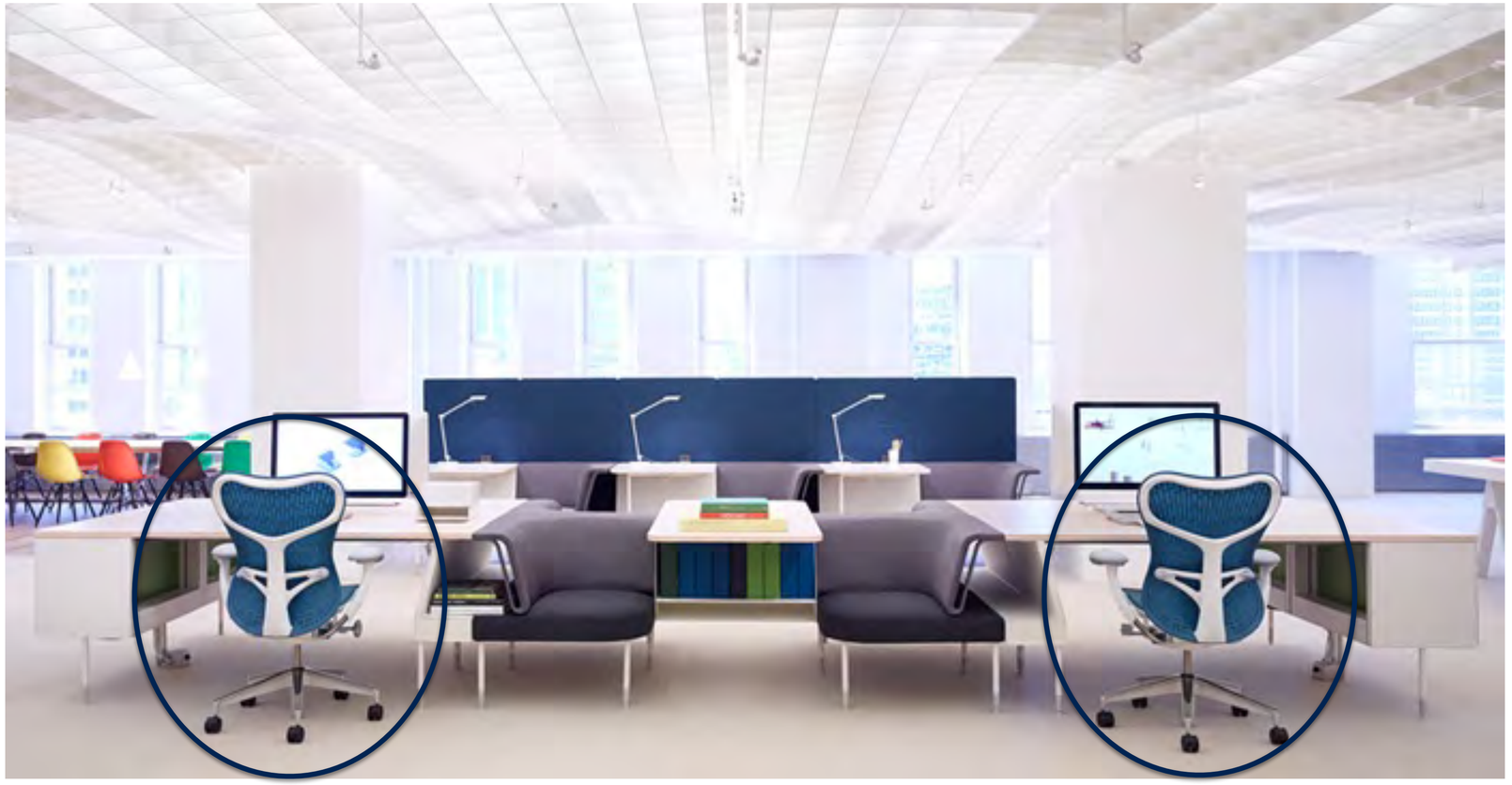

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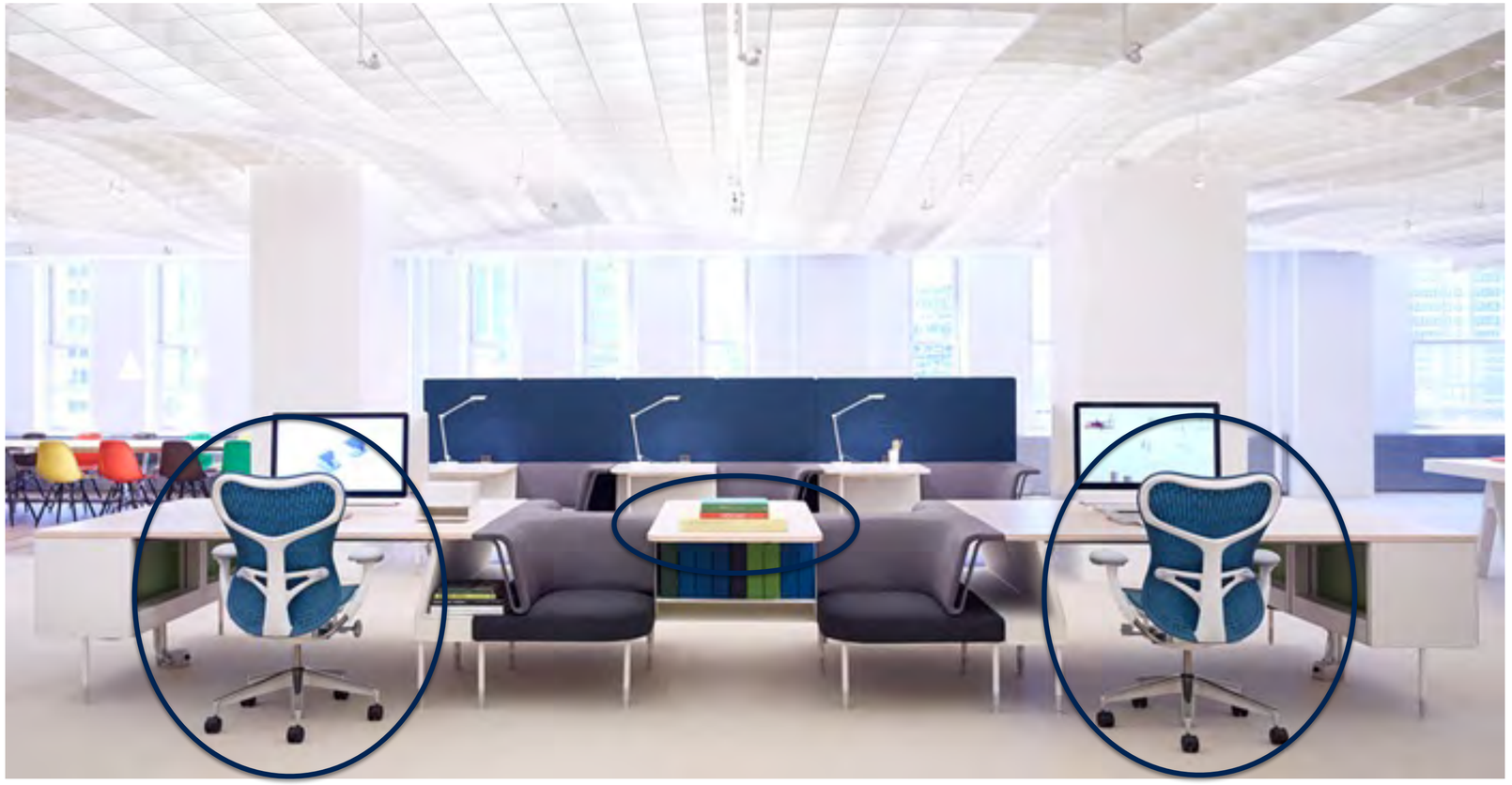

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Point Cloud Artifacts

- Nonuniform Sampling
- Noise
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These factors inform *prior* development in surface reconstruction