Shape Analysis

Thomas Funkhouser
Princeton University

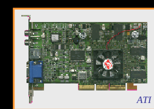
CS526, Fall 2006

Introduction

Images courtesy of Cyberware, ATI, & 3Dcafe

3D data is becoming widely available


Cheap Scanners


Fast Graphics Cards


World Wide Web

Someday 3D models will be as common as images are today

Motivation

Images courtesy of Stanford & Utah

When 3D data is ubiquitous, there will be a shift in research focus

Previous research has asked: "How do we acquire 3D data?"


Utah VW Bug


Utah Teapot


Stanford Bunny

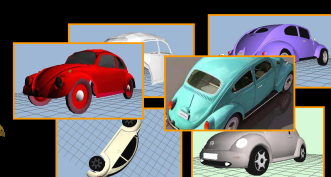
Future research will ask: "How do we find 3D data?"

Introduction

Images courtesy of De Espona & Utah

3D data acquired via the Web will often be void of structural and semantic information

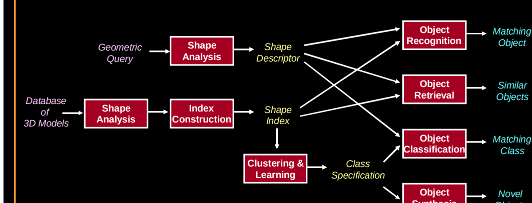

Utah VW Bug



Analysis algorithms also are needed to create "useful" 3D models from "raw" 3D data

Introduction

Research in retrieval & analysis 3D data will follow the trends of other media types



Introduction

Images courtesy of Georgia Tech and www.dreamhorse.com

Which is harder to analyze?


3D Model


2D Image

Lecture Outline

Introduction

Problems ⟵

Applications

Shape Matching

Shape Analysis Problems

Examples:

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

Shape Analysis Problems

Examples:

Ø Feature detection
- Segmentation
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"How can we find significant geometric features robustly?"

Shape Analysis Problems

Images courtesy of Ayellet Tal, Technion & Princeton University

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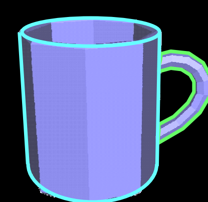

"How can we decompose a 3D model into its parts?"

Shape Analysis Problems

Images courtesy of Ayellet Tal, Technion & Princeton University

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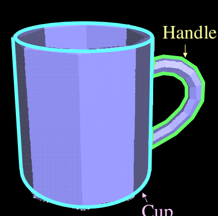

"How can we decompose a 3D model into its parts?"

Shape Analysis Problems

Images courtesy of Emil Praun

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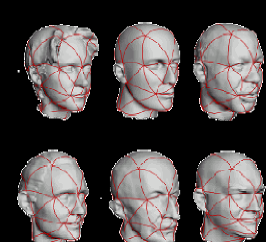

"How can we align features of 3D models?"

Shape Analysis Problems

Image courtesy of Ilya Vakser, GRAMM

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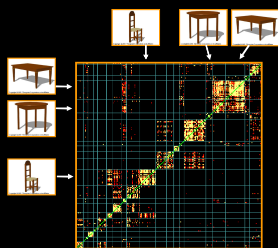

"How can we compute a measure of geometric similarity?"

Shape Analysis Problems

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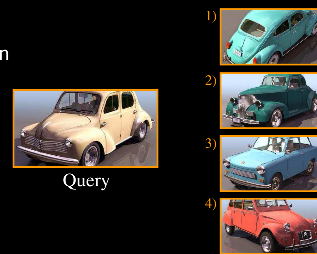

Query

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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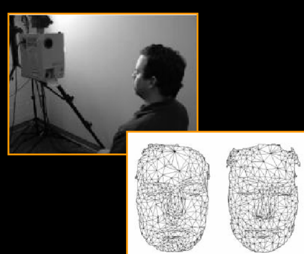

"How can we find a given 3D model in a large database?"

Shape Analysis Problems

Images courtesy of Darpa E3D Project

Examples:
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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?"

Lecture Outline

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Problems

Applications ←

Shape Matching

Shape Analysis Applications

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- Virtual worlds
- Animation
- Mechanical CAD
- Chemistry
- Military
- Paleontology
- Molecular bio
- Medicine
- Forensics
- Art

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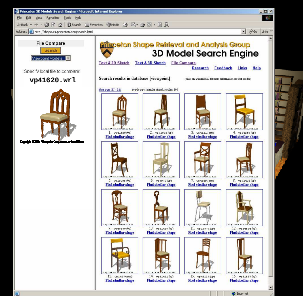

Shape Analysis Applications

Image courtesy of Ayellet Tal, Technion & Princeton University

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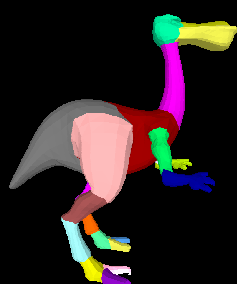

Shape Analysis Applications

Images courtesy of Bill Regli, Drexel University

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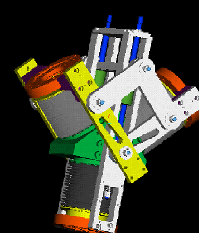

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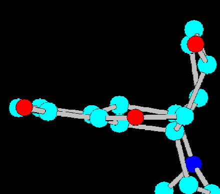

Morphine

Shape Analysis Applications

Images courtesy of Darpa E3D Project

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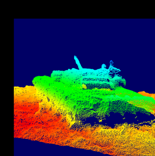

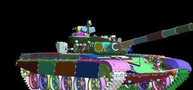

Shape Analysis Applications

Images courtesy of Delson & Freiss

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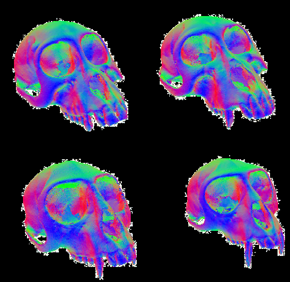

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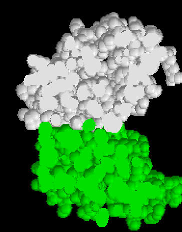

Shape Analysis Applications

Image courtesy of Polina Golland, MIT

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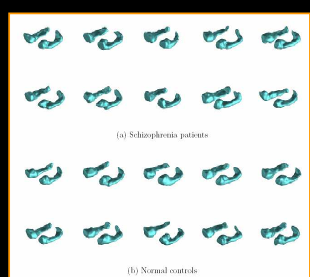

Hippocampus-amygdala study in schizophrenia

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

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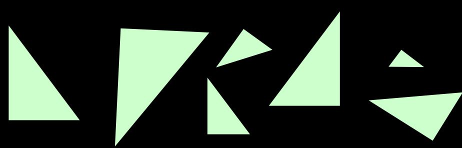
Shape Matching

Shape

Definition from Merriam-Webster's Dictionary:

- **a :** the visible makeup characteristic of a particular item or kind of item
  b : spatial form or contour



Shape Matching

Need a shape distance function d(A,B) that:

- Matches our intuitive notion of shape similarity
- Can be evaluated by a computer

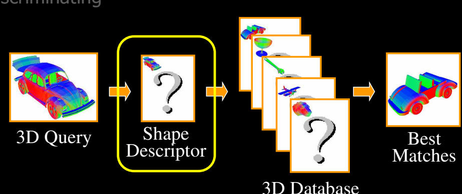
Perhaps, shape distance function should be a metric:

- Non-negative: $d(A,B) \geq 0$ for all A and B
- Identity: $d(A,B) = 0$ if and only if A=B
- Symmetry: $d(A,B) = d(B,A)$ for all A and B
- Triangle inequality: $d(A,B) + d(B,C) \geq d(A,C)$

Shape Matching Challenges

Need shape descriptor & matching method that is:

- Concise to store
- Quick to compute
- Efficient to match
- Discriminating



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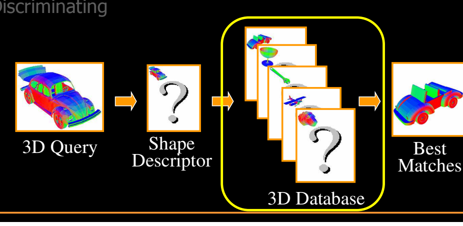

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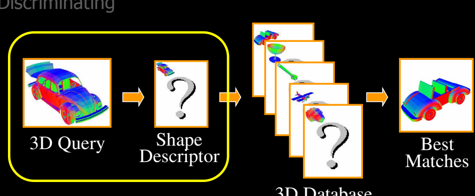

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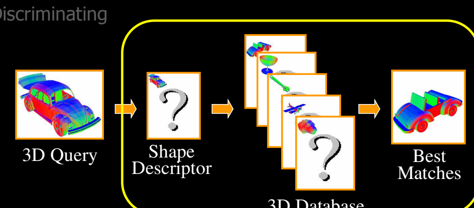

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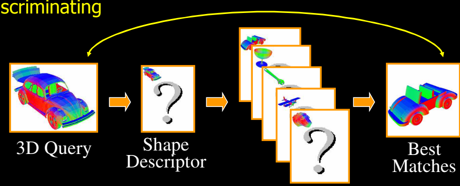

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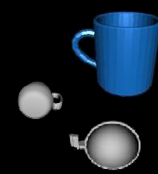

Different Transformations
(translation, scale, rotation, mirror)

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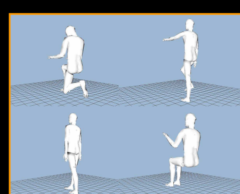

Different Articulated Poses

Shape Matching Challenges

Image courtesy of Ramamoorthi et al.

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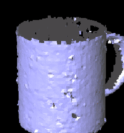

Scanned Surface

Shape Matching Challenges

Images courtesy of Viewpoint & Stanford

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Different Genus

Different Tessellations

Shape Matching Challenges

Images courtesy of Utah & De Espona

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No Bottom!

&*Q?@#A%!

Taxonomy of 3D Matching Methods

Images courtesy of Amenta & Osada

Structural representations
- Skeletons
- Part-based methods
- Feature-based methods

Statistical representations
- Attribute vectors
- Volumetric methods
- Surface-based methods
- View-based methods

Taxonomy of 3D Matching Methods

Image courtesy of Mao Chen

Structural representations
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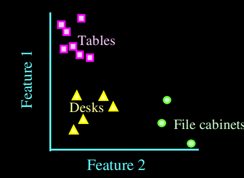


Example

Shape distributions
- Shape representation: probability distributions
- Distance measure: difference between distributions
- Evaluation method: classification performance

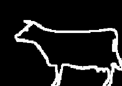
We are starting with discussion of a simple method to introduce the basic ideas

Shape Distributions

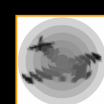
Motivation: general approach to finding a common parameterization for matching

Audio

3D Surface



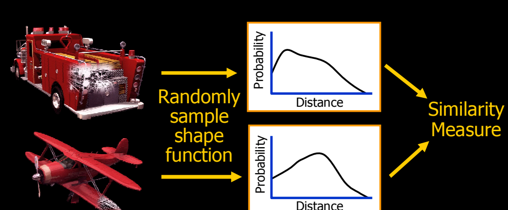
2D Contour



3D Volume

Shape Distributions

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

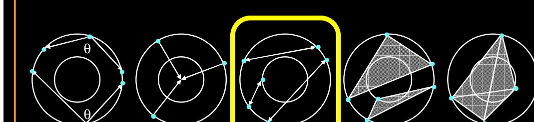


3D Models

D2 Shape Distributions

Which Shape Function?

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



A3 (angle) | D1 (distance) | D2 (distance) | D3 (area) | D4 (volume)

[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?

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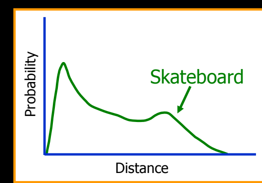

512 bytes (64 values)
0.5 seconds (10^6 samples)

D2 Shape Distribution

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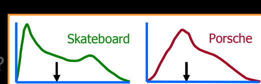
- ü Translation
- ü Rotation
- ü Mirror
- ü Scale (w/ normalization)



Normalized Means

D2 Shape Distribution

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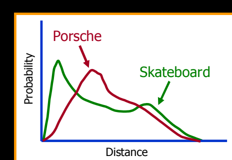

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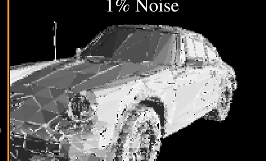
1% Noise



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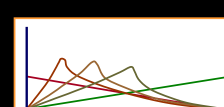

Ellipsoids with
Different Eccentricities

D2 Shape Distribution

Properties

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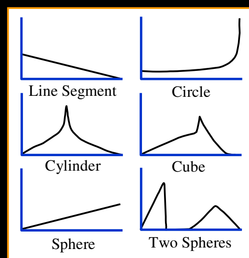


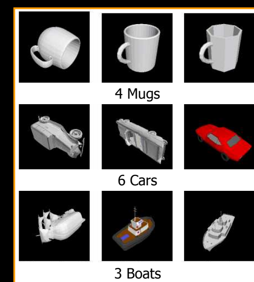
D2 Shape Distribution Results

Question

- How discriminating are D2 shape distributions?

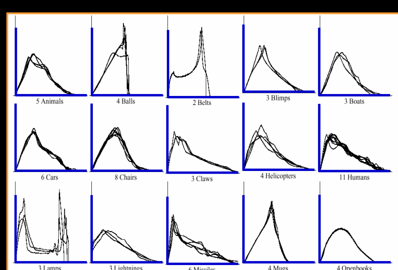
Test database

- 133 polygonal models
- 25 classes



D2 Shape Distribution Results

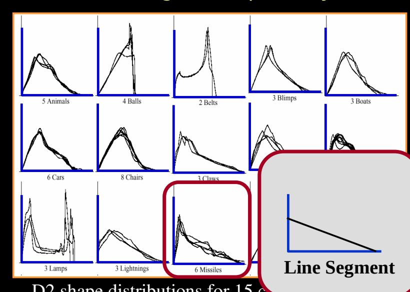
D2 distributions are different across classes



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results

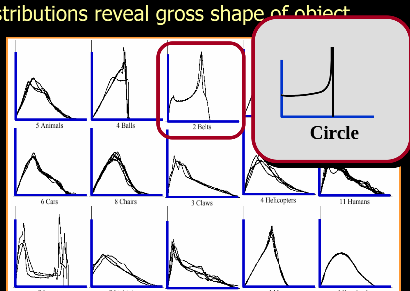
D2 distributions reveal gross shape of object



D2 shape distributions for 15 c...

D2 Shape Distribution Results

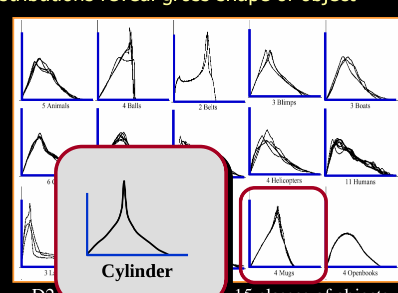
D2 distributions reveal gross shape of object



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results

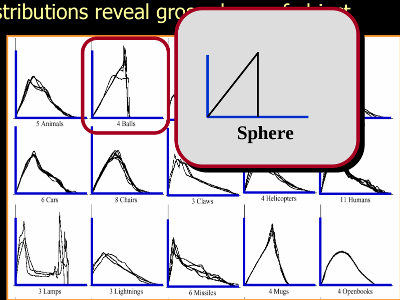
D2 distributions reveal gross shape of object



D2 ... 15 classes of objects

D2 Shape Distribution Results

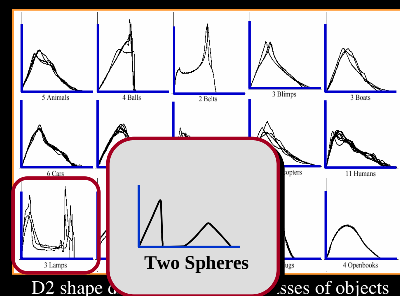
D2 distributions reveal gross shape of object



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results

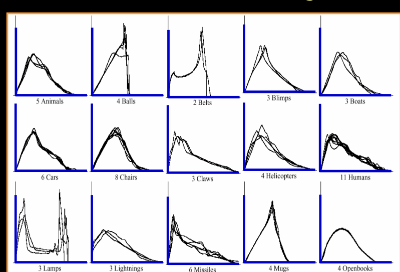
D2 distributions reveal gross shape of object



D2 shape d… …sses of objects

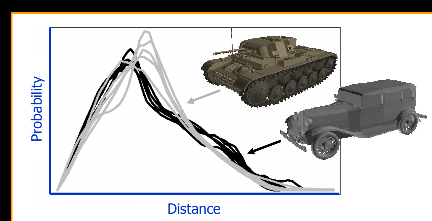
D2 Shape Distribution Results

But … are D2 distributions discriminating?



D2 shape distributions for 15 classes of objects

D2 Shape Distribution Results

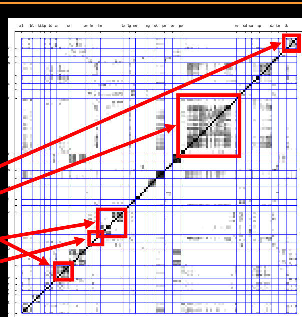


D2 distributions for 5 tanks (gray) and 6 cars (black)

D2 Shape Distribution Results

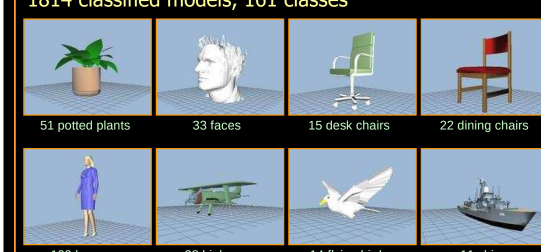
Similarity Matrix
- Darkness represents similarity

Blocks
- Tanks, cars
- Airplanes
- Humans
- Helicopters



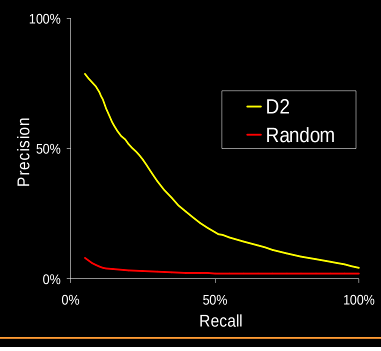
D2 Shape Distribution Results

Princeton Shape Benchmark
1814 classified models, 161 classes



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

D2 Shape Distribution Results



D2 Shape Distribution Results

Shape Descriptor	Storage (bytes)	Compute Time (s)	Compare Time (us)	Nearest Neighbor	DCGain	Norm DCGain
LFD	3.25	4,700	1,300	66%	64%	21%
REXT	2.22	17,416	229	60%	60%	13%
SHD	1.69	2,184	27	56%	58%	10%
GEDT	1.69	32,776	450	60%	58%	10%
EXT	1.17	552	8	55%	56%	6%
SECSHEL	1.38	32,776	451	55%	55%	3%
VOXEL	1.34	32,776	450	54%	54%	2%
SECTORS	0.90	552	14	50%	53%	0%
CEGI	0.37	2,056	27	42%	48%	-10%
EGI	0.41	1,032	14	38%	47%	-11%
D2	1.12	136	2	31%	43%	-18%
SHELLS	0.66	136	2	23%	39%	-27%
RANDOM	0	0	0	2%	26%	-54%

Next Times …

Better shape representations

More shape analysis applications