On Visual Similarity Based 3D Model Retrieval

Ming Ouhyoung, Ding-Yun Chen . Xiao-Pei Tian
Edward Yu-Te Shen .

Department of Computer Science and Information Engineering
National Taiwan University
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Outline

- Introduction
- Previous works
- Our proposed approach
- 3D shape search engine
- Experimental results
- Conclusion & future work

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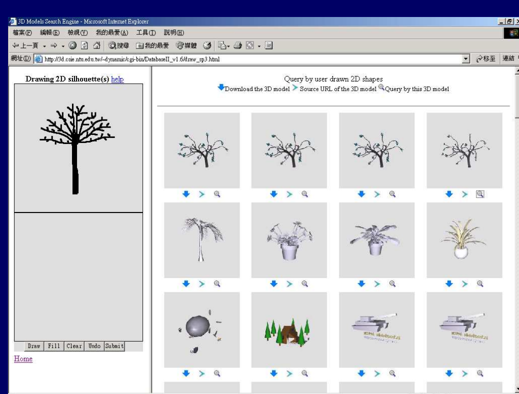
Introduction

Online demo

- 3D models in the database
- http://3d.csie.ntu.edu.tw



Motivation

- Content-based retrieval for multimedia has become important
- The lack of meaningful description for automatic matching
- Development of 3D modelling and digitizing technology
- Fast 3D model generation via modifying retrieved models: Virtual Sculptor DEMO

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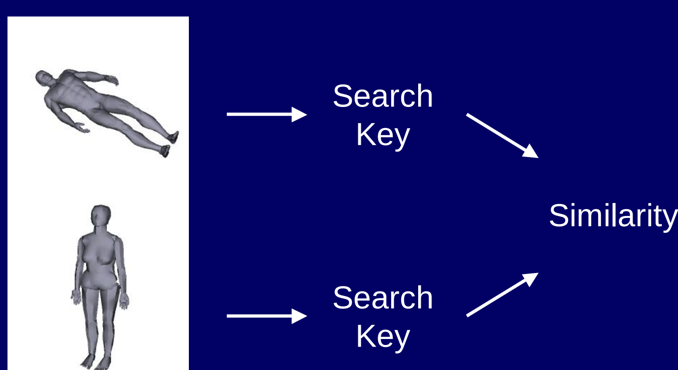
Problem statement

- Similarity between two given 3D objects
  - Features and distance metric



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Previous Works

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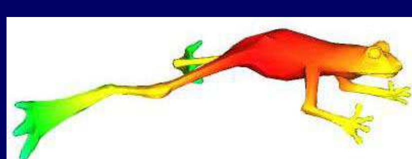
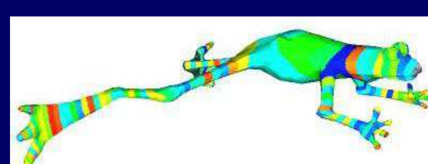
Topology matching
for fully automatic similarity estimation of 3D shapes

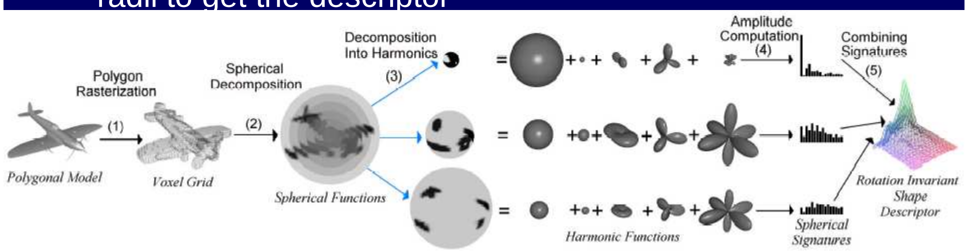
- M. Hilaga et al., *ACM SIGGRAPH*, 2001.
- Geometry-based and topology-based approach
- For each vertex of the object, calculate a sum of the geodesic distance from this vertex to others
- Reeb graph, where each node represents a region according to the value
- Construct multi-resolutional Reeb graph by grouping adjacent regions





Spherical harmonic descriptor

- Funkhouser et al., *ACM Trans. on Graphics*, Jan. 2003
- Geometry-based and shape-based approach
- Transform 3D model to concentric spheres
- Frequency components by spherical harmonics (Fourier transformation in spherical coordinates)
- Combining these different signatures over the different radii to get the descriptor



Overview of 3D model retrieval systems

- Geometry-based approach
  - Shape-based
  - Topology-based
- Projected image-based approach — Shape-based — Geometry alignment and then matching by image

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Our proposed approach

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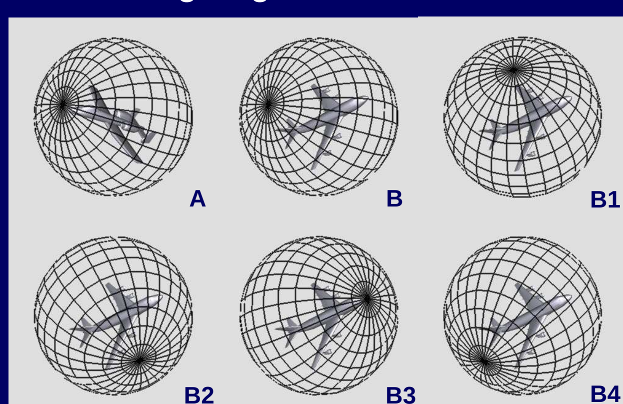
The main idea of our approach

- If two 3D models look similar, they look similar from all viewing angles



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Design issues

- Correctness, discrimination
- Efficiency, automation
- Robustness
  - Similarity transformation: translation, rotation and scaling
  - Connectivity changes: re-meshing, sub-division and simplification
  - Model degeneracy: missing, wrongly oriented normals, intersecting, disjoint and overlapping polygons
  - Noise, deformation, etc.
- Scope
  - Static objects
  - Not for articulated creatures

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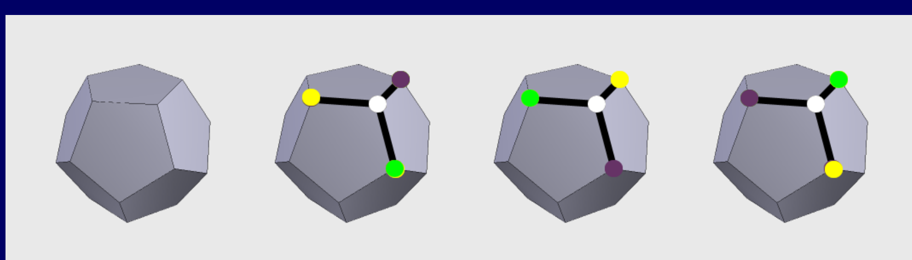
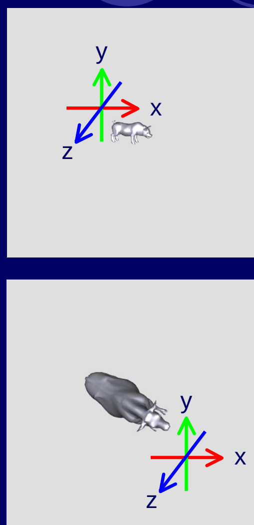
Cameras on a regular dodecahedron

- A dodecahedron is a polyhedron with 12 faces and 20 vertices
- A regular dodecahedron has most vertices from all regular convex polyhedrons
- 60 different rotations when matching (3 * 20 = 60)



Matching between two 3D models (I)



- Two 3D models with different translation, rotation and scaling

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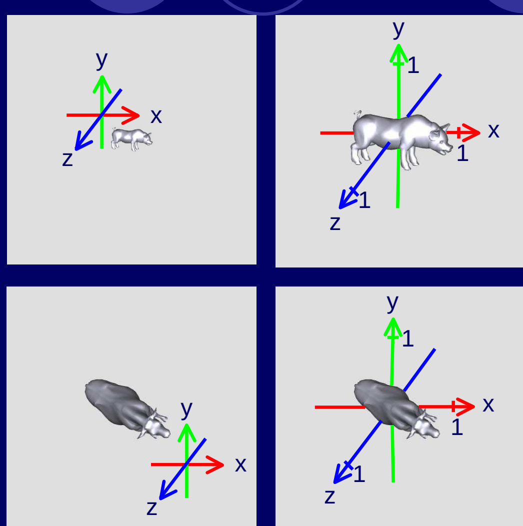
Matching between two 3D models (II)



- Translation and scaling roughly in 3D space
- The error in translation and scaling will be diminished by 2D image matching

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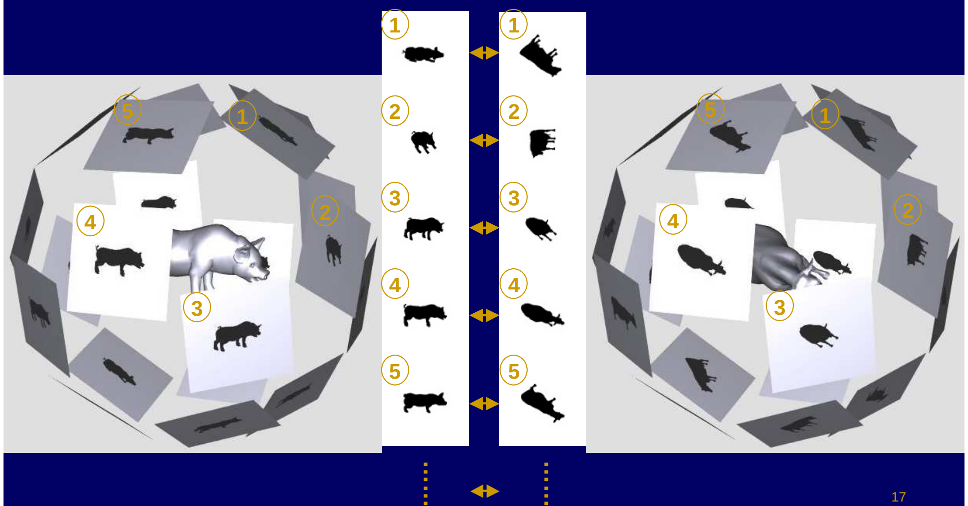
Matching between two 3D models (III)



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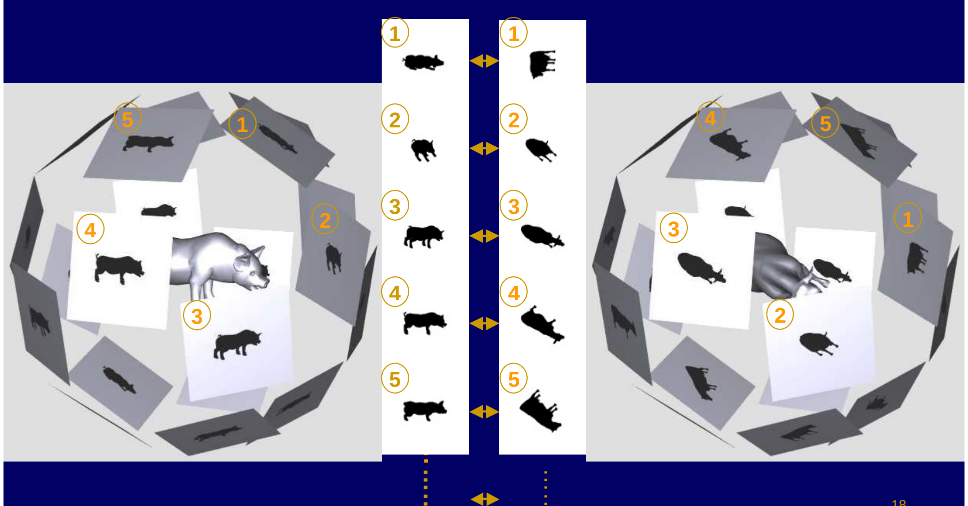
Matching between two 3D models (IV)



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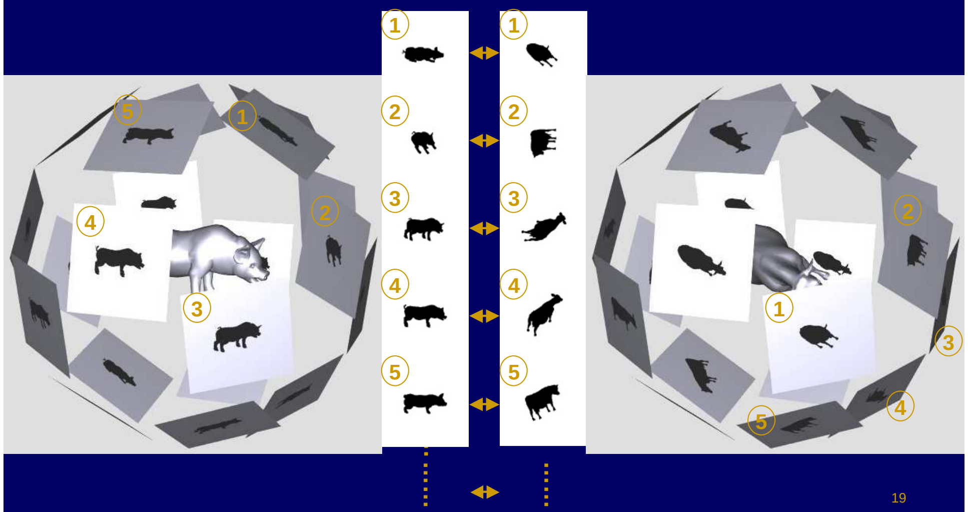
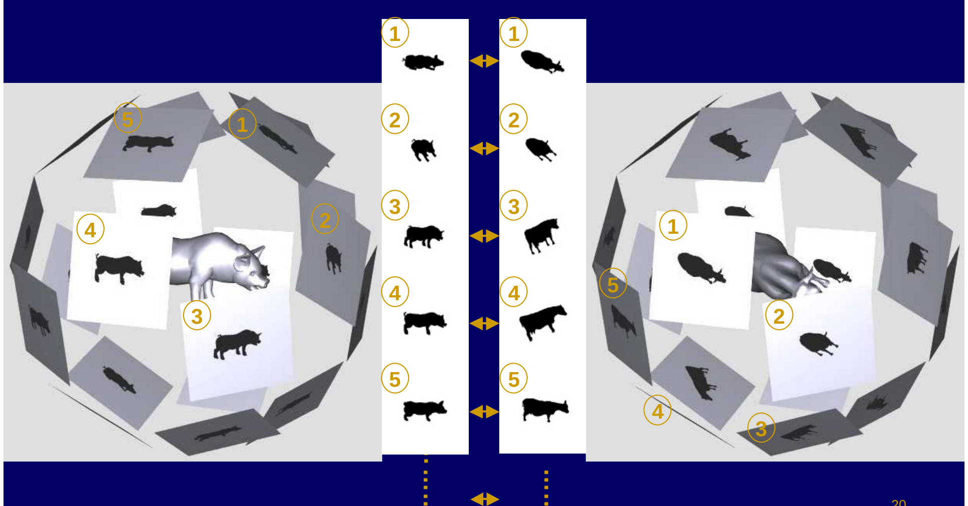
Matching between two 3D models (V)

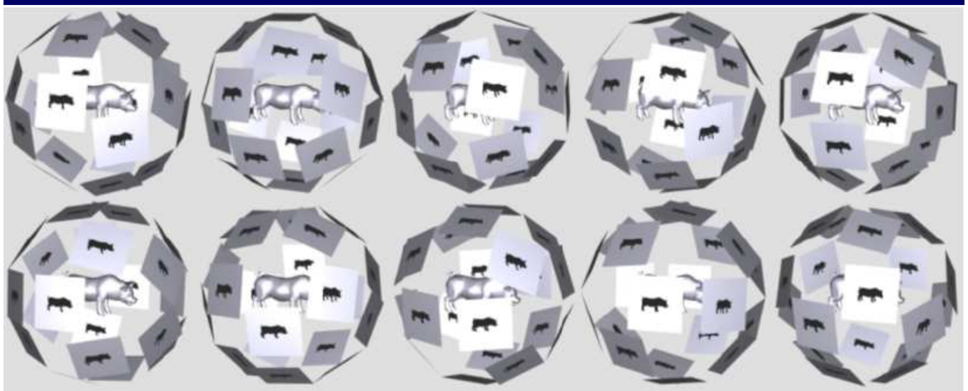


Matching between two 3D models (VI)



Minimum error from all corresponding 2D shapes

To be more robust in rotation(I)



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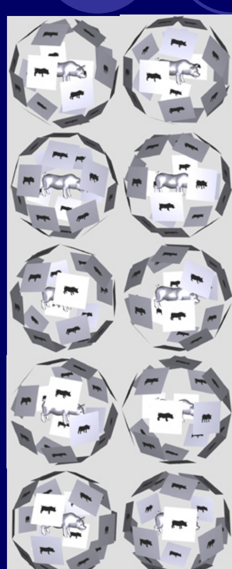
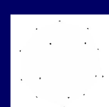
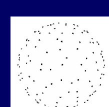
To be more robust in rotation(II)



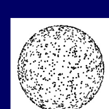
1-1
60



1-10
600



10-10
5460



Different rotation:
(Mx(N-1)+1)x60

$$\frac{180^\circ}{x} \times \frac{360^\circ}{x} = 5460 \Rightarrow x \cong 3.4^\circ$$

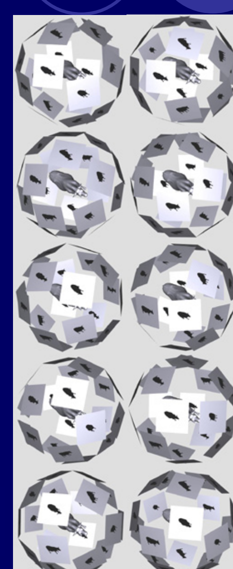


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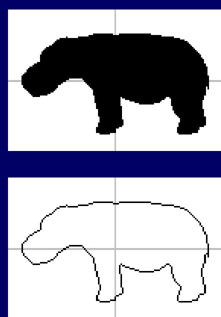
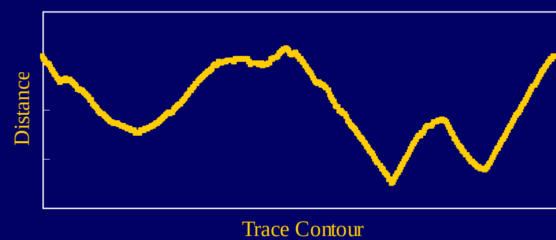
Image metrics

- Integrated region-based and contour-based approach
  - Zernike moment (35 coefficients)
  - Fourier Descriptor (10 coefficients)





- Robust from translation, rotation and scaling

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2D Zernike Moments

- Teague proposed Zernike moments based on orthogonal Zernike polynomials
- Teague, J. Opt. Soc. Am. 70 (8), 1980
- Rotation invariant
- Khotanzad *et al*, IEEE PAMI, 12 (5), 1990
- Translation invariant
- Chong *et al* Pattern Recognition 36, 2003, pp.1765-1773

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2D Zernike moments

Zernike moments

$$Z_{pq} = \frac{p+1}{\pi} \int_0^{2\pi} \int_0^1 V_{pq}^*(r,\theta) f(r,\theta) r\,dr\,d\theta$$

where $p - |q|$ is even and non-negative

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Zernike polynomials of order p, with repetition q

$Vpq(r, \theta) = R_{pq}(r)\ e^{jq\theta}$

$R_{pq}(r) = \sum_{k=0}^{(p-|q|/2)} (-1)^k (p-k)!/\{k!((p+|q|/2-k)!(p-|q|)/2-k)!\}\ r^{p-2k}$

$R_{00}(r) = 1, \quad R_{11}(r) = r,$

$R_{20}(r)= 2r^2-1, \quad R_{22}(r) = r^2$

$R_{31}(r) = 3r^3-2r, \quad R_{33}(r) = r^3$

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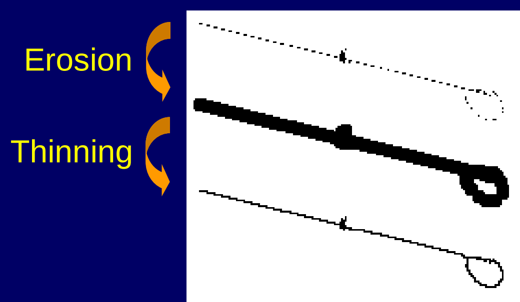
Trace contour for rendered image

- Erosion operation to connect the separated parts
- Thinning, but don’t remove the rendered pixels



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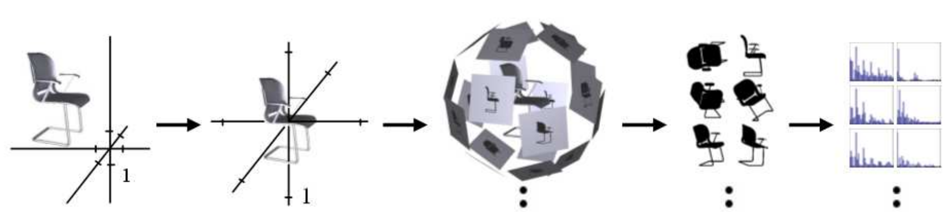
Steps Extracting the Descriptors

- Translation and scaling
- Render images from the camera positions
- Totally 100 images are rendered because of 10 Descriptors.
- Descriptors for a 3D model are extracted from the 100 images as Zernike Descriptors and Fourier Descriptors



Retrieval from a large database

- Iterative early rejection of non-relevant 3D models
- Only parts of the images and coefficients are compared
- 6 iterations in total
  - 1st~5th iteration: Zernike moment
  - 6th iteration: Fourier descriptor
  - The threshold of removing models is set as the mean of the similarity

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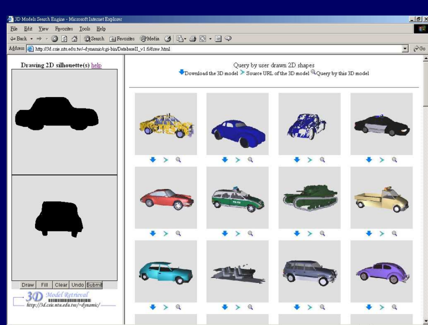
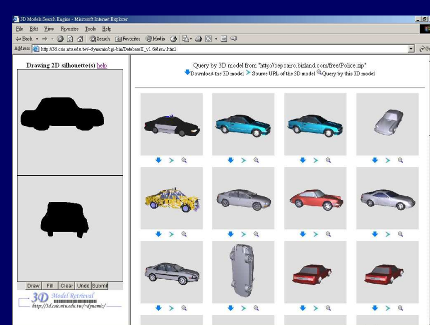
Speed of 3D shape search engine

(>10,000 3D models)



Retrieval results from user drawn 2D shapes

0.1 seconds



Retrieval results from interactively searching by selecting a 3D model

2 seconds

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Experimental results

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Ground truth data set

- 3DCAFE, downloaded in Dec. 2001
- All 1833 3D models
- Classified class
  - 47 class (category of airplane, car, chair, etc.)
  - 549 3D models
- Miscellaneous class
  - 1284 3D models

64 models | 52 models | 61 models | 15 models | 13 models

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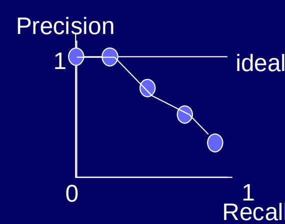
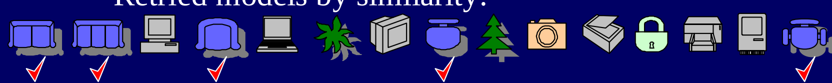
“Precision” vs. “Recall” diagram

$$\text{Precision} = \frac{\text{relevant correctly retrieved}}{\text{all retrieved}}$$

$$\text{Recall} = \frac{\text{relevant correctly retrieved}}{\text{all relevant}}$$



Input: Retried models by similarity:



Precision	1	3/4	4/8	5/15
Recall	1/4	2/4	3/4	4/4

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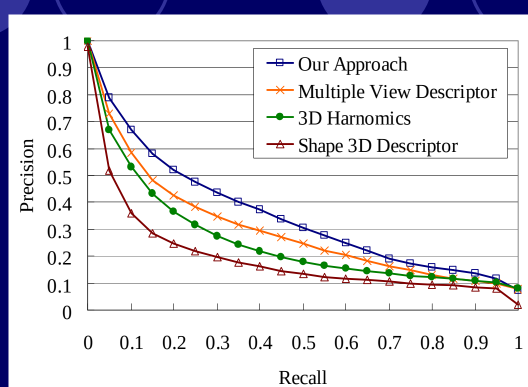
Performance evaluation on NTU data



22% better
43% better
95% better

- Our Approach
- Multiple View Descriptor: MPEG-7 international standard
- 3D Harmonics: *ACM Trans. on Graphics*, Jan. 2003.
- Shape 3D Descriptor: MPEG-7 international standard

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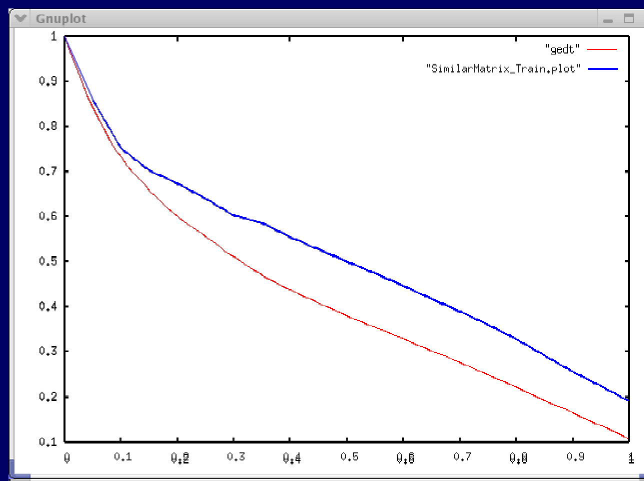
Precision Recall Plot for PSB

blue line:ours, red: the spherical harmonics

Data provided by Phil Shilane



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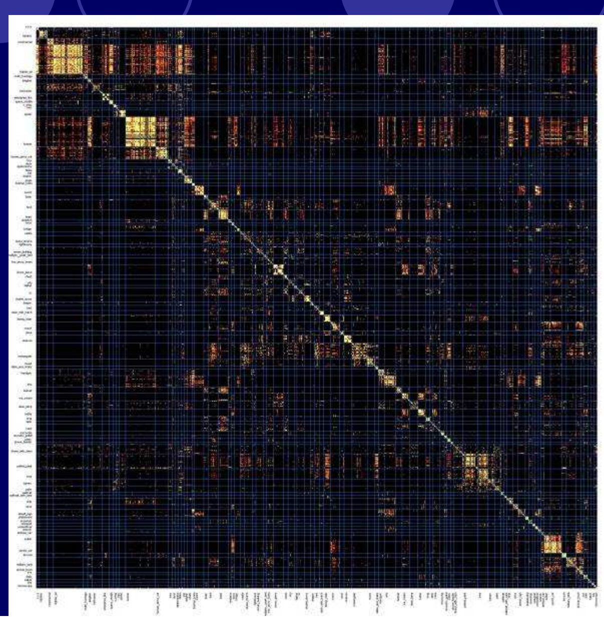
Visualization of the similarity matrix, Data provided by Phil Shilane

YELLOW, RED, BLACK: similarity values in decreasing order



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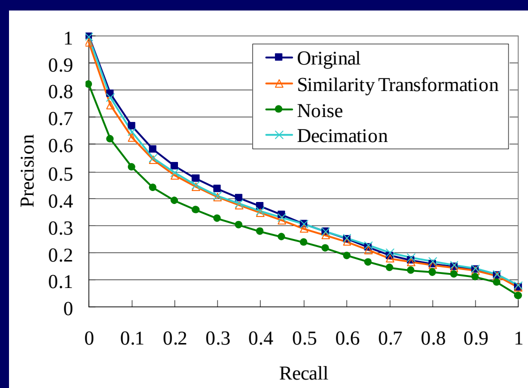
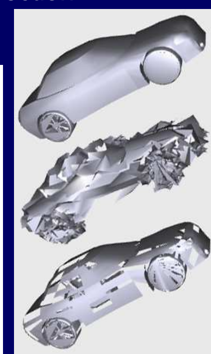
Robustness evaluation

- Similarity transformation: rotations(0º ~ 360º), translation(-10 ~ +10 times of ℓ) and scaling(a factor between -10 and +10)
- Noise: translating -3%~+3% times of ℓ in x, y, or z direction
- Decimation: deleting 20% of the polygons





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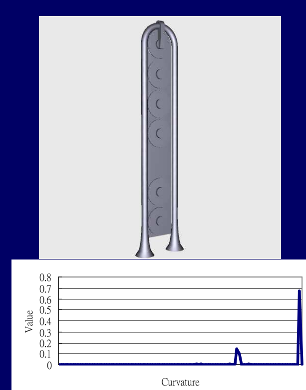
Shape 3D Descriptor

- Curvature histogram
- Discrimination: different models have the same curvature histogram
- Model degeneracy



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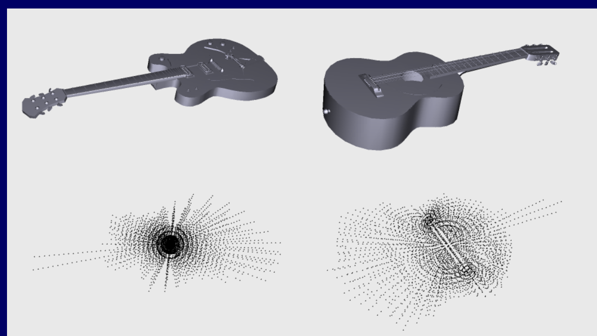
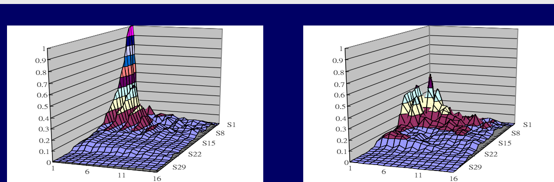
3D Harmonics



- Voxelization
- Shape near the center of mass has larger effects



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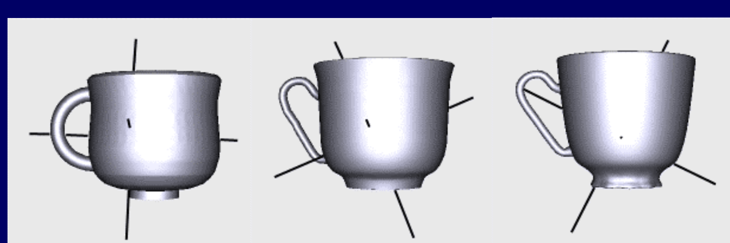
Multiple View Descriptor (PCA based)

- Based on Principal Component Analysis (PCA)
- Principal axes are not good enough at aligning orientations of different models within the same class



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Timing statistics in computing the similarity matrix

- The average time is 0.0013 second to compare two shape descriptors
- The average storage is 4700 bytes for a single shape descriptor
- The average time is 3.25 seconds to compute each shape descriptor
- on a PC with Pentium 4 CPU 2.4GHz, 256MB RAM and NVIDIA GeForce 2 MX

Future works

- More image metrics
- Cocktail approach
- Training / learning mechanism
- Partial matching

Conclusion

- A 3D model retrieval system is proposed based on visual similarity
- The new metric for 3D models is proposed
- Robustness, efficiency, discrimination, etc.
- 3D shape search engine for practical use
  - http://3d.csie.ntu.edu.tw

Thank You