Retrieval on Parametric Shape Collections

Adriana Schulz\textsuperscript{1}
Ariel Shamir\textsuperscript{2}
Ilya Baran\textsuperscript{3}
David Levin\textsuperscript{1,4}
Pitchaya Sitthi-amorn\textsuperscript{1,5}
Wojciech Matusik\textsuperscript{1}

\textsuperscript{1}Massachusetts Institute of Technology
\textsuperscript{2}The Interdisciplinary Center, Hertzliya
\textsuperscript{3}Onshape Inc.
\textsuperscript{4}University of Toronto
\textsuperscript{5}Chulalongkorn University
Shape Retrieval

[Osada et al. 2001]
[Chen et al. 2003]
[Brownstein et al 2011]

[Shilane et al. 2004]
[Velkamp.et al 2008]
[SHREC 2013 - 2017]
Parametrization

Advantages:
• constrains manipulations
  – e.g., fabrication-oriented constraints
• reduces the search space
Available Collections

SolidWorks
creo™ 1.0
OpenScad
Onshape

Thingiverse
GrabCAD
Onshape's Repository
Parametrization Techniques

Application Examples:

Linear Blend Skinning

Offset Surfaces

Cages


[Prevost et al. 2014] [Musialski et al. 2015] [Bharaj et al. 2015]
Data-Driven Modeling

[Xu et al. 2013]

[Xu et al. 2011]

[Nan et al. 2012]

[Schulz et al. 2014]

[Shen et al. 2012]

[Yang et al. 2015]
Parametric Shape Collections
Retrieval in Parametric Shape Collections

Parametric Shape Collection

Query
Typical Pipeline

Parametric Shape Collection

Query Shape
Typical Pipeline Fit-First

Parametric Shape Collection

parameter fitting

Fitted Shapes

matching

Query Shape

[Nan et al 2012]
Our Approach

Parametric Shape Collection

Precomputed descriptors

Descriptor Space

Matching

Query Shape
Retrieval Using Descriptors

$$F_{\theta}(\text{Shape descriptor}) \rightarrow [x_1, x_2, \ldots, x_n] \rightarrow \text{Descriptor Space}$$
Shape Retrieval with Descriptors

Descriptor Space

Parametric Shapes?
Parametric Shape Retrieval with Descriptors
Parametric Shape Retrieval with Descriptors
Parametric Shape Retrieval with Descriptors
Regions in Descriptor Space

Parameter Space

$\mathbb{R}^N \rightarrow \mathcal{M}$

$\mathcal{F}$

$\mathcal{D}$

$\mathbb{R}^K$

$\mathbb{R}^N$

$K \ll N$

Descriptor Space
Parametric Shape Retrieval with Descriptors
Approach

\[ \mathcal{M}(A) \rightarrow \mathcal{M}(A) = \{ P_1, \ldots, P_K \} \]

point

\[ P_i = p_i \]

bounded tangent space

\[ P_i = T_i \cap E_i \]
Technical Contribution

Algorithm for efficiently representing parametric shapes with these primitives to allow accurate retrieval.
Accuracy Criteria

\[
d_2(\bar{M}, x) \approx d_2 (M, x)
\]

\[
|d_2(\bar{M}, x) - d_2(M, x)| \leq \delta
\]

user specified
Coverage and Tightness

\[
|d_2(\bar{M}, x) - d_2(M, x)| \leq \delta \quad \forall x \in \mathbb{R}^N
\]

Coverage Property

\[
d_2(\bar{M}, y) \leq \delta \quad \forall y \in M
\]

Tightness Property

\[
d_2(M, y) \leq \delta \quad \forall y \in \bar{M}
\]
Algorithm

Initialize $\overline{M} = \emptyset$

Sample $y \in M$

if $\mathbb{R}^k d_2(\overline{M}, y) \leq \delta \Rightarrow \text{reject sample}$

else $\overline{M} \leftarrow P_i(y)$
Choosing Between Primitives

Cost of tangent = \((K + 1)\) cost of point
Coverage of tangent > \((K + 1)\) coverage of points

Point

\(P_i = p_i\)

Bounded tangent space

\(P_i = T_i \cap E_i\)

K tangent vectors + center point
Coverage of Points and Tangents

\[
\frac{d}{\delta} = \sqrt{\frac{2}{\delta \kappa}}
\]

curvature
Criteria for Primitive Selection

One-Dimensional Case

Use tangents if: \( \kappa \leq \frac{2}{\delta(K+1)^2} \)

Multi-Dimensional Case

Use tangents if: \( \kappa^{max} \leq \frac{2}{\delta(K+1)^K} \)
Bounding Tangent Primitives

\[ P_i = T_i \cap E_i \]

Hyperphere of radius \( r \)

Tightness Bound

\[ r \]

\[ \delta \]

\[ c(t) \]
Handling the Feasible set $A$

$$P_i = T_i \cap E_i$$

Ellipsoid

Tightness Bound

Feasible set $c(t)$
Our Approach: Retrieval

Descriptor Space $\mathbb{R}^N$
Retrieving the Parametric Shape

\[ \text{Dist} \left( x, p_i \right) \]

\[ \text{Dist} \left( x, T_i \cap E_i \right) \]

cost of tangent ~ \( K \) cost of point
Parameter Fitting

Parameter fitting

\( \mathbb{R}^N \)
Evaluations
Experiments: Data

Number of parameters: 2-9

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<th>Number of Models</th>
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<td>carts</td>
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Experiments: Descriptors

D2 Shape Distribution
VOXEL Shape Histogram
Light Field Descriptors
Manifold Representation: Efficiency

$K = 3$

$K = 5$

$K = 7$
Manifold Representation: Efficiency

$K = 3$

$K = 5$

$K = 7$

5X more efficient
Querying Parametric Variations

Parameter variations

Queries

“Mean” Shapes

Descriptors Space $\mathbb{R}^N$

Retrieval

Closest Mean shapes

29% Accuracy
Querying Parametric Variations

Our Method

Naïve Approach

Parameter Space

Descriptor Space

\[ \mathbb{R}^N \]

\[ \mathbb{R}^K \]

\[ A \]

\[ \mathcal{M} \]

same storage
Comparison with Naïve Method

Chairs

Planes

Boats

Full Database

Lamps

Carts

Tables

Worst Case Error vs. Target Error for Our Method

Our Method

Naïve Method
Querying Shapes from Online Repositories

Query D2 Descriptor Voxel Descriptor Light Field Descriptor

Error(\(\delta\)) 0.05 0.1 0.2 0.4 0.075 0.1 0.2 0.4 0.6 0.8 1.0 2.0
Classification

![Classification Diagram](#)

- **D2 (Manifold)**
- **Voxel (Manifold)**
- **Light Field (Manifold)**

Precision vs. Recall graph showing the performance of different methods across varying recall levels.
High Quality Descriptors ⇒ improves precision/recall
Low Quality Descriptors ⇒ additional complexity cannot be captured (noise)
Beyond Classification

Query

Closest mean shape

Closest parametric Shape (our Method)
Limitation and Future work

- Scalability (number of parameters)
Limitation and Future work

• Scalability (number of parameters)
• Supporting Discrete Variations
Limitation and Future work

- Scalability (number of parameters)
- Supporting Discrete Variations
- Retrieval Methods
Conclusion

First approach for efficient retrieval on a collection of parametric shapes
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Data available at:
http://people.csail.mit.edu/aschulz/paramShapeRetrieval