Surface Reconstruction Methodologies

Global Structure

Data-driven

User-Driven

Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva

Objects share many commonalities due to

Strasbourg Cathedral

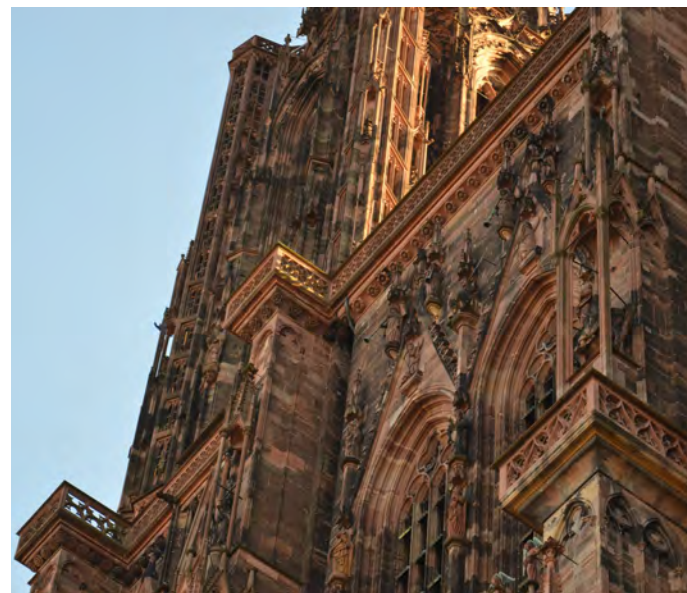- Modular design, function, and manufacturing techniques
- Appear as different structures across different scales: part, object, shape class

Symmetry

Repetition

Intra-Object Relationships

Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva

Global Regularities

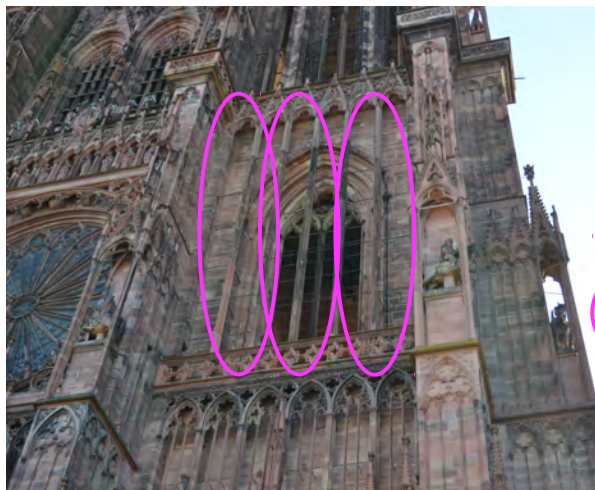Objects share many commonalities due to

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Intra-Object Relationships

Goal: Exploit regularities in global shape to complete, denoise, & refine incomplete scan data

Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva

Global Regularities: *Symmetry*

Pairwise Similarity Transforms [Pauly et al. 08]

- Detect repeating elements related by a local similarity transformation

- Cluster in transformation space
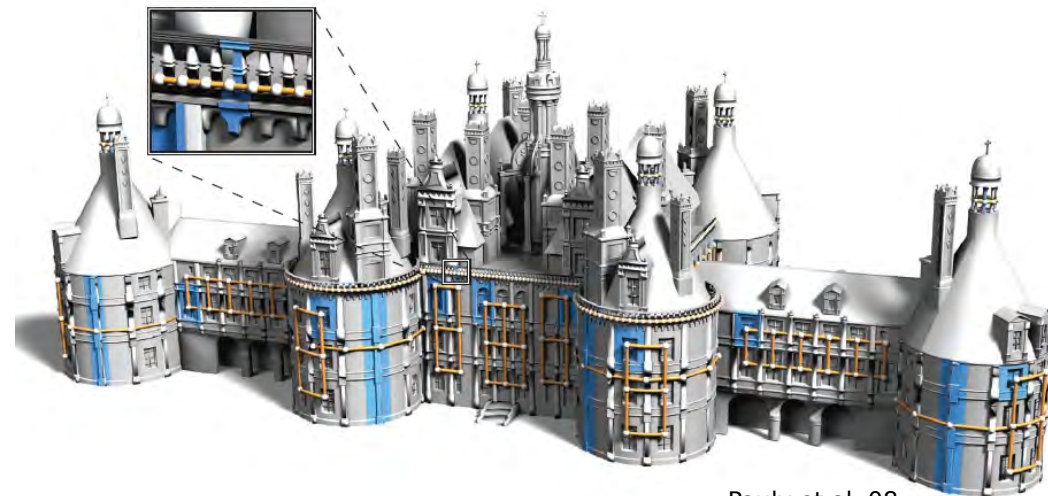
Symmetry Factored Embedding [Lipman et al. 10]

- Detect local rotational, bilateral, intrinsic symmetries

- Symmetry factored distance → continuous measure

- Robust → captures *approximate* symmetries
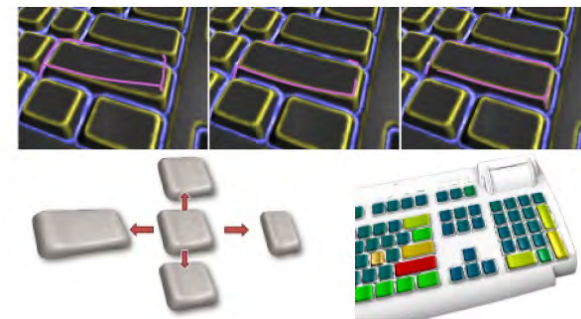
Subspace Symmetries [Berner et al. 11]

- Low-dimensional shape space

Pauly et al. 08

Lipman et al. 10

Berner et al. 11
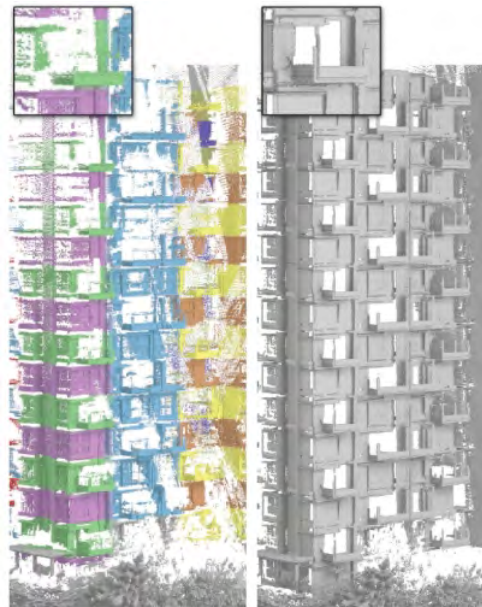
Scan consolidation [Zheng et al. 10]

- Non-local consolidation & filtering

- Decompose facade planar components in common coordinate space

- In-plane & off-plane denoising

- Extensions
  - Adaptive facade partitioning [Shen et al. 11]
  - Grammar-based [Wan et al. 12]

Dominant frequencies detection [Friedman et al. 12]

- Periodic feature detection → vertical scanline analysis to extract periodicity and phase

- Complete missing periodic features

Image-space repetition detection [Li et al. 11]

- Fuse RGB images with LIDAR

- Detect repetitions in image-space across facade depth layers → transfer to 3D

- Perform consolidation
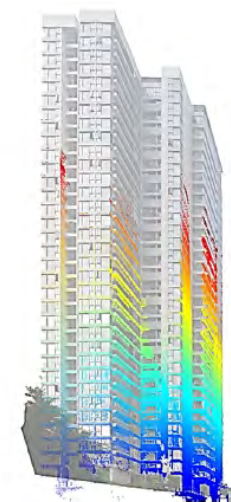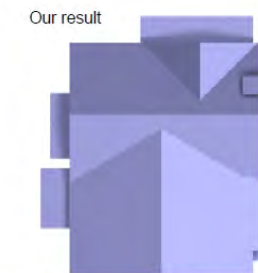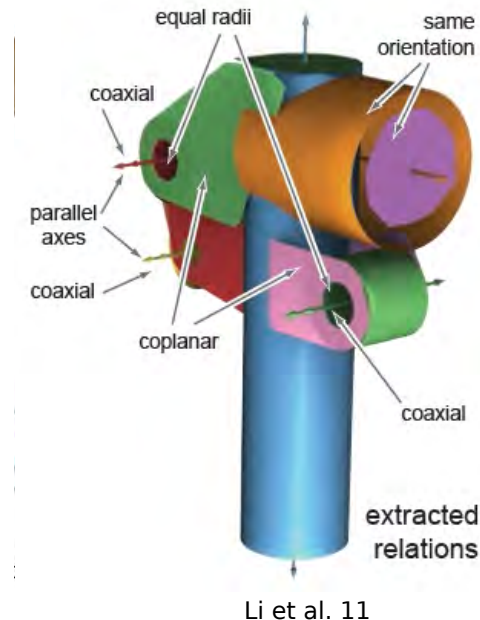
Friedman et al. 12

Zheng et al. 10

Li et al. 11

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Consolidating Relations [Li et al. 11]

- *Detect* shape primitives

- *Discover* relations → orientation, placement, equality

    - Relation consistency & simplification

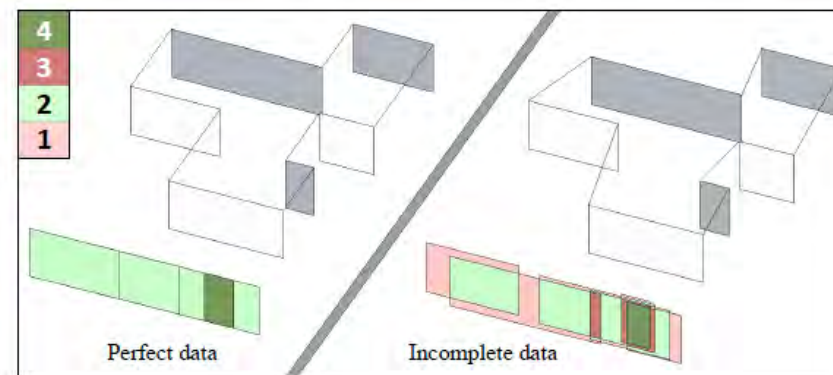- *Optimize* primitive fits → data & relation fitting costs

Building Relations [Zhou et al. 12]

- Aerial building reconstruction

- Discover building relationships

    - Roof-Roof → placement & orientation

    - Roof-Boundary → parallel & orthogonal

    - Boundary-Boundary → Height & position

Building Volumetric Relations [Vanegas et al. 12]

- Consider wall, edge, corner

- Label and cluster points → MW bounding box

- Extract volume regions from axis-aligned boxes

Li et al. 11

Zhou et al. 12

Vanegas et al. 12

Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva

Data-driven Methods

Leverage database of *known* shape models to aid reconstruction

Perform shape matching, retrieval, & fitting

Model and matching granularity → Category, object, or part

Database shape representation → Polygon, point cloud, patches, synthetic incomplete scans, mean shape

Shen et al. 12

Shape fitting & evaluation → Rigid / nonrigid transformation, geometric and deformation costs

**Challenge:** Recover fine-grained details, handle substantial missing data

(a) Car

(b) Fruit

Bao et al. 13

EUROGRAPHICS 2014
Strasbourg, France
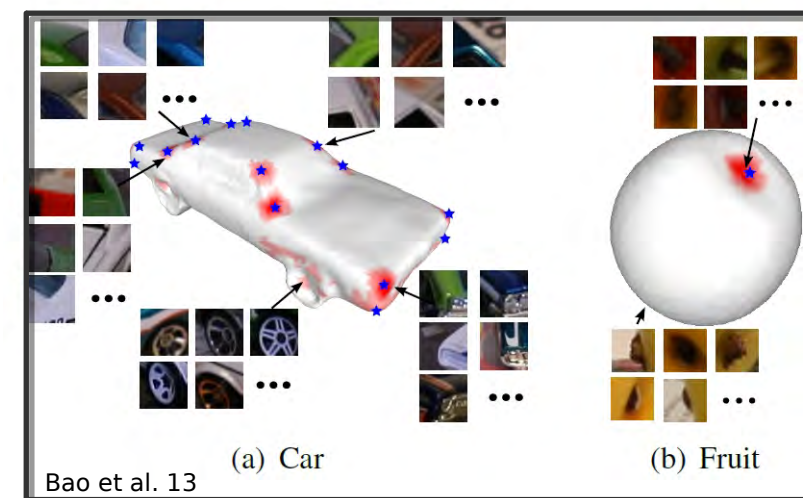
Direct object matching

- Example-based 3D scan completion
  [Pauly et al. 05]

- Database of complete models → Match against incomplete point cloud query

input data   context model

final model   evaluation

Pauly et al. 05
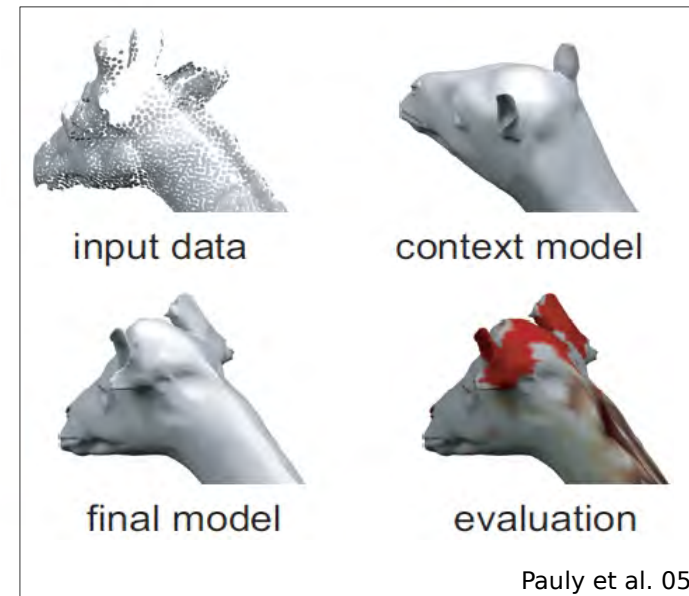
Local Shape Priors

- Surface reconstruction using local shape priors
  [Gal et al. 07]

- Match point-set neighborhood patches

Gal et al. 07

EUROGRAPHICS 2014
Strasbourg, France
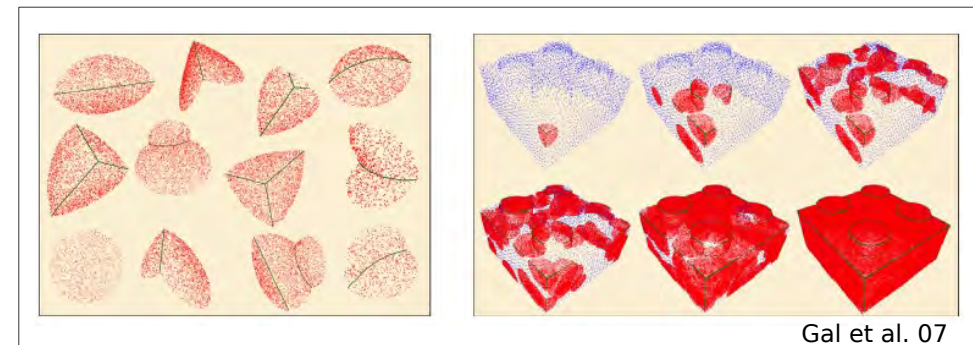
Shape Database - Store object point clouds

Synthetic *incomplete* point clouds from multiple views, orientations, distance

Segmentation - Semantically segment point cloud

Data-driven

- Appearance, geometric consistency [Shao et al. 2012]

Jointly

- Search-Classify [Nan et al.12]
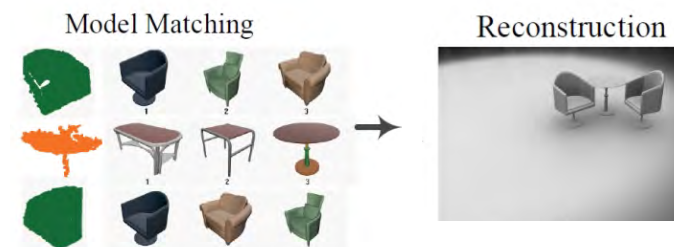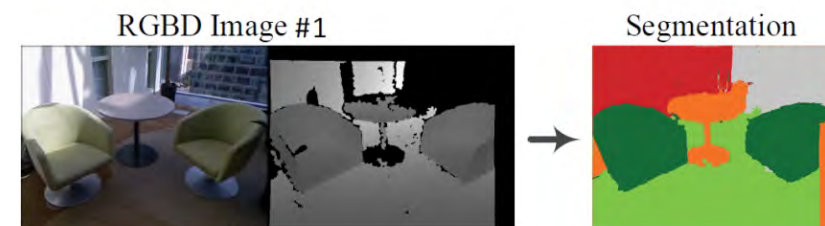
- Part-driven with deformation modeling [Kim et al. 12

Retrieval - Find *closest* matching object

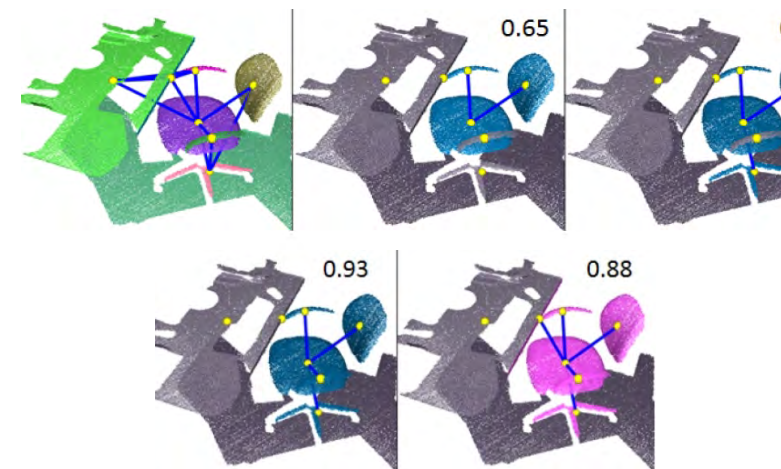Rigid Matching [Shao et al. 2012]

- Class-labeled objects, local consistency appearance & geometry

Non-rigid Matching [Nan et al. 12]

- Non-rigid deformation & residual alignment error

RGBD Image #1   Segmentation

Model Matching   Reconstruction

Shao et al. 2012

0.65

0.93   0.88

Nan et al. 12

Dense object reconstruction with semantic priors [Bao et al. 13]

- Model shared geometry for category of shapes → Mean Shape
- Transfer object instance level detail → image + feature matching
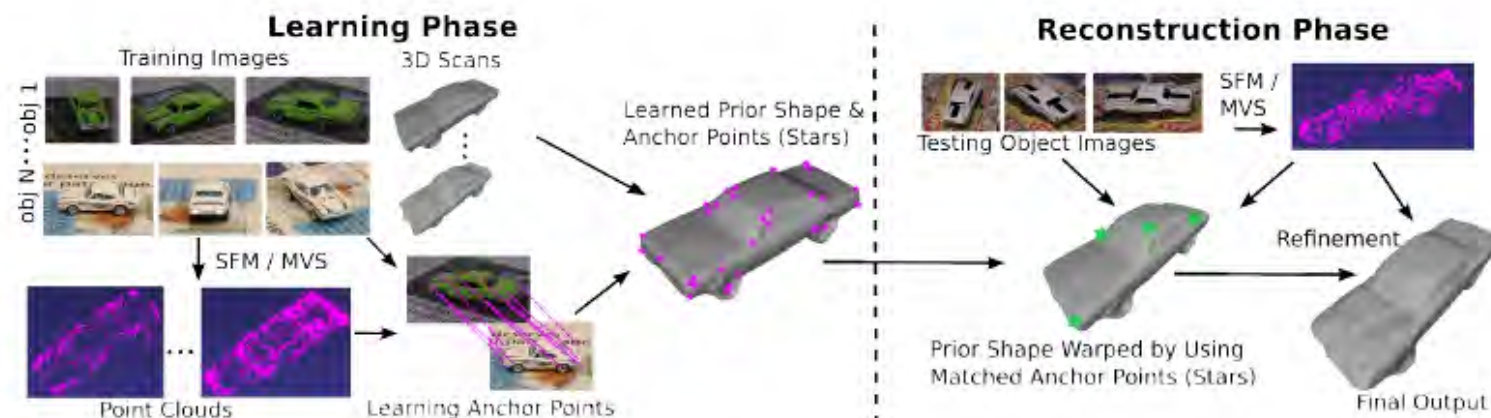
3D scan & image training data

- Extract 2D feature points
- Build mean shape → Warp scans aligning features

Category-level Mean Shape

Matching & Reconstruction

- Given sparse SfM point cloud & image query
- Warp mean shape to query anchor points
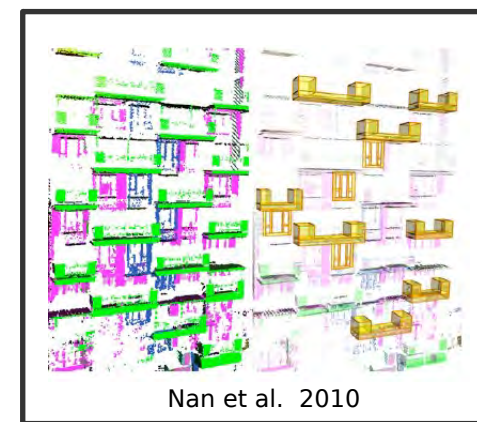- Refine fine-detail using MVS confidences
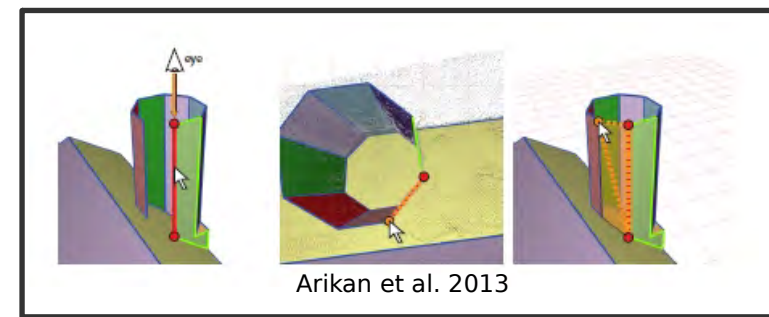

Images: Bao et al. 13
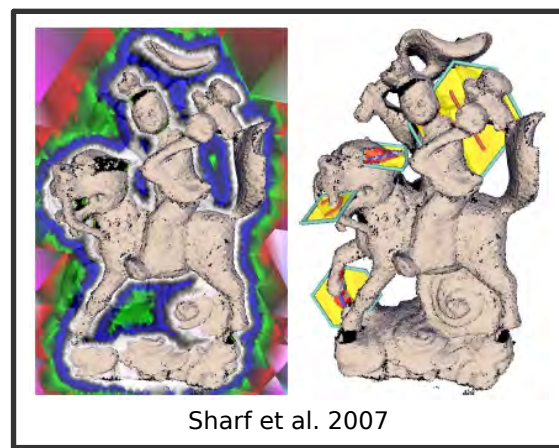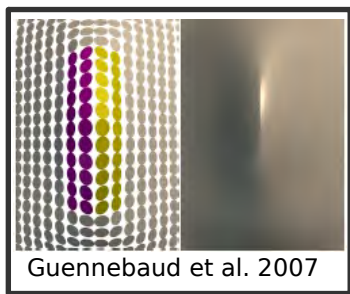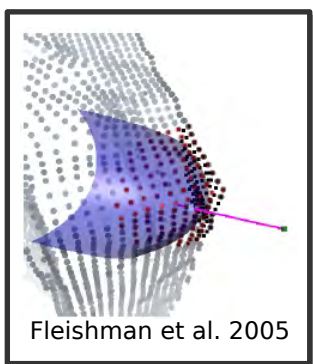
Interactive Methods

Incorporate user input to guide reconstruction process

Prompt user for key information

- Feature classification, topological, structural, & relationship cues

Challenge: Balance ease-of-use, speed, & algorithm integration

Arikan et al. 2013

Fleishman et al. 2005

Sharf et al. 2007

Nan et al. 2010

Guennebaud et al. 2007

Trend: Tight integration between user interaction and reconstruction pipeline

Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva

Interactive: *Topology Preserving*

Topology-aware Surface Reconstruction [Sharf et al. 2007]

- Augment initial implicit function approximation with user information
- Detect topologically weak regions
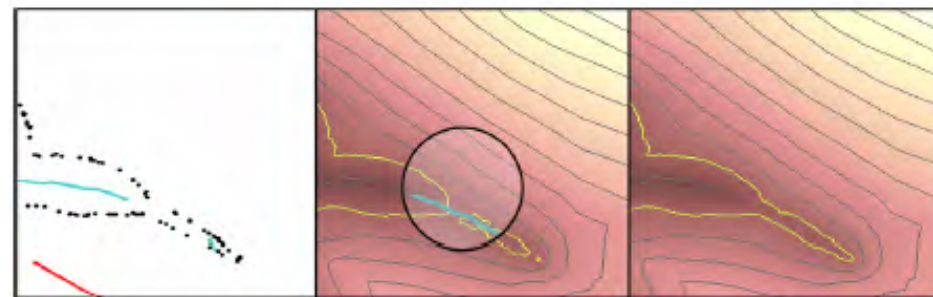- Examine local stability of zero-level set

Weak regions presented to user

- User scribbles on 2D tablet define interior/exterior regions
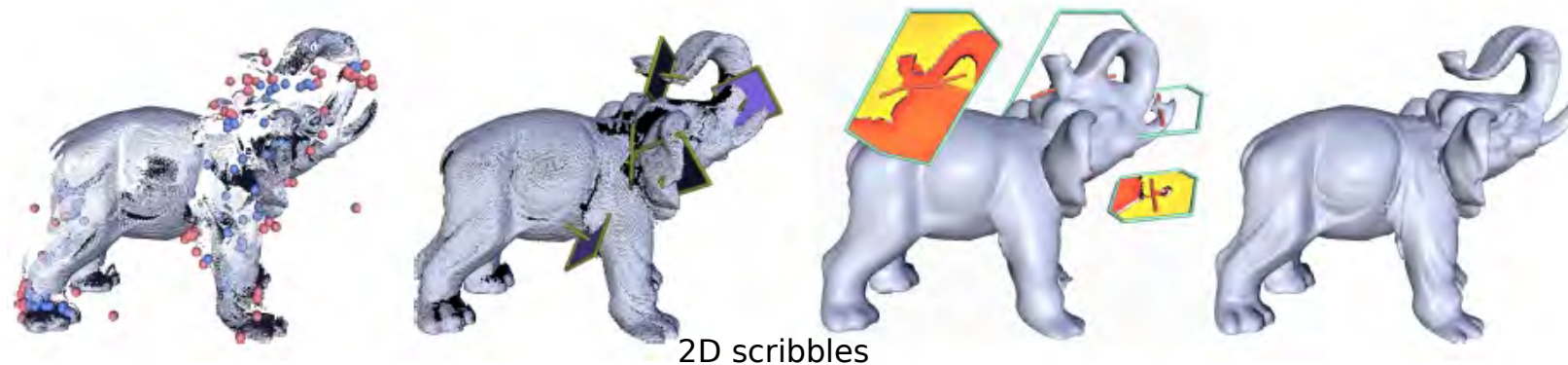- Incorporate as additional constraints

Iteratively update implicit function
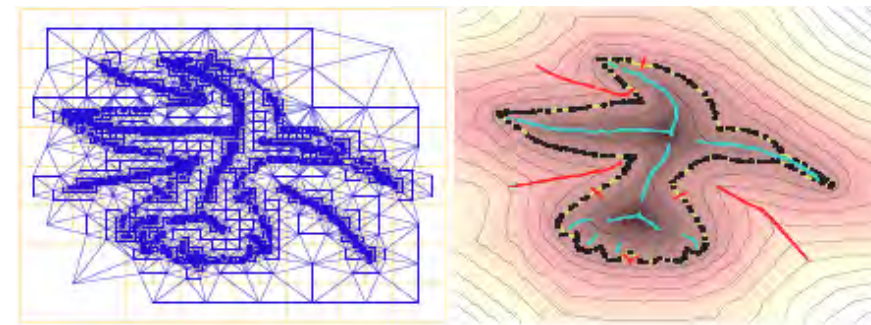
Decomposition & zero level set

Detecting & augmenting weak regions

2D scribbles

Sharf et al. 2007

Reconstructing structural regularities with user assistance

**Smartboxes for Interactive Urban Reconstruction** [Nan et al. 2010]

- Introduced simple axis-aligned geometric cuboid concept
- Coarse user manipulations → automatic refinement optimization

Considers both ***data*** and ***contextual*** terms for fitting & placement

- How well does the primitive fit the points wrt location, orientation, & size?
- How well does the primitive relate to previously positioned boxes wrt interval, alignment, & size?

Tightly integrated interactive environment

- *Smartbox* candidate selection
- Drag-and-drop of repeated structures
- Grouping

Smartbox fitting

Data vs. Contextual Fitting

Nan et al. 2010
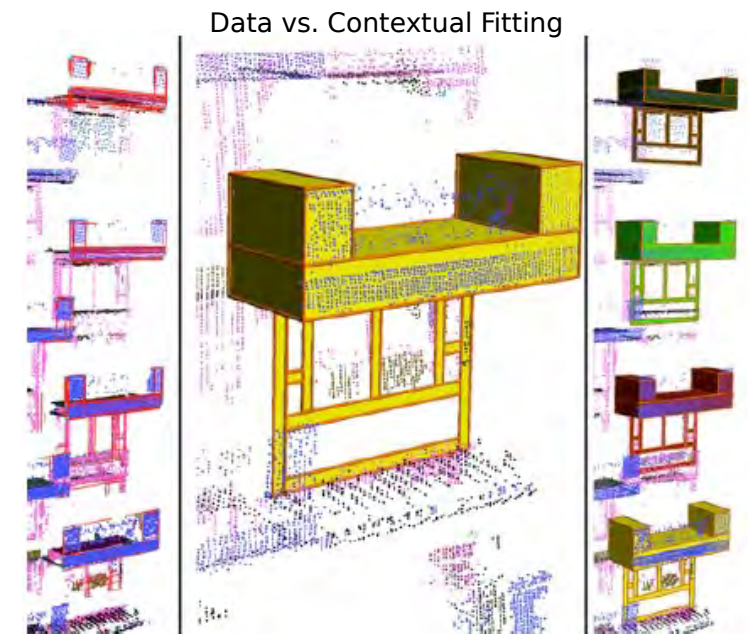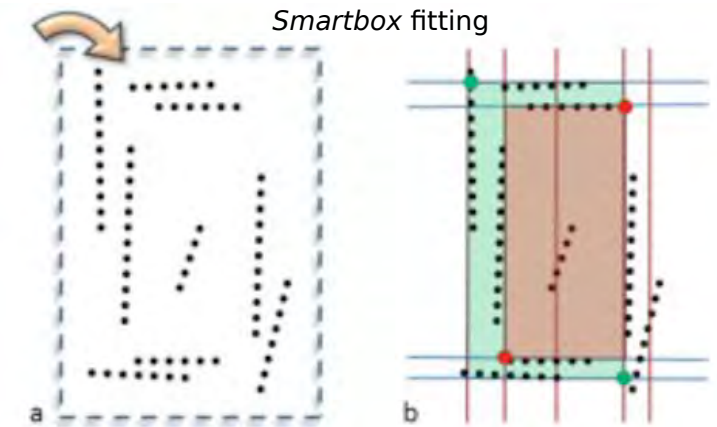
Interactive: *Relationships*

Reconstructing intra-shape relationships

Interactive polygonal modeling and boundary snapping
- O-Snap Optimization-Based Snapping for Modeling Architectures [Arikan et al. 2013]

Polygon Soup Snapping

- Automatic polygon extraction

- Adjacent relationship identification: vertex, edge, face

- Alignment optimization

Tightly integrated modeling environment

- *Polygon edit:* Refine automatically detected polygons & boundaries

- *Polygon sketching:* Create new polygons

- *Automatic Snapping:* Optimization continuously *snaps* edits through local and global relationship constraints

Arikan et al. 2013
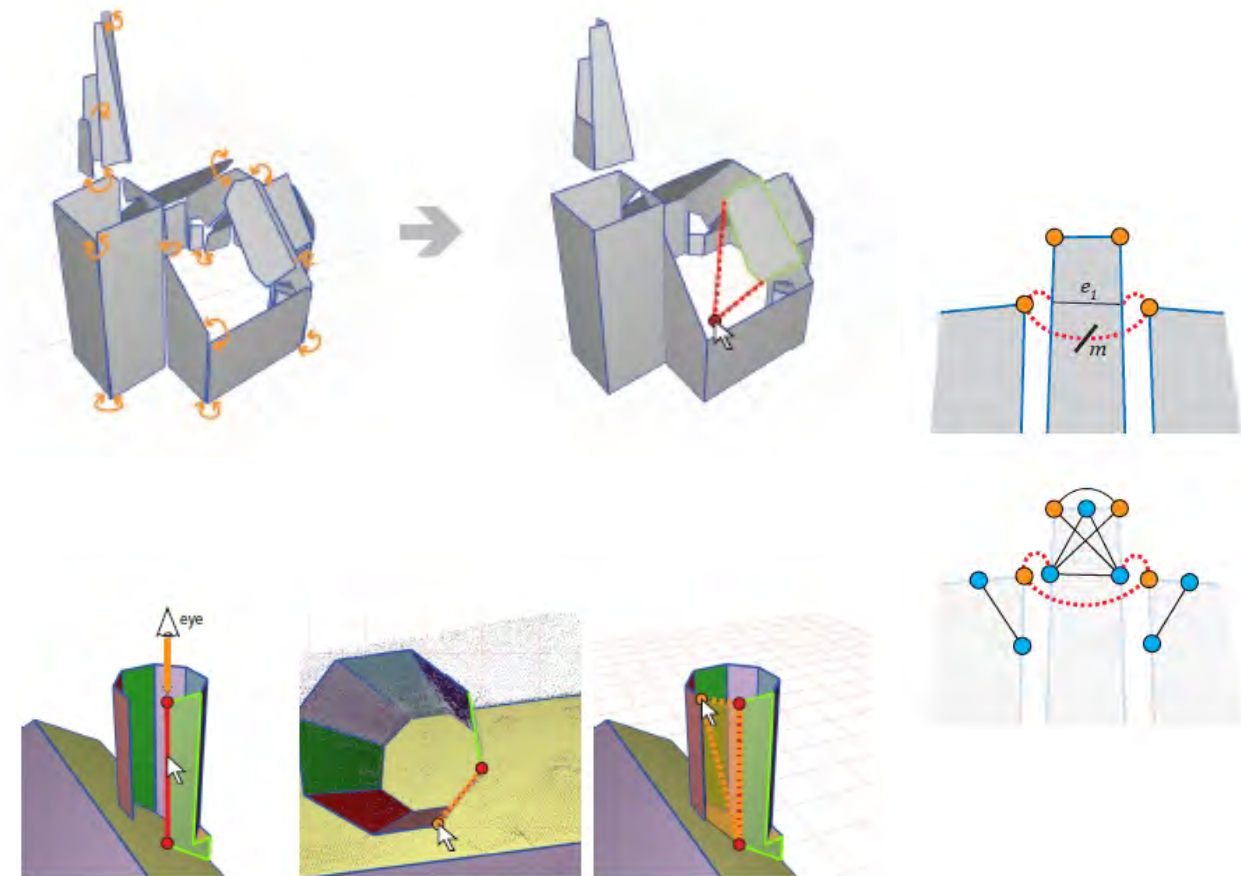
Surface Reconstruction Priors

Visibility, Volume Smoothness, Primitives
Global Structure, Data-driven, User-Driven

State of the Art in Surface Reconstruction from Point Clouds   Berger, Tagliasacchi, Seversky, Alliez, Levine, Sharf, Silva