The Hitchhiker's Guide to the Galaxy of Mathematical Tools for Shape Analysis

SIGGRAPH 2012 *Course Notes*

wrap up

to sum up: theory says ...

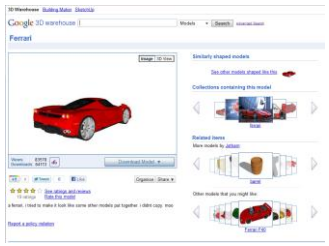
- we have seen:
  - how to represent a shape (topological spaces, manifolds, metric spaces, simplicial complexes…)
  - how to analyze, describe, compare shapes (geodesics, curvature, diffusion geometry, Morse theory, algebraic machinery…)
  - examples of different applications
- we have investigated:
  - the right tool for the right problem (the right space, invariance, property…)
  - theoretical assumptions vs real world assumptions
- what's next?
  - mathematics in the forthcoming landscape

getting out of a maze

- complex shapes, complex problems and… mathematical methods…
  - what is the only maths you can't ever apply? the one you don't know!
    (Mario Pezzana, by way of Massimo Ferri)
- but if we go back to «real» shapes and problems, are we sure that everything works ok?
  - services which could use the theories discussed
  - discretization issues and applicability

complex shapes, complex problems

- online repositories of 3D models
  - Google 3D Warehouse http://sketchup.google.com/3dwarehouse/



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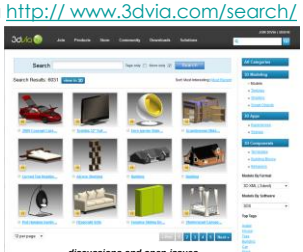

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  - Turbosquid http://www.turbosquid.com/
    - "…search our stock catalog to get the 3D model you want, or use our Custom 3D modeling service for made-to-order 3D models. Join the world's top artists who use TurboSquid 3D models in advertising, architecture, broadcast, games, training, film, the web, and just for fun"

complex shapes, complex problems

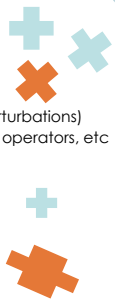
- 3D Object Retrieval & Content-based search
  - Princeton Shape Benchmark
  - Digital Shape Workbench v5.0 http://visionair.ge.imati.cnr.it/

to sum up: theory says …

- 3D shapes maybe very complex and services we can imagine for sharing, searching, and even design new shapes are many, so…
- … how to get out of this maze?
- basics
  - the choice of one or another shape description should be guided by
    - type of shapes and their variability/complexity
    - invariants or properties to be preserved / captured
  - topological spaces and functions are promising to model and reason about similarity in a mathematically well-formulated manner

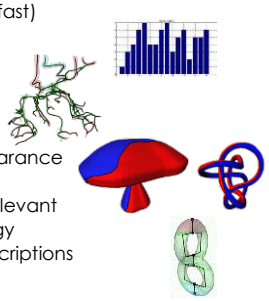
pay attention to…

- … the right space
  - rigid transformations (rotations, translations)
    - Euclidean distances
  - isometries
    - Riemannian metric
    - curvature (but unstable to local noise/perturbations)
    - geodesics, diffusion geometry, Laplacian operators, etc
  - local invariance to shape parameterizations
    - conformal geometry
  - similarities (i.e. scale operations)
    - normalized Euclidean distances
  - affinity (and homeomorphisms)
    - persistent topology
    - Morse theory
    - size theory



pay attention to…

- … a suitable shape description
  - coarse coding (but fast)
    - histograms
    - matrices
  - articulated shapes
    - medial axes
    - Reeb graphs
  - overall global appearance
    - silhouettes
  - if shape loops are relevant
    - persistent topology
    - graph-based descriptions



to sum up: benchmarking

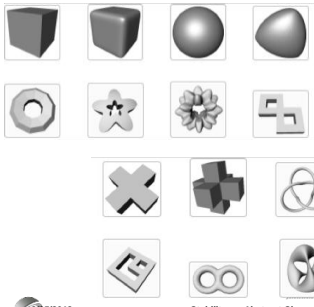
- importance of benchmarking and evaluation!
  - not only publishing papers but also to demonstrate real innovation and applicability potential
- Shape segmentation benchmark
- SHape Retrieval Context http://www.aimatshape.net/event/SHREC
  - an annual event to to evaluate the effectiveness of 3D shape analysis algorithms
  - a multi-track event spanning
    - different models: from watertight objects to triangle soups, from abstract shapes to medical data
    - different tasks: from 3D retrieval to correspondence finding and segmentation

example: SHREC'12 - SAS

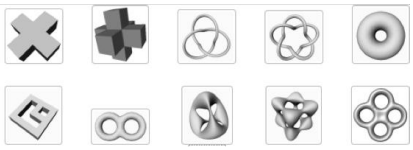
- to evaluate the stability of the algorithms under variations of abstract shapes characterized by
  - smooth/sharp features,
  - partial/global symmetries
  - different genus.
- to create a new benchmark where to measure the capability of the retrieval methods to be invariant to
  - noise addition and resampling
  - affine transformations

dataset

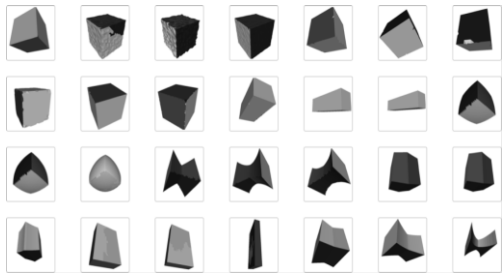
9 transformations, 3 degrees each, for a total of 27 perturbations



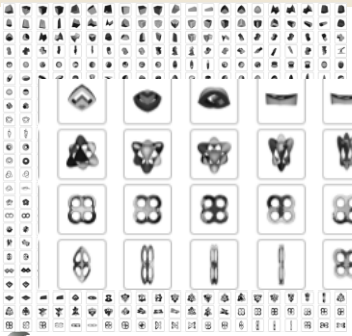
1. addition of Gaussian noise
2. different regular sampling
3. uneven sampling
4. & .5 two stretching
6. & .7 two non-uniform dilations
8. & .9 two non-uniform erosions



dataset



504 watertight models without self-intersections



conclusions

- the right tool for the right problem
  - mathematically sound methods
  - benchmarking & evaluation
- geometry, structure, similarity, context
  - is it possible to understand something about functionality or affordance?
  - machine learning vs geometric-reasoning
  - 3D query modalities
  - what if shape is influenced/modified by the context?

acknowledgements

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at the end of the day...

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thank you for your attention!

these course notes are available at: http://www.ge.imati.cnr.it/training

SO LONG
&
THANKS FOR ALL THE FISH
05/08/2012
discussions and open issues