Finding Surface Correspondences With Shape Analysis

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Motivation

Finding surface correspondences is important for understanding relationships in 3D data.
Motivation

Applications:

- Similarity measurement
- Collection exploration
- Surface interpolation
- Annotation transfer
- Surface registration
- Symmetry detection
- Saliency estimation
- Object recognition
- Visualization
- etc.
Motivation

Applications:
- Similarity measurement
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  - etc.

[Boyer, Lipman, et al., 2011]
Motivation

Applications:

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- etc.

[Kim et al., 2012]
Goal

Develop algorithms to find point correspondences

- Align “equivalent” features (semantic, functional, etc.)
- Consistent
- Robust
- Automatic
- Efficient
Previous Work

Classical methods:

- Local features
  - Global maps

[Kazhdan et al., 2004]
Previous Work

Classical methods:

- Local features
- Global maps

[Kim et al., 2011]
Challenge

Classical methods don’t work well for shapes with large local and global shape differences
Hypothesis

Discovering latent structure can be helpful for finding surface correspondences

Symmetries

Parts

Constraints

Affordances

Assemblies
Outline of Talk

Introduction

Latent structures
  ◦ Symmetries
  ◦ Parts
  ◦ Affordances
  ◦ Constraints
  ◦ Assemblies

Conclusion
Outline of Talk

Introduction

Latent structures
  ➢ Symmetries
    ◦ Parts
    ◦ Affordances
    ◦ Constraints
    ◦ Assemblies

Conclusion
Symmetry-Aware Correspondences

Observation 1: symmetry is ubiquitous in natural shapes
Symmetry-Aware Correspondences

Observation 2: detecting symmetries is easier than finding correspondences
Symmetry-Aware Correspondences

Approach: detect reflective symmetry axes and use them to find correspondences

[Image: Diagram showing the process of symmetry axis detection, alignment, and correspondence extrapolation]

[Liu et al., 2011]
Symmetry Axis Detection

Given a mesh, extract potential symmetry axes

Symmetry Axis (stationary points of symmetry map)
Symmetry Axis Alignment

For every pair of symmetry axes, find optimal alignment for every pair of starting points

\[ Q(C_1^i, C_2^j, c) = Q_{Axis}(C_1^i) \cdot Q_{Axis}(C_2^j) \cdot Q_{Align}(C_1^i, C_2^j, c) \]
Correspondence Extrapolation

Given an alignment between symmetry axes, extrapolate correspondences to rest of surfaces

Aligned Symmetry Axes

Aligned Extremal Feature Points

Full Surface Map
Symmetry-Aware Correspondence Evaluation

Surface Correspondence Benchmark [Kim 2011]

- TOSCA [Bronstein et al., 2008]
- SCAPE [Anguelov et al., 2004]
- SHREC Watertight 2007 [Giorgi et al., 2007]
Symmetry-Aware Correspondence Results

Evaluation methodology

% Correspondences vs. Geodesic Error

Ground-Truth vs. Predicted Correspondences

Evaluation methodology
Symmetry-Aware Correspondence Results

Comparison to Blended Intrinsic Maps [Kim 2011]
Outline of Talk

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  ➢ Parts
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  ◦ Assemblies

Conclusion
Part-Aware Correspondences

Observation: semantic correspondences are often based on parts

Consistent segmentation

[Golovinskiy et al., 2009]
Part-Aware Correspondences

Approach: learn part-based templates for collection of models and use them to find correspondences

Part-Based Template

- Variance in scale
- Variance in positions

[Kim et al., 2013]
Part-Aware Correspondences

Part-Based Template
Part-Aware Correspondences

Part-Based Template
Part-Aware Correspondences

Part-Based Template
Part-Aware Correspondences

Part-Based Templates
Part-Aware Correspondences

Part-Based Templates
Part-Aware Correspondences

Part-Based Templates
Part-Aware Correspondence Algorithm

Search for a set of templates that best explains a collection of models

Template Initialization

Template Fitting

Template Refinement

repeat until convergence
Part-Aware Correspondence Results

2 Templates

3113 Airplanes
Part-Aware Correspondence Results

Correspondence benchmark (7442 seats)
Outline of Talk

Introduction

Latent structures

○ Symmetries
○ Parts

➢ Affordances
○ Constraints
○ Assemblies

Conclusion
Affordance-Aware Correspondences

Observation 1: almost all man-made objects are used by people
Affordance-Aware Correspondences

Observation 2: the poses people take when using objects reveal functional correspondences
Affordance-Aware Correspondences

Approach: predict poses of people and use them to find correspondences

[Kim et al., 2014]
Pose Prediction Algorithm

Pose Parameters
- Contact points
- Joint Angles

Energy Function
- Contact Distance
- Feature Compatibility
- Pose Prior
- Symmetry
- Surface intersections

Search Procedure
- Sample pose parameters
- Solve contact points or joint angles (inverse kinematics)
- Evaluate energy function
Pose Prediction Results
Pose Prediction Results
Pose Prediction Results
Pose Prediction Failures
Affordance Correspondence Results

- Affordance-based Correspondences
- Shape-based Correspondences
Outline of Talk

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Latent structures
  - Symmetries
  - Parts
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  - Assemblies

Conclusion
Constraint-Aware Correspondences

Observation 1: global registration of RGB-D scans requires finding “loop closure” correspondences
Constraint-Aware Correspondences

Observation 2: almost all indoor environments follow the Manhattan World assumption

Intel Research Lab in Seattle
Constraint-Aware Correspondences

Observation 2: almost all indoor environments follow the Manhattan World assumption

- Orthogonal corners
- Parallel surfaces

Intel Research Lab in Seattle
Constraint-Aware Correspondences

Approach: detect and enforce Manhattan World constraints and use them to find correspondences

[Halber et al., submitted]
Constraint-Aware ICP Algorithm

Like a global ICP algorithm …
Constraint-Aware ICP Algorithm

…but detect constraint model in inner loop, and …
Constraint-Aware ICP Algorithm

... optimize correspondences and constraints jointly
Constraint-Aware ICP Issue

How detect constraints in warped point clouds?
Fine-to-Coarse Registration

Iteratively:

1. Detect constraints within windows of size \( w \)
2. Optimize
3. Increase \( w \)
Fine-to-Coarse Registration

Creates hierarchy of structure and constraints
Fine-to-Coarse Registration

Iteration 0
Fine-to-Coarse Registration

Fixes corners, straighten walls, ...
Fine-to-Coarse Registration

Fixes corners, straighten walls, closes loops, …

Iteration 6
Fine-to-Coarse Registration

Fixes corners, straighten walls, closes loops, snaps
Fine-to-Coarse Registration Example
# Constraint-Aware ICP Results

## Comparison to previous methods:

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<th>Xiao et al.</th>
<th>Choi et al.</th>
<th>Ours</th>
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Constraint-Aware ICP Results

[Xiao et al., 2013]
Constraint-Aware ICP Results

[Choi et al., 2015]
Constraint-Aware ICP Results

Ours
Constraint-Aware ICP Results

Comparison to previous methods:

[Xiao et al., 2013]  Ours
Constraint-Aware ICP Results

Comparison to previous methods:

[Choi et al., 2015]  Ours
Constraint-Aware ICP Results

Comparison to previous methods:
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- Constraints
  - Assemblies

Conclusion
Assembly-Aware Correspondences

Observation 1: assembling fractured objects requires finding complementary surface correspondences

Fragments of fractured wall painting from Akrotiri [Doumas et al.]
Assembly-Aware Correspondences

Observation: fracture correspondences are constrained by latent structure of global assembly
Assembly-Aware Correspondences

Approach: search for global assembly directly

Scanned Fragments

Global Assembly

[Sizikova et al., submitted]
Assembly Search Algorithm

Genetic algorithm:

- **Initialization**
- **Selection**
  - Round robin selection
  - Distribution of # of Clusters Per Fragment
- **Recombination**
  - By Match
  - By Fragment
- **Merge Feasibility And Scoring**
  - Fragment Overlap
  - Convex Hull Ratio
- **Diversification**
- **Termination**

Iterations:
- Iter. 2: 8 fragments
- Iter. 4: 16 fragments
- Iter. 6: 28 fragments
- Iter. 8: 45 fragments
- Iter. 10: 53 fragments
- Iter. 10: 53 fragments
- Iter. 11: 56 fragments
- Iter. 12: 69 fragments
- Iter. 13: 72 fragments
- Iter. 14: 88 fragments
Assembly Search Result

Able to predict correspondences with higher precision and recall with our genetic algorithm
Assembly Search Result

Able to predict correspondences with higher precision and recall with our genetic algorithm.

Pairwise Correspondences

Our Result

Ground Truth

Hierarchical Clustering

[Casteneda et al., 2011]
Assembly Search Result

Precision of predicted correspondences gets better as recall increases during our genetic search.
Conclusion

Discovering latent structure can be useful for finding correspondences

- Symmetries
- Parts
- Affordances
- Constraints
- Assemblies

Future work on surface correspondence should focus more on structure and semantics

- Hierarchies, supports, contexts, shape priors, physical properties, manufacturing methods, etc.
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Thank You!