Shape Descriptors I

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CS597D, Fall 2003
Princeton University

3D Representations

What properties are required for analysis and retrieval?

Property	Editing	Display	Analysis	Retrieval
Intuitive specification	Yes	No	No	No
Guaranteed continuity	Yes	No	No	No
Guaranteed validity	Yes	No	No	No
Efficient boolean operations	Yes	No	No	No
Efficient rendering	Yes	Yes	No	No
Accurate	Yes	Yes	?	?
Concise	?	?	?	Yes
Structure	Yes	Yes	Yes	Yes

Shape Analysis Problems

Examples:

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

Query

1) 2) 3) 4)

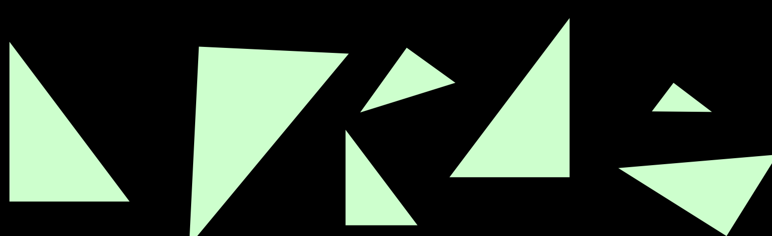
Ranked Matches

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

Shape

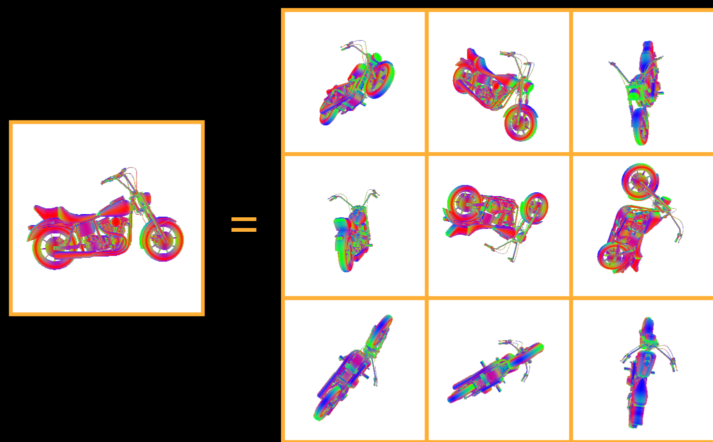
Definition from Merriam-Webster's Dictionary:

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



Shape

Shape is independent of similarity transformation (rotation, scale, translation, mirror)



Shape Similarity

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

- matches our intuitive notion of shape similarity
- can be computed robustly and efficiently

Perhaps, shape distance function should be a metric:

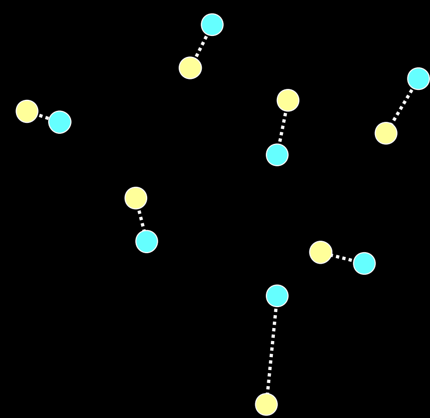
- Non-negative: $d(A,B) \geq 0$ for all A and B
- Identity: $d(A,B) = 0$ if and only if $A=B$
- Symmetry: $d(A,B) = d(B,A)$ for all A and B
- Triangle inequality: $d(A,B) + d(B,C) \geq d(A,C)$

Example Distance Functions

L_p norm:

Hausdorff distance:

Others (Fréchet, etc.)



Shape Matching

Compute shape distance function for pair of 3D models

- Can matching two objects
- Can find most similar object among a small set

Are these the same chair?

Shape Retrieval

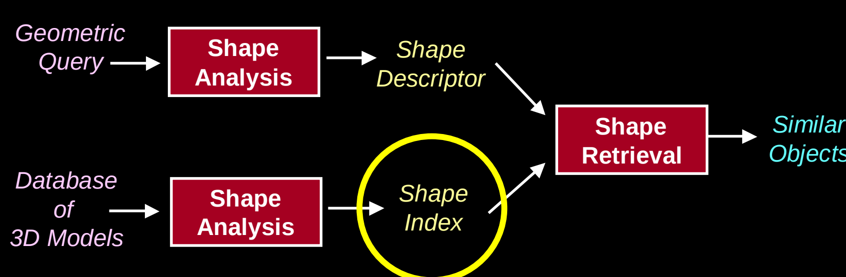
Find 3D models with shape most similar to query

- Searching large database must take less than O(n)

Is this blue chair in the database?

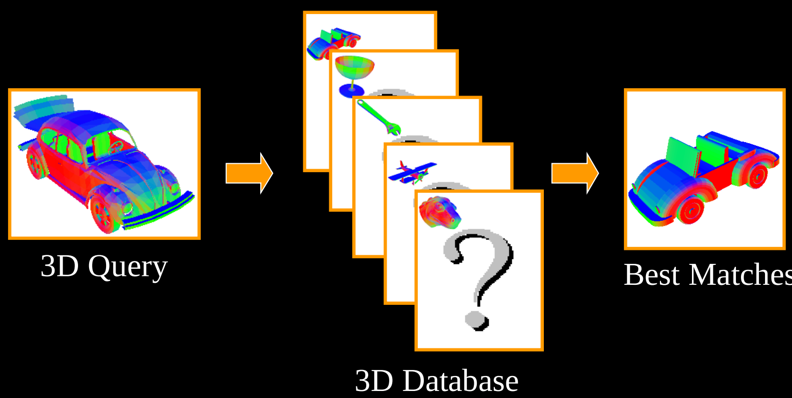
Shape Retrieval

Build searchable shape index



Shape Retrieval

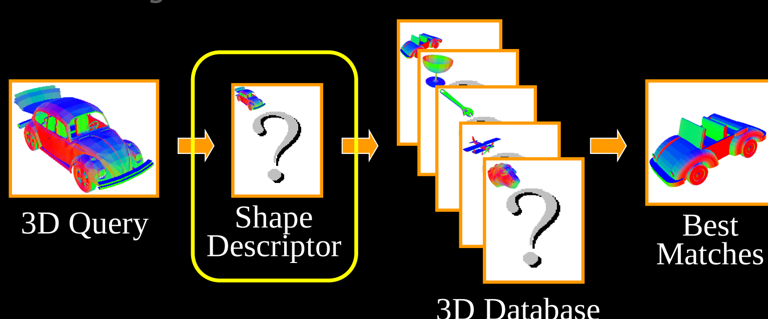
Find 3D models with shape similar to query



Challenge

Need shape descriptor that is:

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



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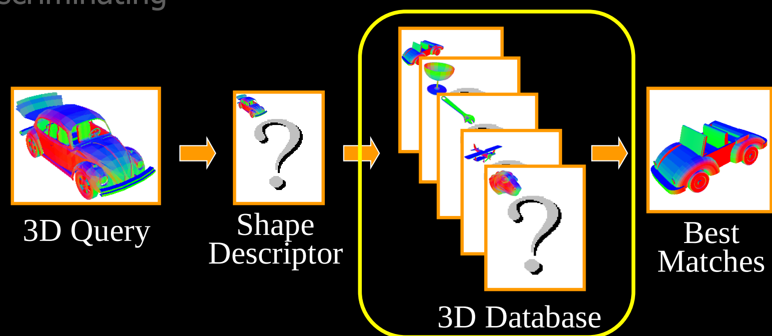

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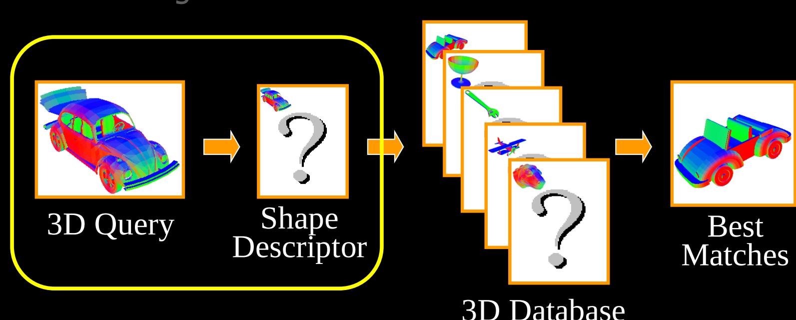

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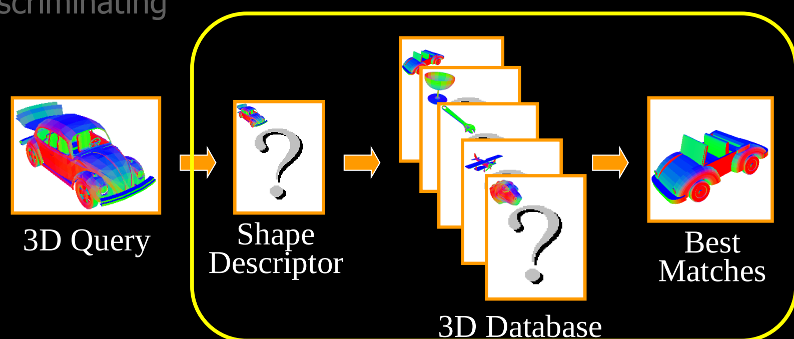

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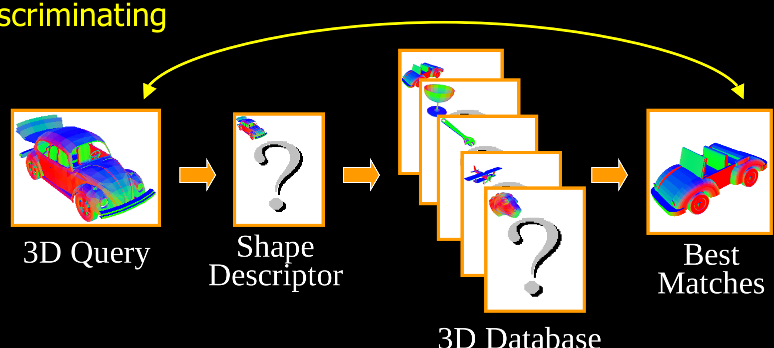

Challenge

Need shape descriptor that is:

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- Quick to compute
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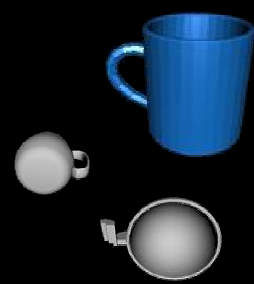
Ø Invariant to transformations

- Insensitive to noise
- Insensitive to topology
- Robust to degeneracies



Different Transformations
(translation, scale, rotation, mirror)

Challenge

Image courtesy of
Ramamoorthi et al.

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Scanned Surface

Challenge

Images courtesy of Viewpoint & Stanford

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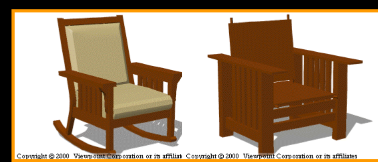
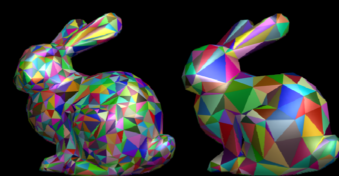


Different Genus



Different Tessellations

Challenge

Images courtesy of Utah & De Espona

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- Ø Robust to degeneracies

No Bottom!

&*Q?@#A%!

Taxonomy of Shape Descriptors

Structural representations

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

Statistical representations

- Voxels, moments, wavelets, …
- Attributes, histograms, ...
- Point descriptors

Taxonomy of Shape Descriptors

Images courtesy of Amenta & Osada

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Image courtesy of De Espona

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Statistical Shape Descriptors

Alignment-dependent

- Voxels
- Wavelets
- Moments
- Extended Gaussian Image
- Spherical Extent Function
- Spherical Attribute Image

Alignment-independent

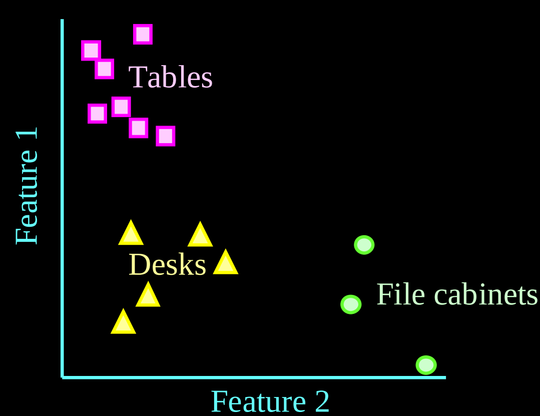
- Shape histograms
- Harmonic descriptor
- Shape distributions

Feature Vectors

Image courtesy of Mao Chen

Map shape onto point in multi-dimensional space

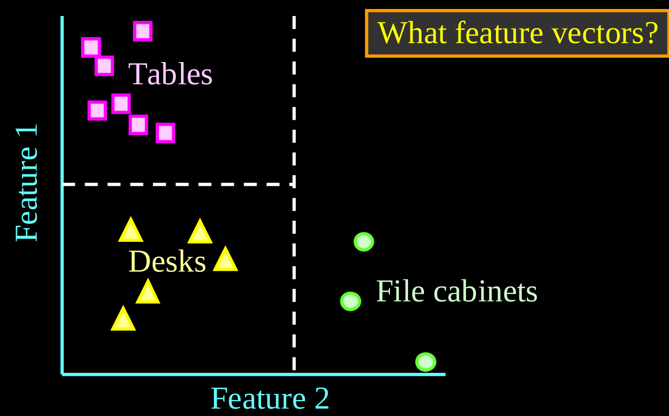
- Similarity measure is distance in feature space



Feature Vectors

Image courtesy of Mao Chen

Cluster, classify, recognize, and retrieve similar feature vectors using standard methods

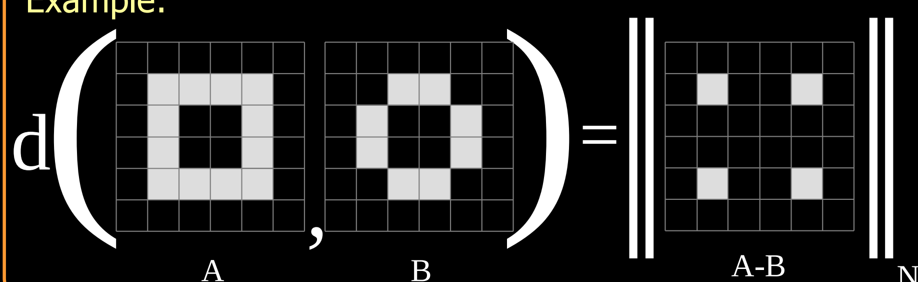


Voxels

Use voxel values as feature vector (shape descriptor)

- Feature space has N^3 dimensions (one dimension for each voxel)
- $d(A,B) = ||A-B||_N$

Example:

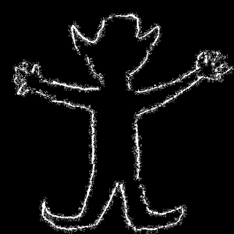


Voxels

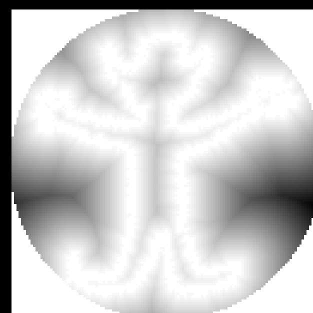
Image courtesy of
Misha Kazhdan

Can store distance transform (DT) in voxels

- $||A\text{-}DT(B)||_1$ represents sum of distances from every point on surface of A to closest point on surface of B



Surface



Distance Transform

Voxels

Image courtesy of
Misha Kazhdan

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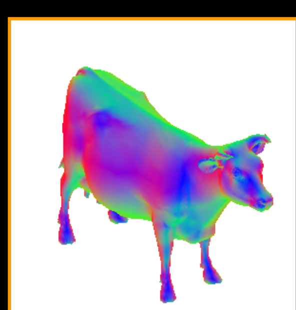


Surface

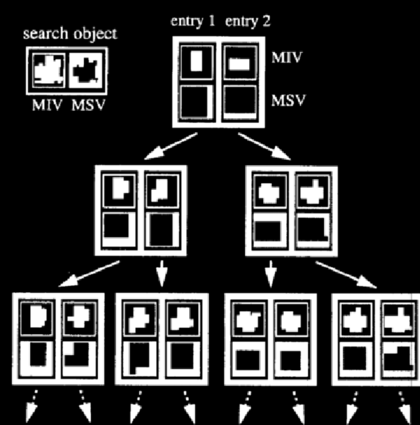
Distance Transform

Voxels

Image courtesy of
Daniel Keim, SIGMOD 1999

Can build hierarchical search structure

- e.g., interior nodes store MIV and MSV



Voxel Retrieval Experiment

Test database is Viewpoint household collection
1,890 models, 85 classes

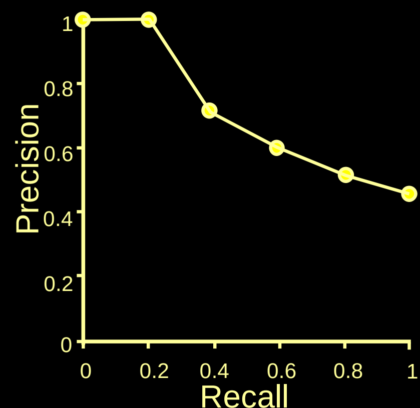
153 dining chairs | 25 livingroom chairs | 16 beds | 12 dining tables

8 chests | 28 bottles | 39 vases | 36 end tables

Evaluation Metric

Precision-recall curves

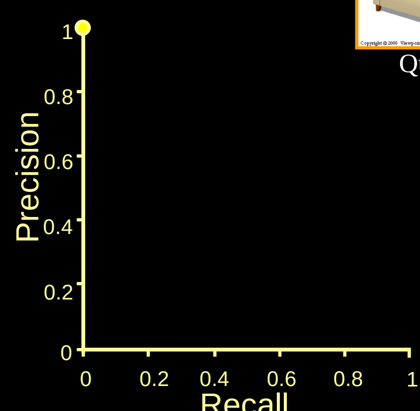
- Precision = retrieved_in_class / total_retrieved
- Recall = retrieved_in_class / total_in_class



Evaluation Metric

Precision-recall curves

- Precision = 0 / 0
- Recall = 0 / 5



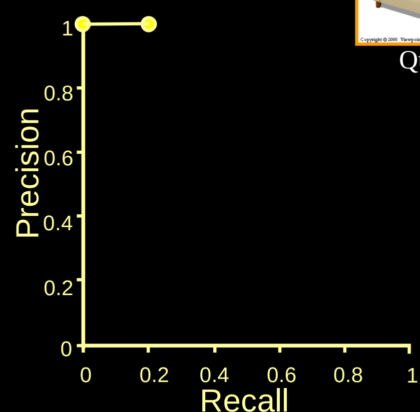
Query

Ranked Matches

Evaluation Metric

Precision-recall curves

- Precision = 1 / 1
- Recall = 1 / 5



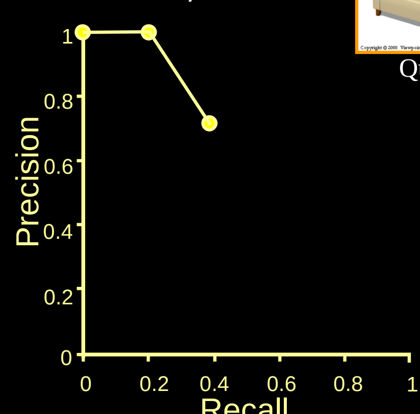
Query

Ranked Matches

Evaluation Metric

Precision-recall curves

- Precision = 2 / 3
- Recall = 2 / 5



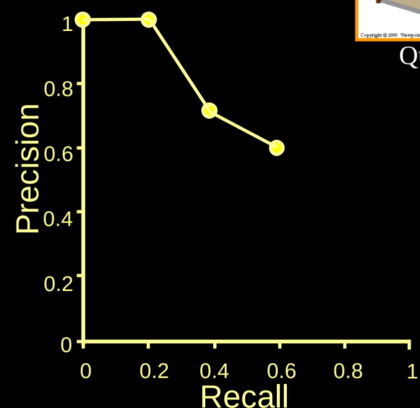
Query

Ranked Matches

Evaluation Metric

Precision-recall curves

- Precision = 3 / 5
- Recall = 3 / 5



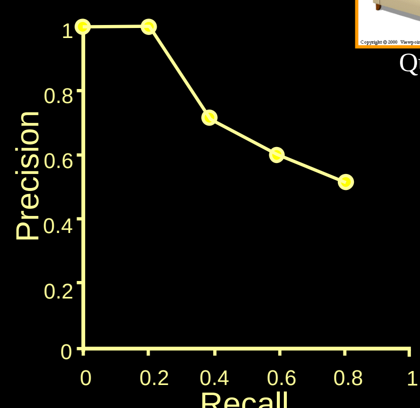
Query

Ranked Matches

Evaluation Metric

Precision-recall curves

- Precision = 4 / 7
- Recall = 4 / 5



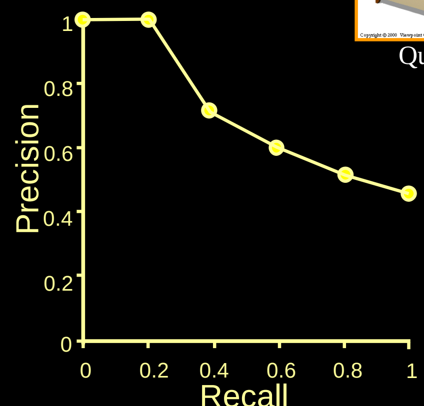
Query

Ranked Matches

Evaluation Metric

Precision-recall curves

- Precision = 5 / 9
- Recall = 5 / 5



Query

Ranked Matches

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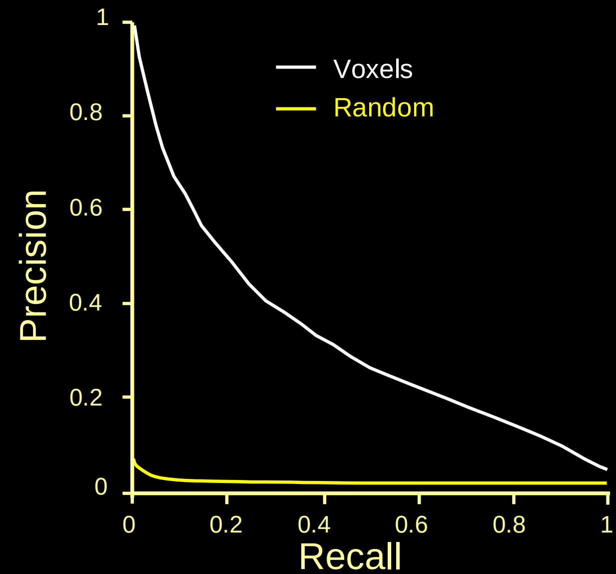
Voxel Retrieval Results



Voxels

Properties

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

Wavelets

Image courtesy of
Jacobs, Finkelstein, & Salesin

Define shape with wavelet coefficients

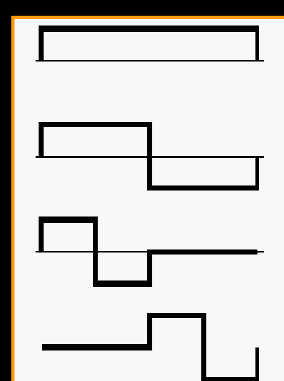
16,000 coefficients | 400 coefficients | 100 coefficients | 20 coefficients

Wavelets

Jacobs, Finkelstein, & Salesin
SIGGRAPH 95

Descriptor 1:

- Given an NxNxN grid, generate an NxNxN array of the wavelet coefficients for the standard Haar basis functions



Wavelets

Jacobs, Finkelstein, & Salesin
SIGGRAPH 95

Descriptor 1:

- Given an NxNxN grid, generate an NxNxN array of the wavelet coefficients for the standard Haar basis functions

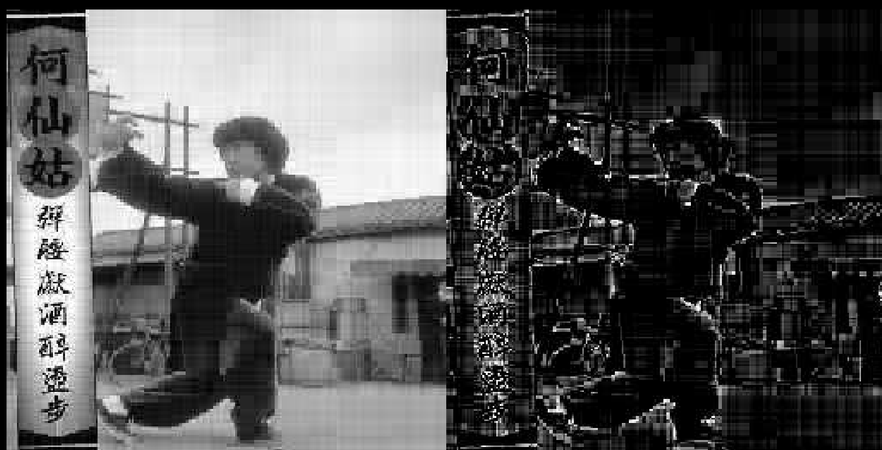
Descriptor 2:

- Truncate: Find the m largest coefficients and set all others equal to zero
- Quantize: Set the non-zero coefficients to +1 or –1 depending on their sign

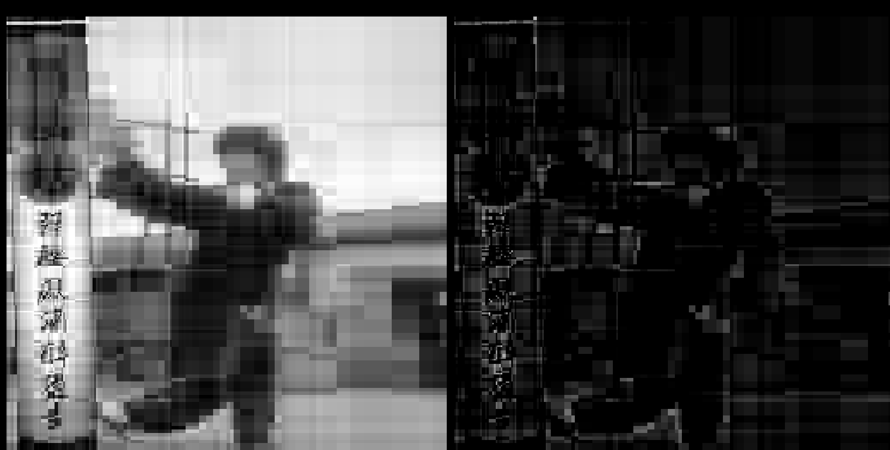
Jackie Chan Example

Original Image (256x256)

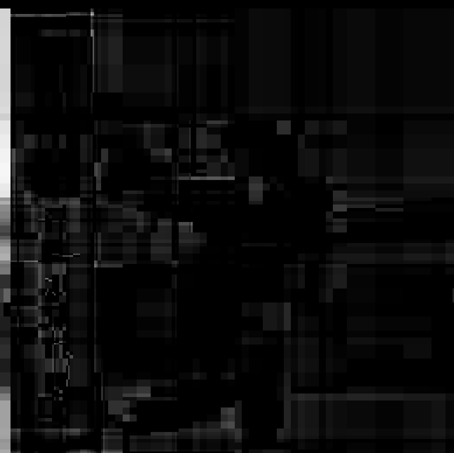
Truncated And Quantized to 5000



Truncated And Quantized to 1000

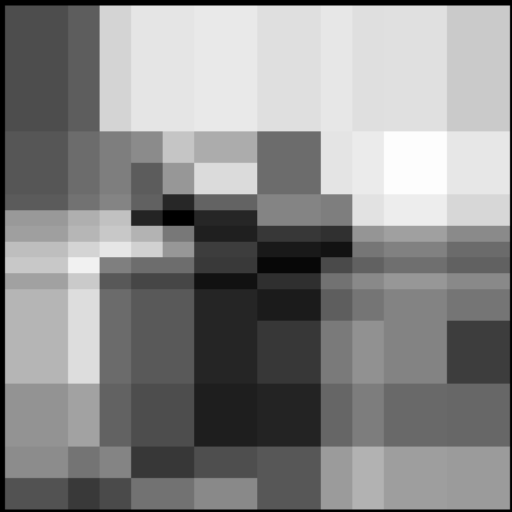


Truncated And Quantized to 500

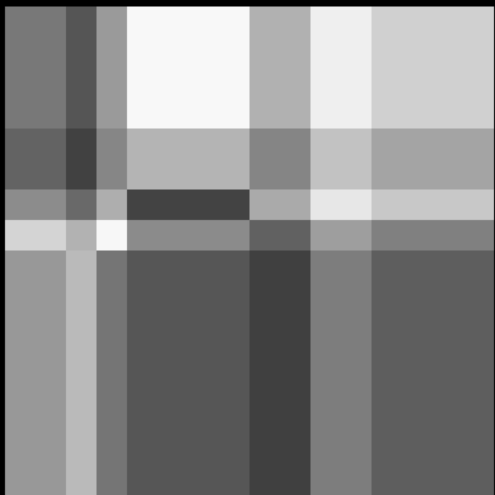


Truncated 100

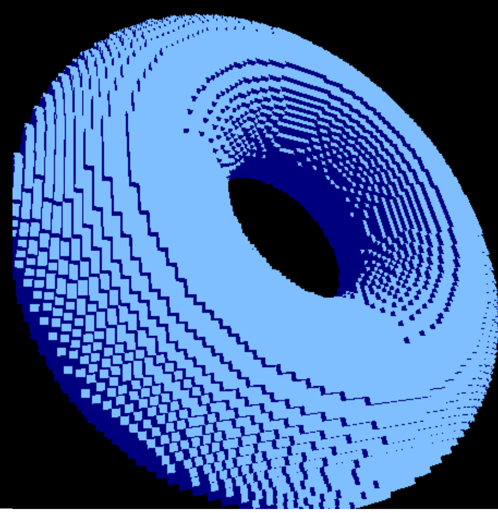
Truncated 50



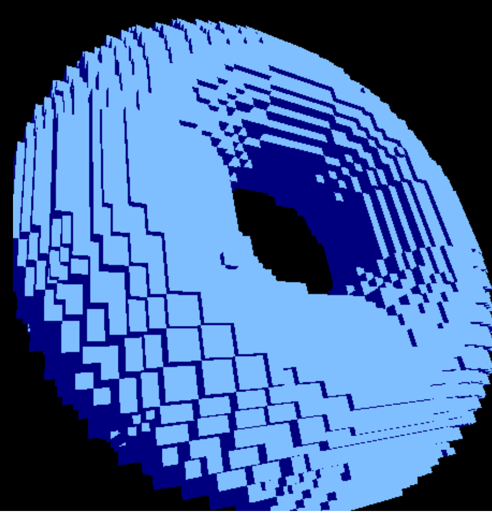
Truncated 10



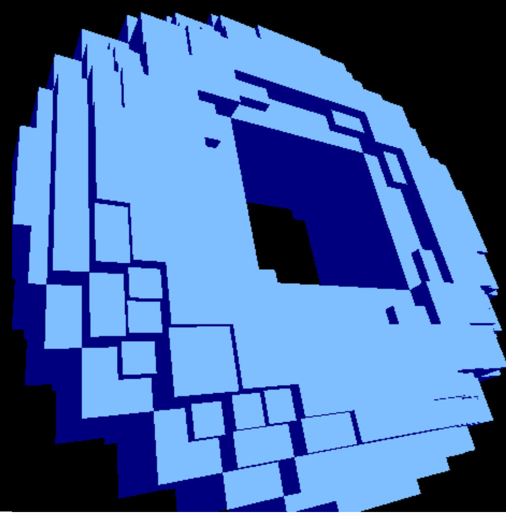
Torus Example



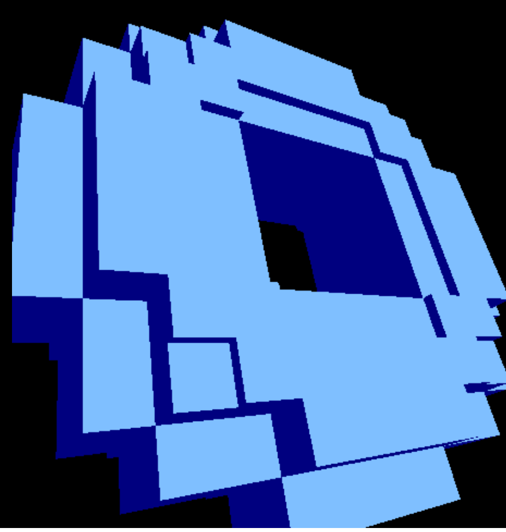
Torus Truncated to 5000

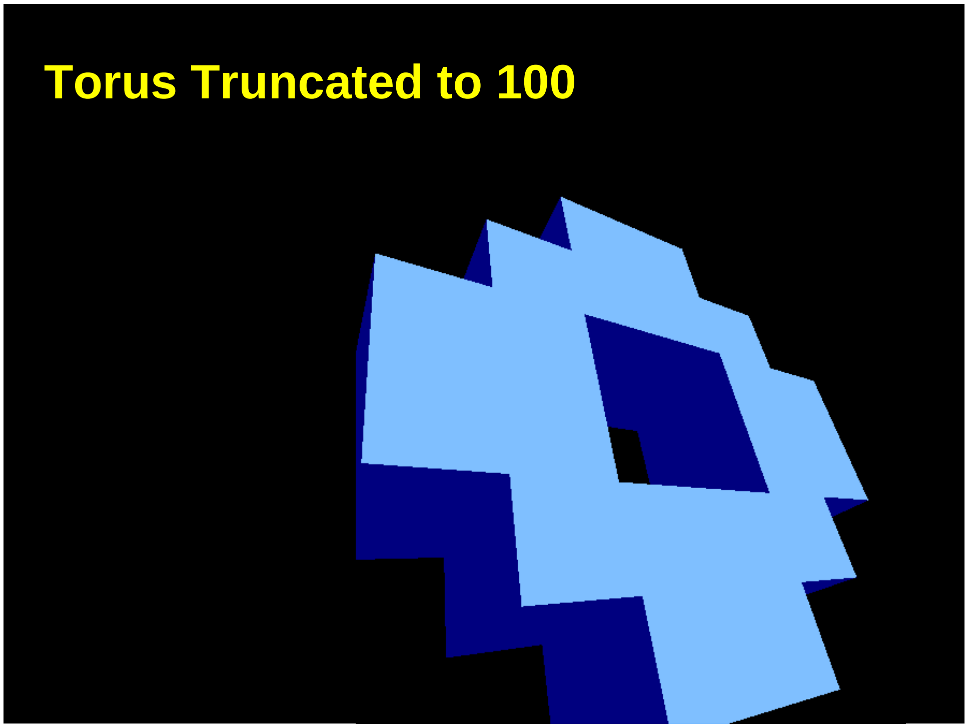


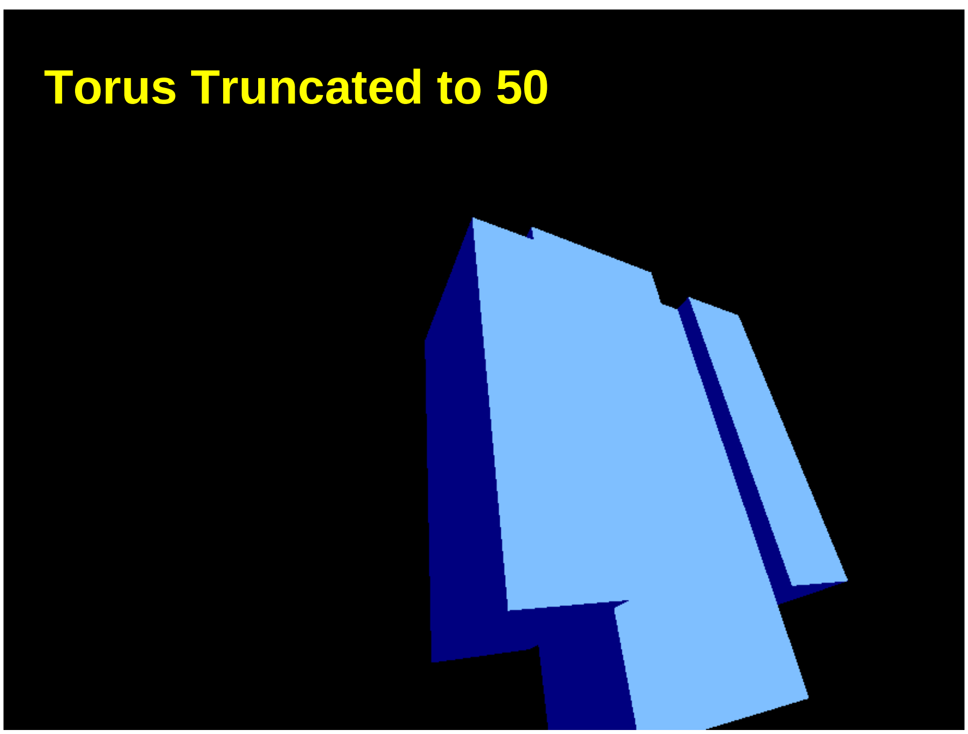
Torus Truncated to 1000



Torus Truncated to 500




Torus Truncated to 100


Torus Truncated to 50

Wavelets

Jacobs, Finkelstein, & Salesin
SIGGRAPH 95

Distance Function 1:

- The query metric is defined by:

$$d(A,B) = \sum_{i,j,k} w_{i,j,k} \left\| A[i,j,k] - B[i,j,k] \right\|$$

where A[i,j,k] and B[i,j,k] are the truncated and quantized coefficients and $w_{i,j,k}$ are weights, fine tuned to the database.

Wavelets

Jacobs, Finkelstein, & Salesin
SIGGRAPH 95

Distance Function 2:

- The query metric can be approximated by:

$$d(A,B) = \sum_{i,j,k:A(i,j,k)\neq 0} w_{i,j,k} \left(A[i,j,k] \neq B[i,j,k] \right)$$

to enable efficient indexing and search.

Wavelets

Jacobs, Finkelstein, & Salesin
SIGGRAPH 95

Properties

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

Moments

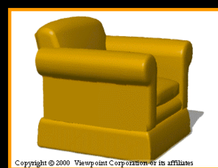
Define shape by moments of inertia:

$$m_{pqr} = \int_{surface} x^p y^q z^r \, dxdydz$$

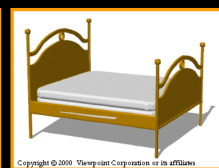
Moments Retrieval Experiment

Test database is Viewpoint household collection
1,890 models, 85 classes

153 dining chairs



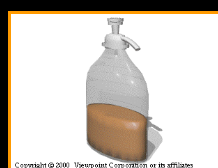
25 livingroom chairs



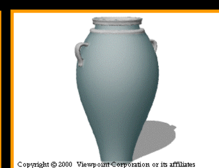
16 beds

12 dining tables

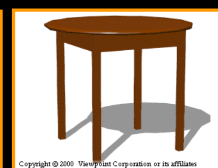
8 chests



28 bottles

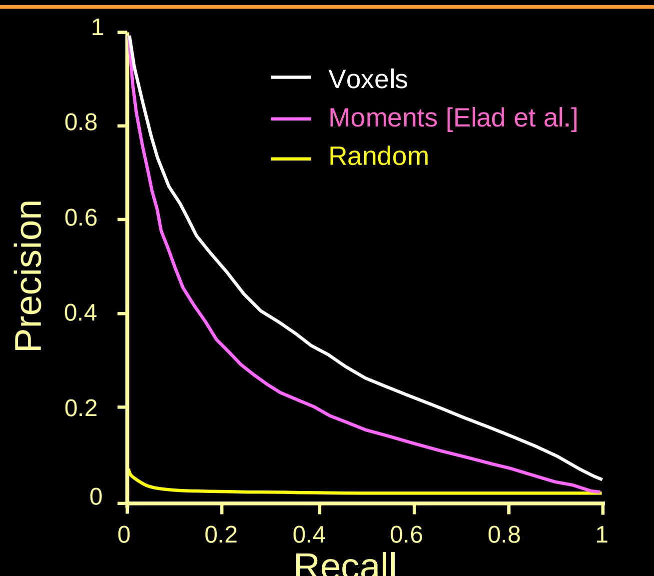


39 vases



36 end tables

Moments Retrieval Results



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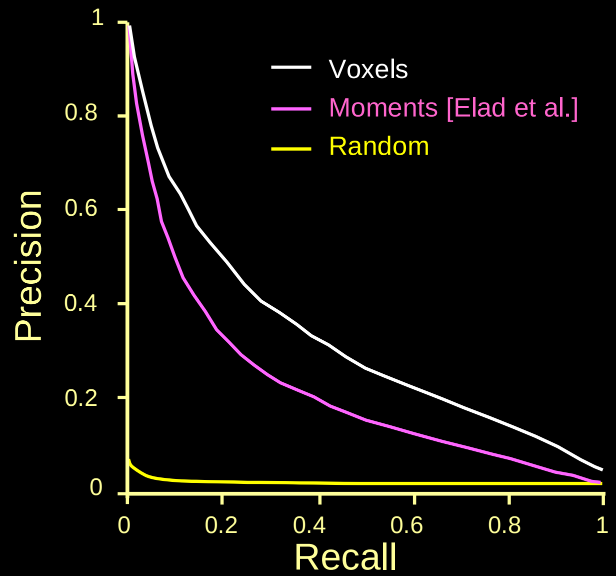

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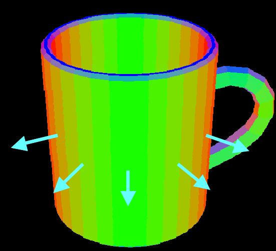
- X Discriminating

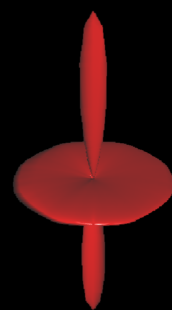
Extended Gaussian Image

Define shape with histogram of normal directions

- Invertible for convex objects
- Spherical function



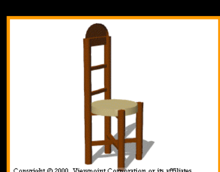
3D Model



EGI

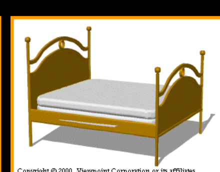
EGI Retrieval Experiment

Test database is Viewpoint household collection
1,890 models, 85 classes



153 dining chairs

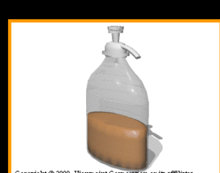
25 livingroom chairs



16 beds

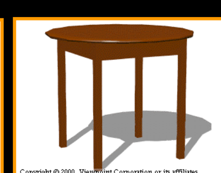
12 dining tables

8 chests



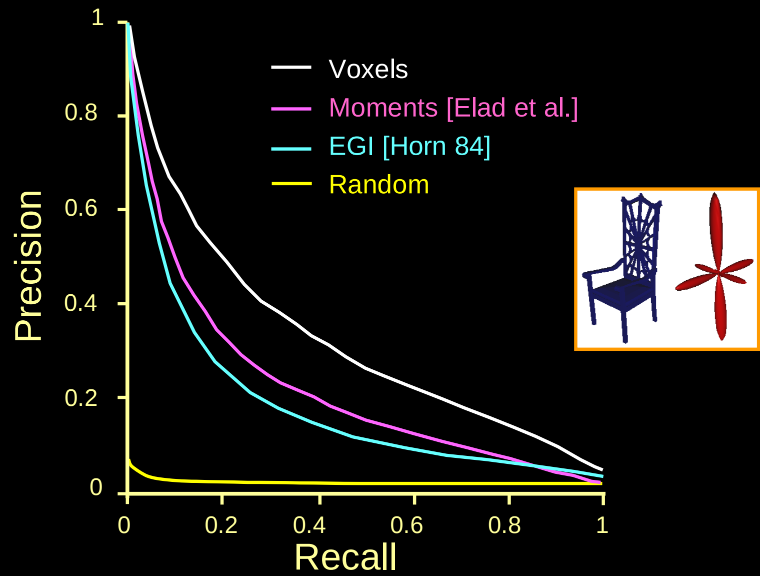
28 bottles

39 vases



36 end tables

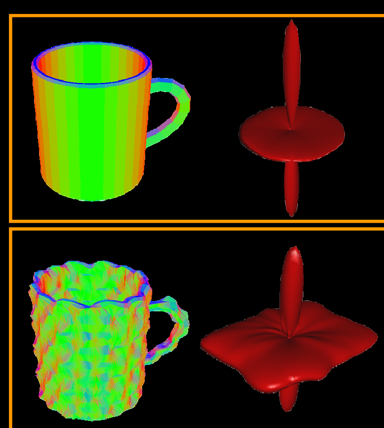
EGI Retrieval Results



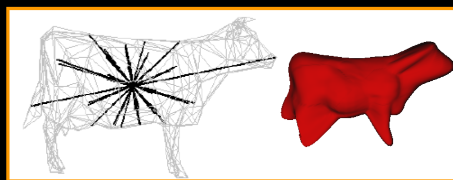
Extended Gaussian Images

Properties

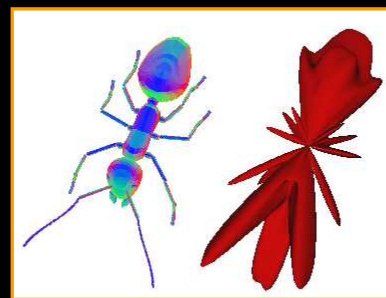
- ü Insensitive to topology
- ü Quick to compute
- ü Efficient to match
- ü Concise to store
- X Insensitve to noise
- X Robust to degeneracies
- X Invariant to transforms
- X Discriminating



Other Rotation-Dependent Descriptors



Spherical Extent Functions
(Vranic & Saupe, 2000)



Shape Histograms (sectors)
(Ankherst, 1999)