Similarità di forma: analisi, descrizione e confronto

Workshop "Matematica, Forme, Immagini"

Michela Spagnuolo

CNR-IMATI-GE - Italy

outline

- intro
  - why 3D models
  - similarity & applications
- similarity among 3D objects
  - similarity evaluation pipeline
  - 3D vs 2D
- description & comparison of 3D objects
  - geometry, structure, semantics
- present & future
  - is geometry enough ?
  - are descriptors adequate ?
  - how to involve users more ?

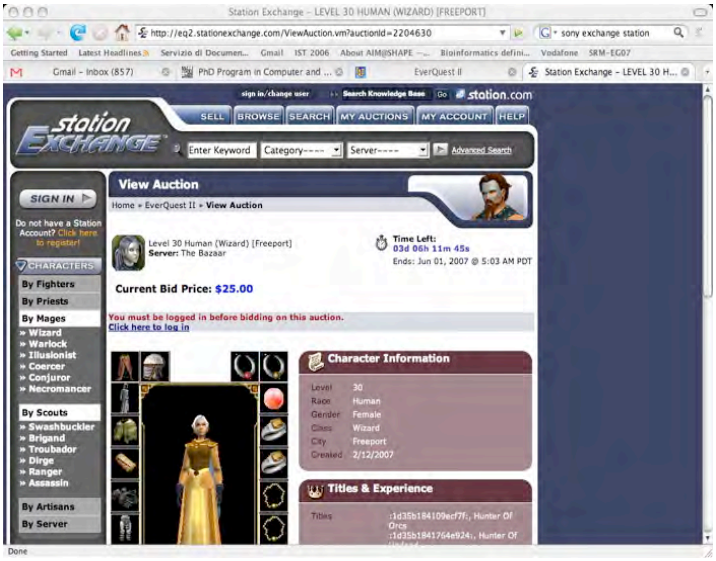
- 3D models are digital representations of either physically existing or virtual objects that can be processed by computer applications

- 3D models
  - single 3D digital objects
  - assembly of 3D components (car engine, ..)
  - virtual environments (objects, avatars, cities, ..)
  - data about physical or virtual experiments/simulations

3D media: why ?

- plenty of online stores selling 3D models
- target customers
  - gaming industry, entertainment, simulation
- industrial impact foreseen at short/medium-term
  - Product Design, 3D-TV, medical sector, gaming, ..
  - SecondLife, EverQuest II, Sony Exchange Station
- everyday life impact foreseen at long-term
  - *shapes*.google.com
  - 3D search issued by mobile or wearable devices

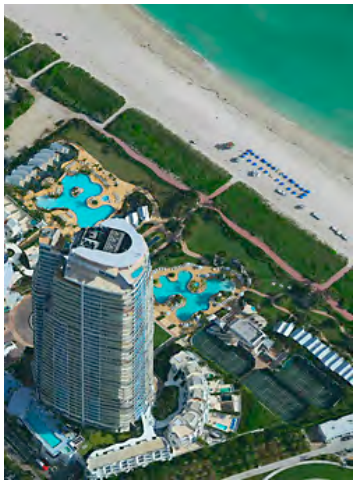
3D media: why ?



3D media: why ?

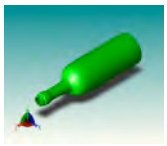
3D media: why ?

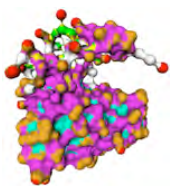
web mapping industry !!



3D media not only for entertainment..

- ✓ Non professionals
  - 3D social networking
  - "broad semantic context"
- ✓ Professionals
  - Product Modeling
  - Design
  - Cultural Heritage
  - Gaming
  - Simulation
  - Medicine
  - Bioinformatics
  - Architecture
  - Archeology
  - …



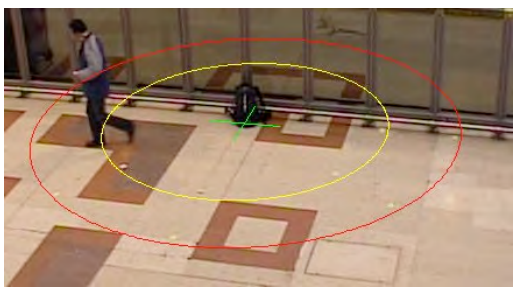


why shape similarity

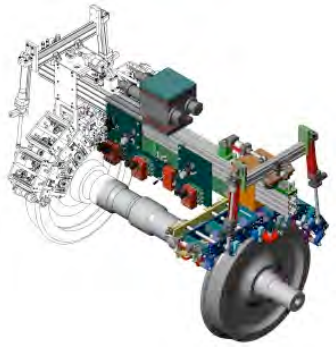
- ✓ reasoning about the similarity of 3D objects is useful in several application contexts
  - search & retrieve data
  - support design and modelling
  - support decision making in scientific contexts
  - provide intelligence to virtual environments
  - ...
- ✓ keys to reasoning about similarity
  - which information carried by the object's shape has to be used?
  - which methodology has to be used to exploit this information?

similarity among 3D objects

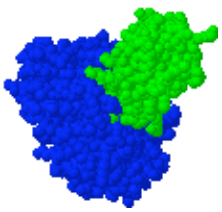
- ✓ Several application contexts deal with problems that can be solved by comparing 3D objects:
  - Security
    - Face recognition (is this person allowed to walk in this area?)
    - Detect dangerous situations (is this unattended object a baggage or a trolley?)

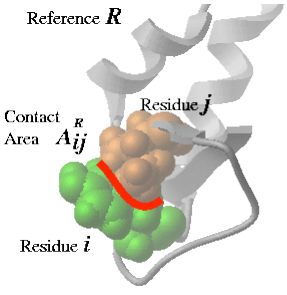


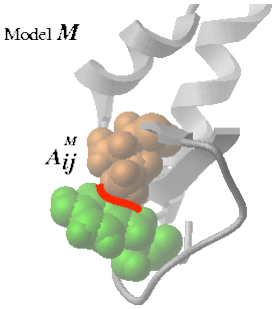
- ✓ Several application contexts deal with problems that can be solved by comparing 3D objects:
  - Industrial manufacturing
    - design a new mechanical part starting from an existing one



- ✓ Several application contexts deal with problems that can be solved by comparing 3D objects:
  - Medicine & Biology
    - drug design (is it available a molecule that docks to a given site?)







the molecules change their shape while interacting

similarity among 3D objects

- Several application contexts deal with problems that can be solved by comparing 3D objects:
  - Gaming & Simulation
    - build virtual worlds and characters (is it available a specific object already designed by others?)
    - simulate dangerous situations (is it available an avatar that can be animated?)

.. but what do we mean by similarity*?*

… *different* flavours …

congruence

equivalence of the structure

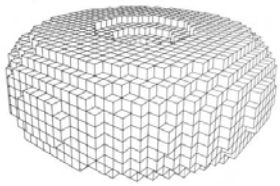
functional equivalence

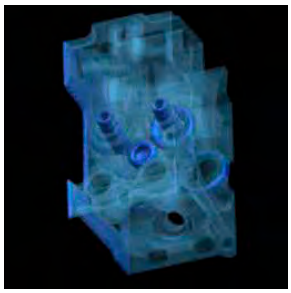
"class" equivalence

3D objects: problems and peculiarities

- ✓ Complete 3D shape models
  - The representation space has the same dimension of the object space: reasoning on 3D objects in 2D images has to cope with occlusions and cluttering, while reasoning about 3D objects in a 3D settings can exploit the representation of the complete shape
- ✓ Complexity of 3D shape models
  - methods developed for images do not generalize easily to 3D
  - not only matrices, but a variety of representations
- ✓ 3D models call for efficient computations
  - storage problems
  - delivery problems

- ✓ Cell decompositions
  - spatial occupancy enumeration (voxels, regular space partitioning,..)
  - object-based (tetrahedra, *octrees*)
- ✓ Constructive Solid Geometry (CSG)
- ✓ Boundary models
  - triangle meshes
  - B-reps
- ✓ Sweeps
  - generalized cylinders, generic sweeps





courtesy of Tom Funkhouser

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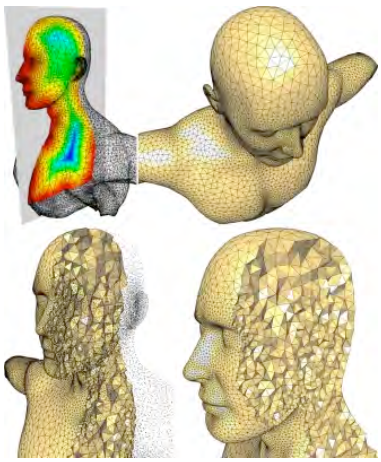

courtesy of Pierre Alliez

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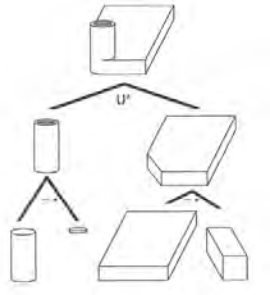

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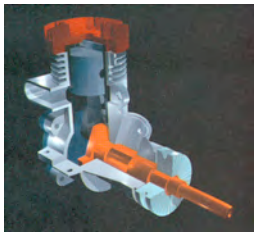

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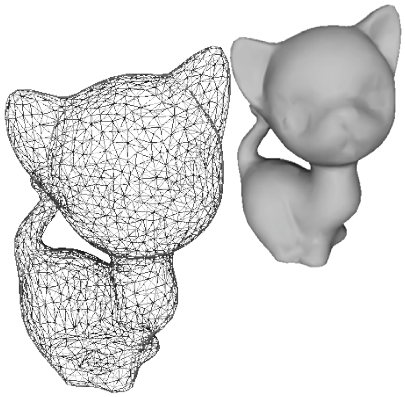

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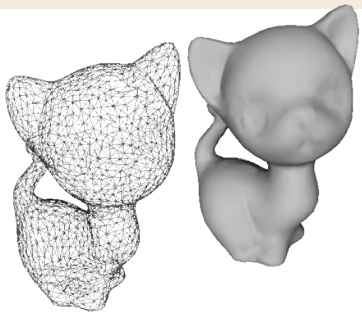

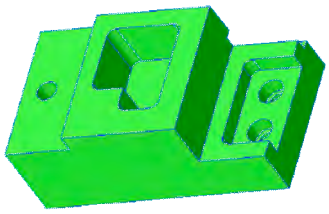

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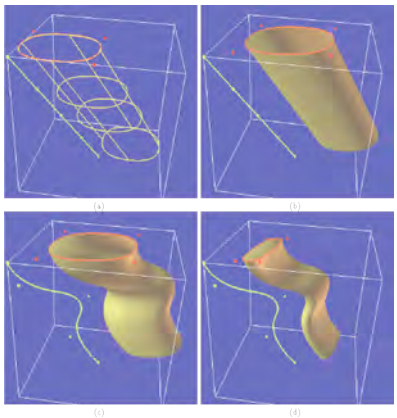
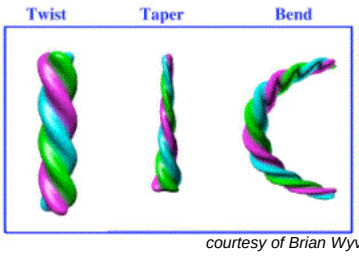


courtesy of Dimitri Terzopoulos

- implicit models
  - F(x,y,z)=0

Bill Lorensen
SIGGRAPH 99
Course #4 Notes

- CSG "new generation"
  - Blob tree



courtesy of Brian Wyvill

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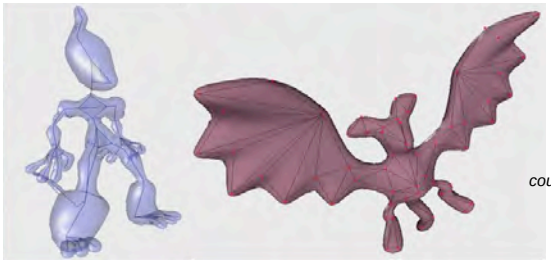
- Skeleton-based implicit surfaces



courtesy of Marie-Paule Cani

- "polygon soups" are very common in non-professional environments
- NURBS, B-reps, implicits, parametric, "high-quality" triangle meshes are used in professional domains for scientific and entertainment applications

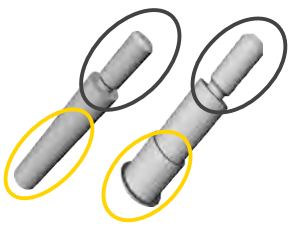
- different representation models can be used for representing the same object
- different file formats can be used for the same representation model
  - triangle meshes: WRL, OFF, PLY, 3Dmax, COLLADA, ..

global matching

- comparison among the overall shape
  - the object is considered as a whole
  - typically interpreted as a geometric congruence

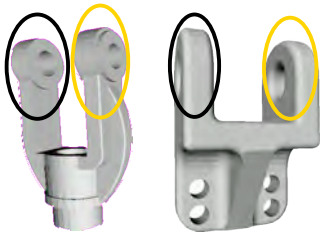
part correspondence

- Mapping among similar sub-parts
  - Similar overall shape
  - Requires the identification of the relevant sub-parts of the objects
  - Explicit representation of the correspondence among object sub-parts



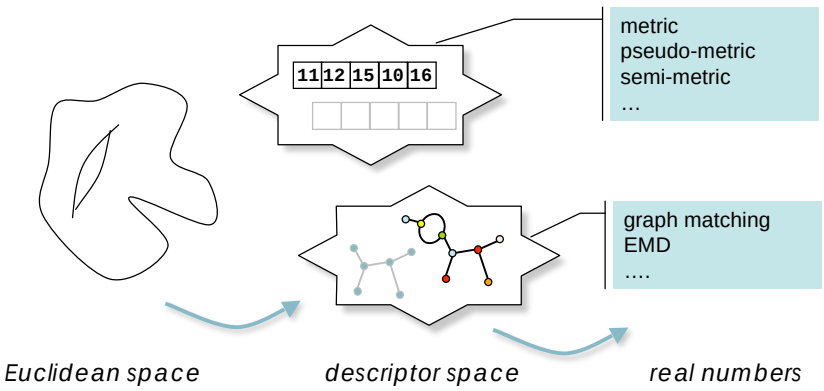
partial matching

- Similar sub-parts between objects having different overall shape
  - Identification of the relevant sub-parts of the objects
  - The two objects may have different overall shape but share similar sub-parts
  - Explicit representation of the correspondence among object sub-parts
  - Highlight of shape differences



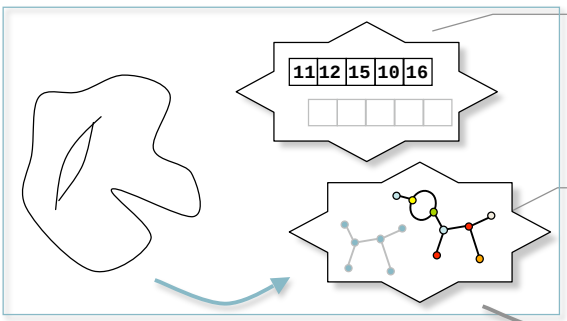
similarity evaluation

- Reasoning about shape similarity is done by associating a description, or signature, to the shapes and by defining a distance, or dissimilarity measure, among descriptors



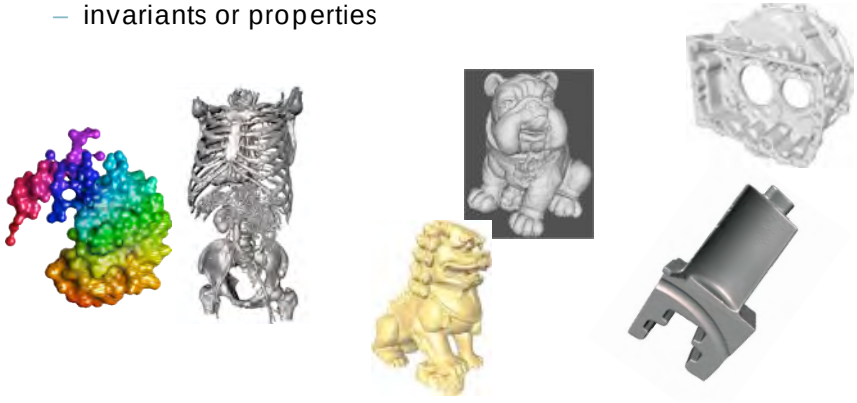
similarity evaluation

- ✓ Capture properties of the shape
  - the context of the shape comparison is very relevant here
  - usually driven by invariants
- ✓ Reduce the complexity of the process
- ✓ Plenty of different approaches and methods



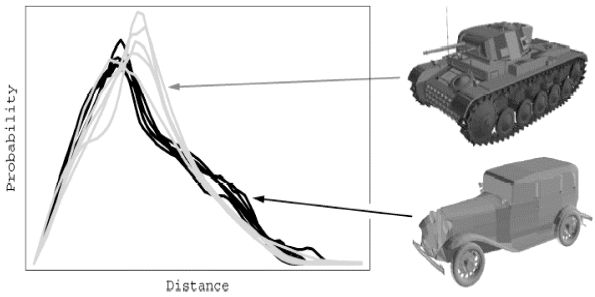
3D shape descriptors

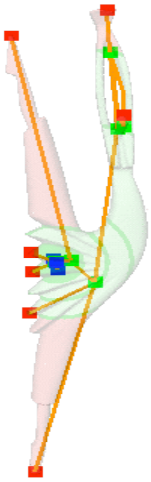
- ✓ Descriptors have to take into account the context in terms of
  - *type* of shapes and their variability/complexity in the context
  - invariants or properties



shape descriptors

- ✓ Concise (storage)
- ✓ Quick to compute (efficient extraction)
- ✓ Discriminating (expressiveness of the encoded features)

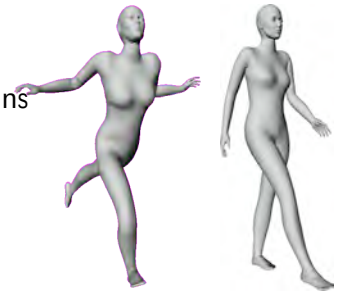




shape descriptors

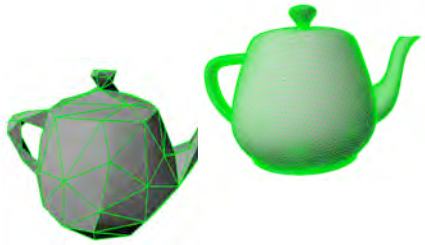
- ✓ Invariant to rigid transformation
  - rotation, translation, scaling

- ✓ Invariant to deformation
  - poses, isometric transformations

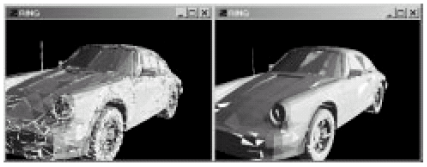


shape descriptors

- ✓ Invariant to representation
  - number of polygons in a mesh, changes of the representation



- ✓ Invariant to noise
  - noise caused by the scanning session



distance measures

- ✓ The measure properties are grouped as in the following:
  - semi-metric: self-identity, positivity, symmetry
  - pseudo-metric: self-identity, symmetry, triangular inequality
  - metric: a pseudo-metric that satisfies the positivity
  - ultra-metric: a metric satisfying strong triangular inequality
- ✓ The perceptual space can be approximated by the metric properties ? [Tversky, Psychological Review N 84, 1977], [Santini et al. PAMI 1999, Vol 21, N 9,]
  - symmetry and triangular inequality should not hold for partial matching
- ✓ Metrics can be used for indexing purposes

Shape retrieval methods

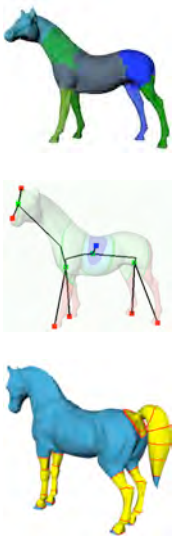
- ✓ focus on geometry
  - Shape distributions
  - Spin images
  - Spherical harmonics
  - Partial Matching with priority driven search
  - Salient geometric features
  - Pose oblivious shape signature
  - Light-field

Shape retrieval methods

- ✓ focus on structure
  - 2D shapes
    - Medial axis
    - Shock graphs
  - 3D shapes
    - Skeletonization based on volumetric thinning
    - Graphs from surface decompositions
    - Reeb graphs
- ✓ focus on intrinsic and embedding-based characteristics
  - Shape DNA
  - Bending Invariant Surface Signatures
  - Spectral Embedding

IMATI approach

- Geometry
  - *Detect relevant local features*
- Structure
  - *Organize them in a structure*
- Semantics
  - *Use the structure to detect high-level features (semantics)*

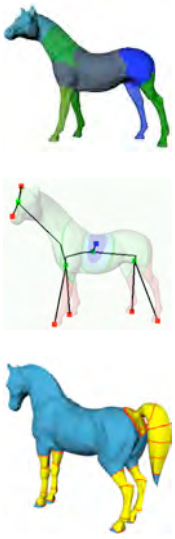


perception

understanding

IMATI approach

- Geometry
  - *3D shape descriptors based on geometric descriptors (e.g., shape distributions, spherical harmonics, PCA, ..)*
- Structure
  - *3D shape descriptors based on the configuration of features (e.g., skeletons*
- Semantics
  - *3D shape ontologies and conceptualization, reasoners and inference*



computer graphics

knowledge technologies

IMATI research activities in shape similarity

- ✓ modelling the similarity assessment process
  - *mathematical modelling of the cognitive aspects related to similarity evaluation*

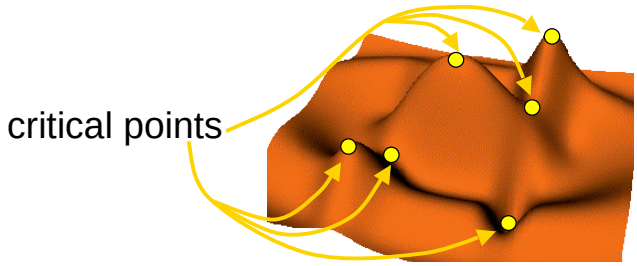
- ✓ developing methods to abstract the properties of shapes
  - segmentation, feature extraction, skeletonization, ...

- ✓ Knowledge-based techniques
  - *knowledge-driven segmentation, annotation, reasoning*

IMATI - shape descriptions

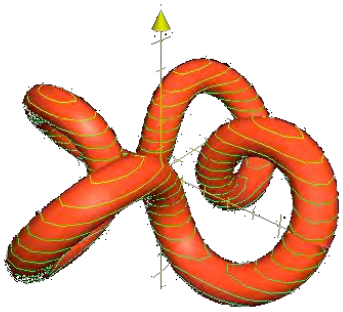
- ✓ Study the shape by studying the behaviour of one, or more, *f* defined over the shape
  - Salient features are detected by studying the behaviour of appropriate functions defined on the shape (eg, curvature, distances between points, critical points, function variation over the shape, harmonic analysis)
  - The choice of *f* is frequently driven by the invariants one wishes to preserve

- the perception of the shape is focused at maxima, saddles and minima



let *M* be a 2-manifold in R^3, *p=(x,y,z)* a point on *M* and *f* a real valued function $f : M \rightarrow R$, then *p* is called a **critical point** if $\nabla f(p)=0$ wrt a local coordinate system about *p*

- the evolution of the level sets or of the lower level sets of *f* provides a compact description of the shape



the choice of *f* depends on the properties or invariants that one wishes to preserve

key issues

- Mathematical methods for shape similarity assessment rely on
  - theoretical results, need to be
  - properly discretized, need to be
  - Efficiently implemented

a variety of challenging problems emerge from the exploration of this pipeline

What mathematical tools ?

- *Topologia computazionale per la descrizione di forma – Silvia –*
  - Morse theory as background
  - Critical points used to locate features
  - Shape described by a topological skeleton (Reeb graphs)
- *Topologia persistente per il confronto di forma – Daniela –*
  - The natural pseudo-distance as the mathematical formulation of shape similarity
  - Size pairs
  - Size functions
- *Analisi spettrale di forma: metodi numerici e applicazioni – Giuseppe –*

what else ?

- ✓ graph-matching techniques for partial similarity
- ✓ prototypes for 3D shapes
- ✓ machine learning for the selection of the "best" features for classification & retrieval
- ✓ fast reject schema for object-in-scene recognition
- ✓ Include the human in the loop
  - Relevance Feedback techniques
    - the system returns a list of results
    - the user gives a feedback about the relevance of each items
    - the system updates the list taking into account the user's opinion

relevance feed back on the similarity measure

- ✓ Get a set of computable rich set of complementary shape descriptors
- ✓ Let the user quantify her/his similarity concept through a friendly interface
- ✓ Inhibit the role of the distances that do not agree with the user's idea (they feel different what the user feels similar), by re-scaling the original similarity measures via a multiplying factor
- ✓ Use the max operator to combine the re-scaled distances

... make similarity emerge from the lack of differences!

3D similarity: content, context and concepts

- The object model carries the information needed assessing its similarity to a given object(s)
  - it is not simple to use this information to obtain an effective evaluation
  - different types of information should be considered depending on the application context, the matching task and the matching approach
- is geometry/structure enough ?
- are descriptors adequate ?
- how to involve users more ?

Shape Modeling Group - Similarity Evaluation

- 3D shape analysis and segmentation
  - Michela Mortara, Giuseppe Patané, Marco Attene
- Computational topology for analysis and retrieval
  - Silvia Biasotti, Daniela Giorgi, Giuseppe Patané
- 3D matching and retrieval
  - Simone Marini, Daniela Giorgi, Silvia Biasotti
- Relevance feed back and query formulation
  - Daniela Giorgi, Francesco Robbiano
- ShapeAnnotator
  - Marco Attene, Francesco Robbiano, Chiara Catalano
- Ontologies for 3D shapes and applications
  - Francesco Robbiano, Chiara Catalano, Riccardo Albertoni

Bianca Falcidieno

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