3D shape description and matching based on properties of real functions


CNR-IMATI-GE

Applied mathematics and information technology
- Geometric Modeling
- Computational Geometry and Topology
- High Performance Computing
- Computational Electromagnetics
- Cognitive models based on ICT

Applications
- Product Design, Spatial Data Handling, Ergonomics, Bioinformatics

Staff
- 21 staff members
- 10 contract researchers (PostDoc)
- 2 PhD

3D shapes
- 3D shapes are digital representations of either physically existing objects or virtual objects that can be processed by computer applications

why is 3D retrieval important?

3D users
- Professionals
  - Product Modelling, CAD/CAM
  - Design
  - Cultural Heritage
  - Gaming
  - Virtual Environments
  - Medicine
  - Bioinformatics
  - Architects
  - Archaeology
- Non professionals
  - why is 3D retrieval important?
Due to great technological advances, 3D content is poised to become the 4th wave of multi-media:

- 3D shapes can be easily digitized
- Modelling and processing of 3D shapes are mature research fields (geometric modeling & computer graphics)
- 3D content can be delivered easily as most of the PCs connected to the Internet are now equipped with high-performance 3D graphics hardware.

**Shape matching: recognition**

- Security
  - Face recognition
  - Detection of dangerous situations

**Shape matching: retrieval for re-use**

- Gaming & Simulation
  - Create new assets from catalogues of existing ones
  - Re-purposing virtual characters

- Industrial manufacturing
  - Design a new mechanical part starting from an existing one

**Shape matching: design and classification**

- Bioinformatics and chemistry
  - Drug design
  - Protein classification

**Shape Recognition**

- Given a query shape $S$, does $S$ belong to the repository $R$?
- Aims the search at a specific shape
- Examples: security, drug design, copyright protection
Shape Retrieval

- Given a query shape $S$, does the repository contain an object similar to $S$?
- Aims the search at a category level: similarity assessment.
- Examples: security, design, gaming & simulation.

Shape Classification

- Given a classified repository and a query shape $S$, find the class $S$ belongs to.
- Aims the match at a category level: similarity evaluation.
- Examples: security, bioinformatics, medical applications.

Shape Matching and Retrieval

- Global vs partial match.
- Correspondence between parts in similar objects.
- Similarity among parts in dissimilar objects.

Shape matching pipeline

- Shape matching is done by associating a shape descriptor, or signature, to the shapes and by defining a distance, or dissimilarity measure, between descriptors.
- Examples: Euclidean space, descriptor space, real numbers.
- Metric, pseudo-metric, semi-metric.
- Graph matching, EMD.

How to measure the performance of shape retrieval systems?

- Precision/Recall: first or second tier, cumulative gain.
- SHREC - Shape Retrieval Contest.

But what are the reasons for good/bad performance results?
The 3D Object Domain

- The homogeneous / heterogeneous nature of the dataset influences the information used for the matching.
- **Narrow domain**: limited and predictable variability of 3D objects (e.g., a specific dataset consisting of faces or mechanical parts).
- **Broad domain**: unlimited and unpredictable variability of 3D objects (e.g., the Internet domain).

(Smoulders et al. PAMI, vol 22, N 12, December 2000)

3D Matching

- "Traditional" hypothesis: the shape model carries all the information needed for the matching.
  - It is not simple to use this information to obtain an effective matching.
  - Different types of information should be considered depending on the application context, the matching task and the matching approach.
    - Recognition
    - Retrieval
    - Classification
    - Narrow or broad domain

Domain Knowledge

- **Literal**
  - Specific approach or algorithm
- **Perceptual**
  - Human perception of equality and similarity
- **Physical**
  - Equality and similarity are based on physical laws
- **Geometric-topological**
  - Equality and differences of patterns in space
- **Categorical**
  - Characteristics common to a specific class
- **Cultural**
  - Equality and similarity are based on cultural-based info

(Smoulders et al. PAMI, vol 22, N 12, December 2000)

Tutorial rationale

- De-couple the main steps and analyse their properties separately.

1. **measure "somehow relevant properties**
2. **build a descriptor based on these properties**
3. **define an appropriate distance between descriptors**
Step 1: measuring shape properties
- Study the shape by studying the behaviour of one or more \( f \) defined over the shape
  - Salient features are detected by studying the behaviour of appropriate functions defined on the shape (e.g., curvature, distances between points, critical points, function variation over the shape, harmonic analysis)
  - The choice of \( f \) is frequently driven by the invariants one wishes to preserve
  - Focus on methods that use real valued functions

Step 2: building shape descriptors
- How to use the salient features detected by \( f \) to compactly describe the shape \( f \)
  - Histograms of \( f \)
  - Connections between critical points
  - Evolution of level sets of \( f \)
  - Harmonic decomposition of \( f \)
  - Eigenvalues or eigenfunction of the solution of the Laplace-Beltrami operator

Step 3: distances between descriptors
- How to measure the similarity measure between shapes as a “distance” between descriptors \( f \)
  - Different approaches, depending on the nature of the descriptor (e.g., graphs, histograms, feature vectors, formal series)
  - Properties: metric, semi-metric, pseudo-metric
  - Robustness: low variation of the measure wrt small variations of the shape descriptor
  - Type of comparison: global and/or partial matching
  - Type of information taken into account (geometrical, topological, structural)
  - Computational complexity
  - Application context

Methods discussed
- Reeb graph
  - Hilaga et al.
  - Tung & Schmitt
  - Biasotti et al.
- Size theory
  - Frosini et al.
- Persistent homology
  - Edelsbrunner et al.
- Descriptors based on spherical decompositions
  - Spherical harmonics
  - Vranic et al.
  - Kashani et al.
- Spherical wavelets
  - Laga et al.
- Bending invariant signature
  - Elad & Kimmel
- Spectral embedding
  - Jain & Zhang
- Pose oblivious signature
  - Gal et al.
- Shape-DNA
  - Reuter et al.
Step 4: is geometry sufficient?

- Is geometry sufficient to devise effective shape matching systems?
- Can we formalize other types of similarity measures that take into account the context?
- How can we deal with the semantics?

**AIM@SHAPE approach**

Content

- Shape matching: motivations and summary (Michi)
- Real Functions (Giuseppe)
- Shape Descriptors (Daniela)
- Comparison Methodologies (Simone)
- Conclusions and perspectives (Bianca)

http://www.ge.imati.cnr.it/ima/smg/training.html

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**Questions?**

Eurographics 2007 Tutorial T12

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**Shape Modeling International SMI’08**

Stony Brook University, June, 4-6, 2008
http://smi08.cs.sunysb.edu

**Important dates**

- Abstracts: November 27, 2007
- Full/Short Papers: Dec. 4, 2007
- STARs: Dec. 4, 2007
- Notification: January 31, 2008
- Camera Ready: March 1, 2008

Conference Chairs
Hong Qin, Stony Brook Univ., USA
Alexander Pasko, Bournemouth Univ., UK

Programme Chairs
Michela Spagnuolo, IMATI, CNR, Italy
Daniel Cohen-Or, Tel Aviv Univ., Israel
Xianfeng David Gu, Stony Brook Univ., USA

SHREC’08 - Shape Retrieval Contest
http://www.imatshape.net/event/SHREC

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.. call for contributions ..

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Mathematical Methods for Shape Analysis and Processing

Abstract 1 November
Paper 15 November
Notification 15 February
Camera-ready 15 April

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