Introduction to Shape Analysis

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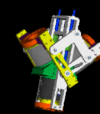
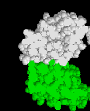
Princeton University
COS 526, Fall 2010

Motivation

Large repositories of 3D data are becoming available


Computer Graphics


Mechanical CAD


Molecular Biology


Medicine


Cultural Heritage


Computer Vision

Lecture Outline

Introduction
Problems ←
Applications
Simple example

Shape Analysis Problems

Examples:
- Feature detection
- Segmentation
- Labeling
- Registration
- Matching
- Recognition
- Classification
- Clustering
- Retrieval

Shape Analysis Problems

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"How can we find significant geometric features robustly?"

Shape Analysis Problems

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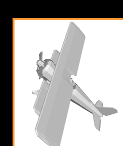
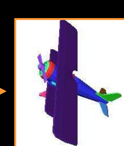

Input Mesh


Part Decomposition

"How can we decompose a 3D model into its parts?"

Shape Analysis Problems

Images courtesy of Ayellet Tal, Technion & Princeton University

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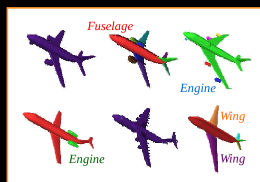

Semantic Labels
(Golovinskiy, Lee, et al.)

"How can we decompose a 3D model into its parts?"

Shape Analysis Problems

Images courtesy of Emil Praun

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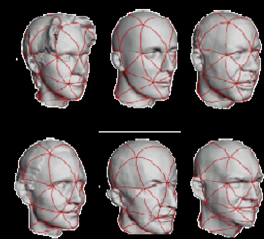

"How can we align features of 3D models?"

Shape Analysis Problems

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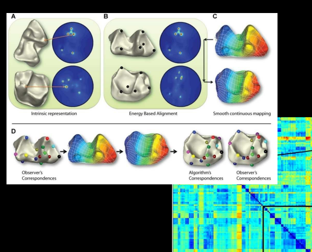

"How can we compute a measure of geometric similarity?"

Shape Analysis Problems

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Query

Ranked Matches

"How can we find 3D models best matching a query?"

Shape Analysis Problems

Images courtesy of Florida State Univ.

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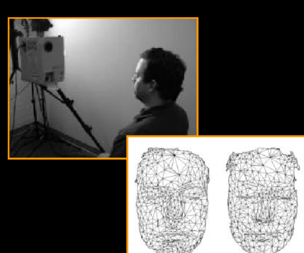

"How can we find a given 3D model in a large database?"

Shape Analysis Problems

Images courtesy of Darpa E3D Project

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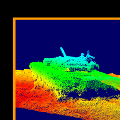
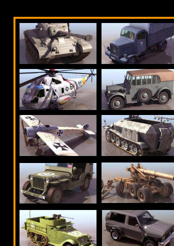

Query


Classes

"How can we determine the class of a 3D model?"

Shape Analysis Problems

Images courtesy of Viewpoint

Examples:

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"How can we learn classes of 3D models automatically?"

A Quick Diversion …

Images courtesy of Georgia Tech and www.dreamhorse.com

Which is harder to analyze?

3D Model

2D Image

Lecture Outline

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Simple example

Shape Analysis Applications

Examples:

- Computer graphics
- Geometric modeling
- Mechanical CAD
- Archaeology
- Virtual worlds
- Paleontology
- Molecular bio
- Medicine
- Forensics
- Art

Shape Analysis Applications

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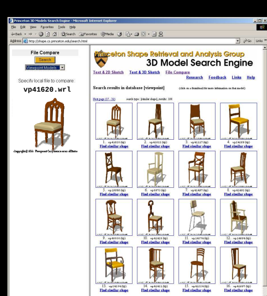

Shape Analysis Applications

Image courtesy Ayellet Tal, Technion & Princeton University

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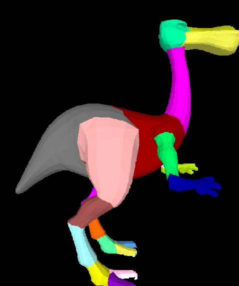

Shape Analysis Applications

Images courtesy of Bill Regli, Drexel University

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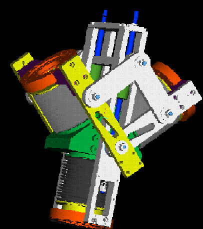

Shape Analysis Applications

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Reconstructing Frescoes from Thera
(Weyrich, Brown, Rusinkiewicz, et al.)

Shape Analysis Applications

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Shape Analysis Applications

Images courtesy of Delson & Freiss

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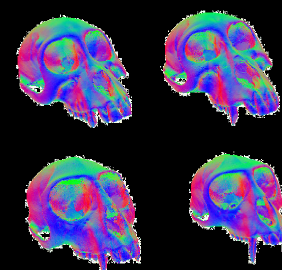

Shape Analysis Applications

Image courtesy of Ilya Vakser, GRAMM

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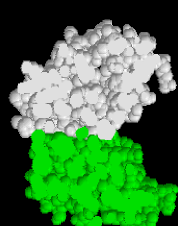

Shape Analysis Applications

Image courtesy of Polina Golland, MIT

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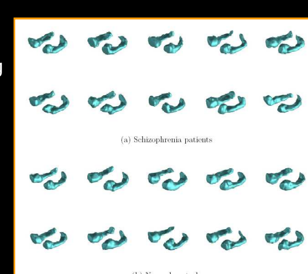

Hippocampus-amygdala study in schizophrenia

Shape Analysis Applications

Images courtesy of Boeing

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Shape Analysis Applications

Images courtesy of Stanford University

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Lecture Outline

Introduction

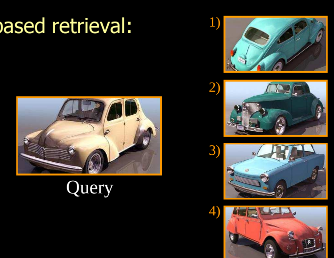
Problems

Applications

Simple example ←

Simple Example

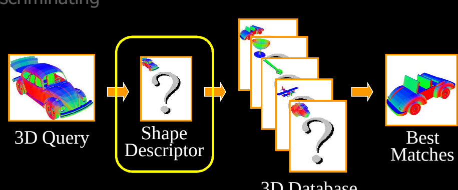
Shape-based retrieval:



"How can we find 3D shapes best matching a query?"

Shape Retrieval Challenges

Need shape descriptor & matching method that is:
- Concise to store
- Quick to compute
- Efficient to match
- Discriminating



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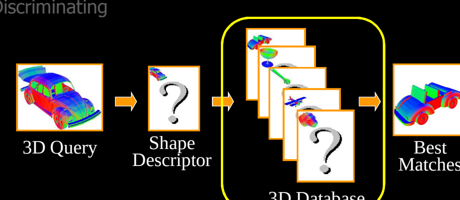

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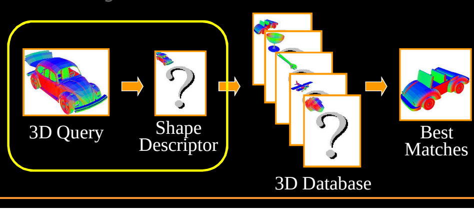

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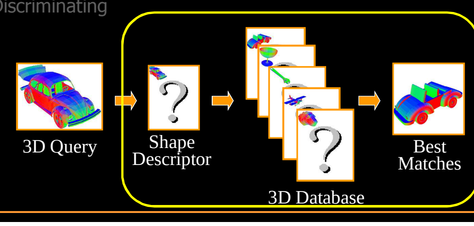

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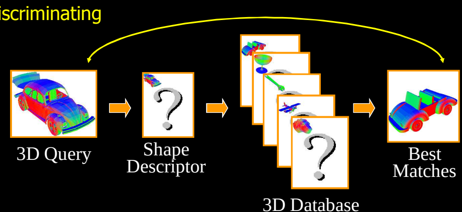

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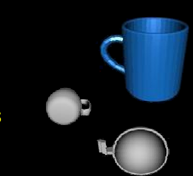
- Robust to degeneracies



Different Transformations
(translation, scale, rotation, mirror)

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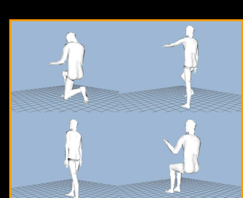

Different Articulated Poses

Shape Retrieval Challenges

Image courtesy of Ramamoorthi et al.

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Scanned Surface

Shape Retrieval Challenges

Images courtesy of Viewpoint & Stanford

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Different Genus

Different Tessellations

Shape Retrieval Challenges

Images courtesy of Utah & De Espona

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No Bottom!

&*Q?@#A%!

Possible Shape Descriptors

Images courtesy of Amenta & Osada

Structural representations

- Skeletons
- Part-based methods
- Feature-based methods

Statistical representations

- Attribute feature vectors
- Volumetric methods
- Surface-based methods
- View-based methods

Possible Shape Descriptors

Structural representations

- Skeletons
- Part-based methods
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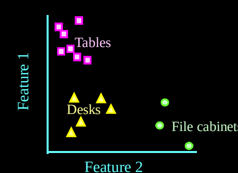


Statistical representations

- Attribute feature vectors
- Volumetric methods
- Surface-based methods
- View-based methods

Simple Method

Shape distributions

- Shape representation: probability distributions
- Distance measure: difference between distributions

We are starting with discussion of a simple method to introduce the basic ideas

Shape Distributions

Motivation: general approach to finding a common parameterization for matching

Audio

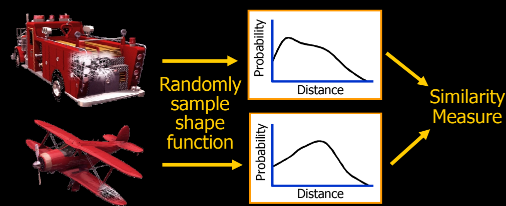
3D Surface

2D Contour

3D Volume

Shape Distributions

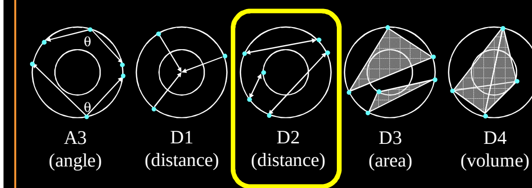
Key idea: map 3D surfaces to common parameterization by randomly sampling shape function



3D Models D2 Shape Distributions

Which Shape Function?

Implementation: simple shape functions based on angles, distances, areas, and volumes



[Ankerst 99]

D2 Shape Distribution

Properties

- Concise to store?
- Quick to compute?
- Invariant to transforms?
- Efficient to match?
- Insensitive to noise?
- Insensitive to topology?
- Robust to degeneracies?
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- Discriminating?

D2 Shape Distribution

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Concise to store?
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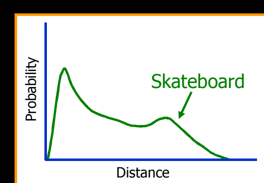


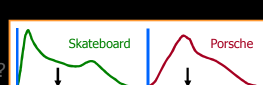
512 bytes (64 values)
0.5 seconds (10^6 samples)

D2 Shape Distribution

Properties

Concise to store
Quick to compute
Invariant to transforms? { Translation, Rotation, Mirror, Scale (w/ normalization)

- Efficient to match?
- Insensitive to noise?
- Insensitive to topology?
- Robust to degeneracies?
- Invariant to deformations?
- Discriminating?



Normalized Means

D2 Shape Distribution

Properties

Concise to store
Quick to compute
Invariant to transforms
Efficient to match?

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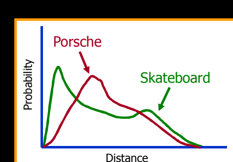

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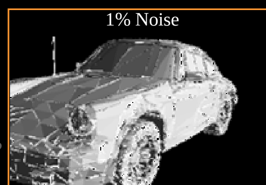

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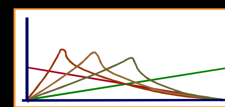

Ellipsoids with Different Eccentricities

D2 Shape Distribution

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- ✗ Invariant to deformations
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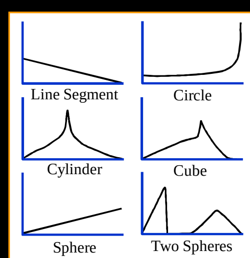
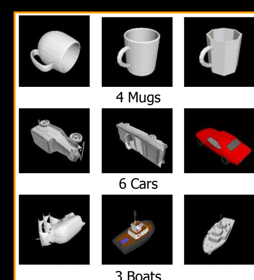


D2 Shape Distribution Results

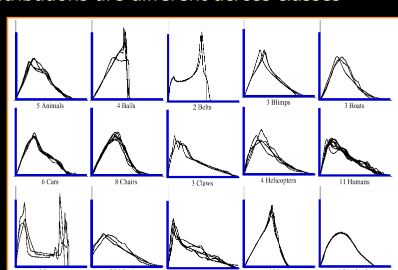
Question
- How discriminating are D2 shape distributions?

Test database
- 133 polygonal models
- 25 classes



D2 Shape Distribution Results

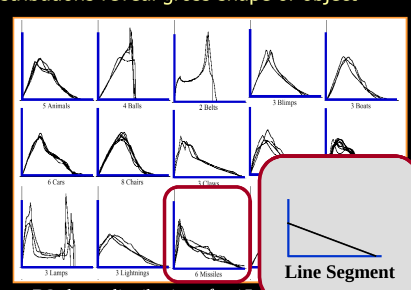
D2 distributions are different across classes



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results

D2 distributions reveal gross shape of object



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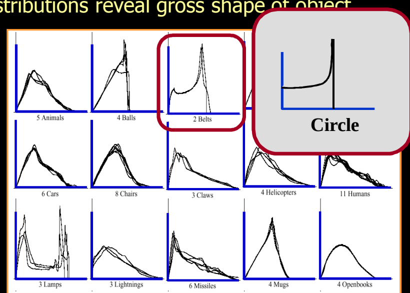

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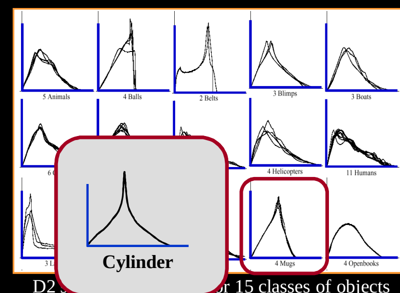
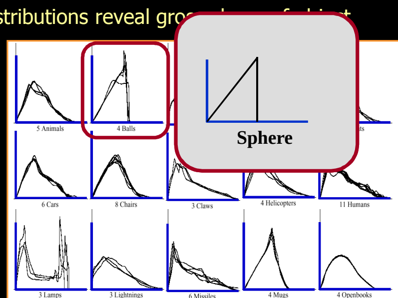


D2 … r 15 classes of objects

D2 Shape Distribution Results

D2 distributions reveal gro…



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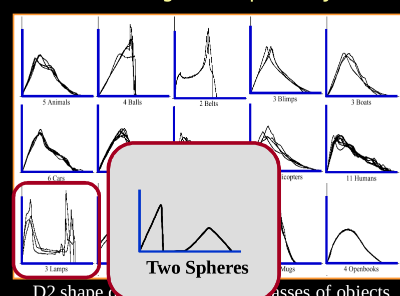
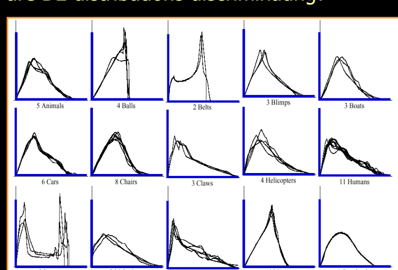


D2 shape … asses of objects

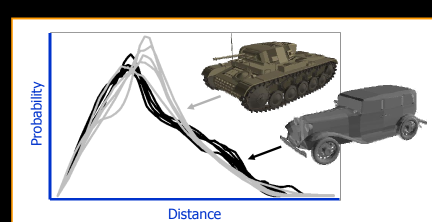
D2 Shape Distribution Results

But … are D2 distributions discriminating?



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results



D2 distributions for 5 tanks (gray) and 6 cars (black)

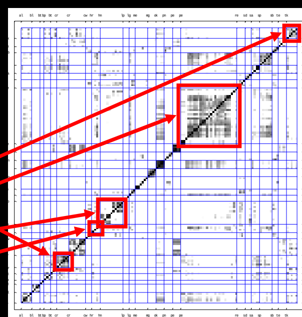
D2 Shape Distribution Results

Similarity Matrix

- Darkness represents similarity

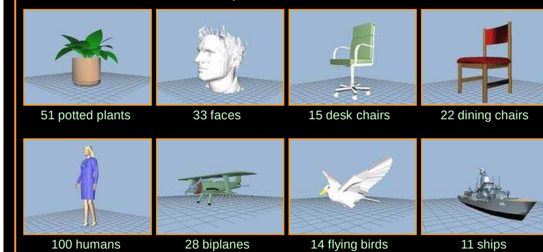
Blocks

- Tanks, cars
- Airplanes
- Humans
- Helicopters



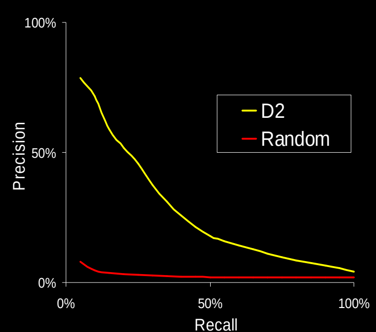
D2 Shape Distribution Results

Princeton Shape Benchmark
1814 classified models, 161 classes

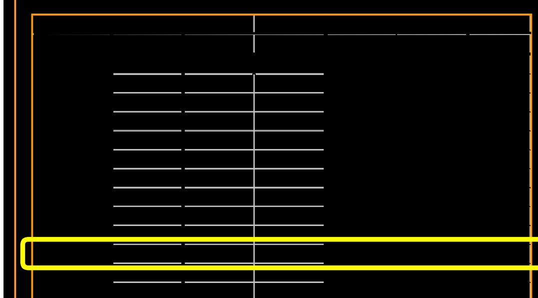


http://shape.cs.princeton.edu/benchmark

D2 Shape Distribution Results



D2 Shape Distribution Results



Next Lectures …

Better shape representations
More shape analysis methods