Fundamentals of Computer Graphics

Introduction
Shape representation

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SAPIENZA
UNIVERSITÀ DI ROMA

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Logistics

- **Lecturer:** Prof. Emanuele Rodolà
- **When:** Mondays 14:00–16:30 and Thursdays 08:00–10:30
- **Where:** Aula Magna - Alfa - Sociologia, via Salaria 113
- **Office Hours:** Drop me an email
- **Official website:** https://erodola.github.io/FundCG-s1-2018/
  Check frequently for news and material (code, papers, ...)!

Disclaimer

This is a new course! Some key differences with last year:

- More geometry (shape analysis, processing and modeling)
- Less rendering and pixels (lights, cameras, materials, etc.)

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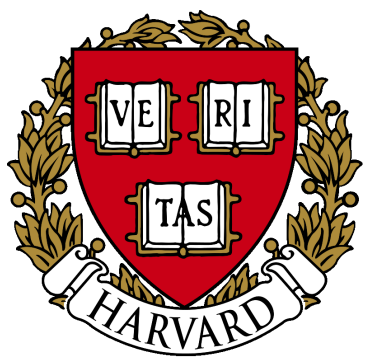
Geometry Pixels

Who am I?

- Had research positions at U Tokyo, TU Munich, U Lugano and visiting positions at Harvard, Stanford, Ecole polytechnique, Technion among others
- 3D computer vision, digital geometry processing, geometric deep learning
- Passionate about anything that is new, cool, and/or crazy
- Approach me for projects and theses!



Examples

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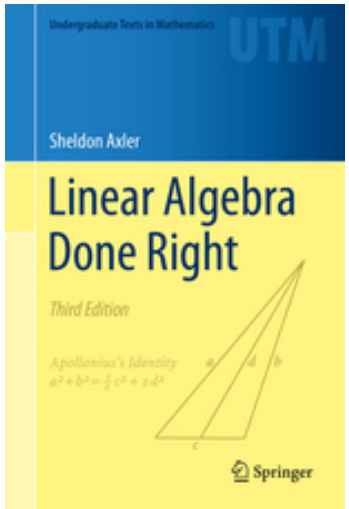
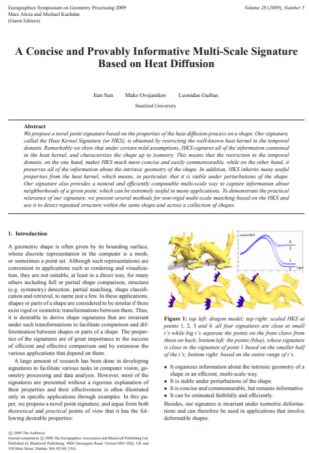
Pre-requisites and reading material

There is no official textbook. Specific references will be given throughout the course in the form of book chapters and scientific articles.





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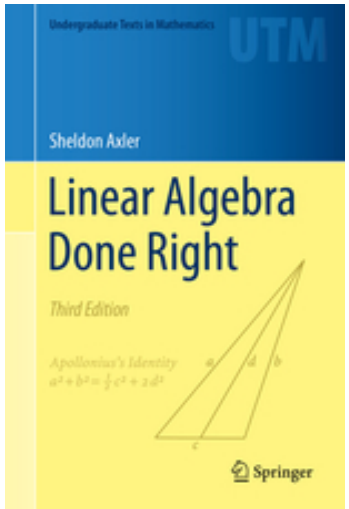

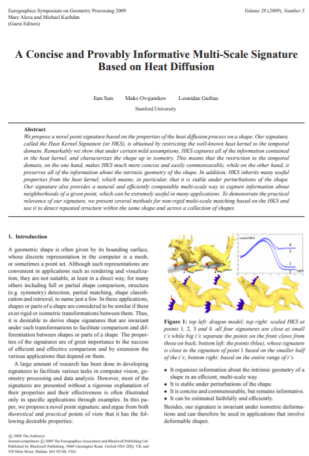

Pre-requisites:

- **Programming fundamentals**. Any language is alright, although the course will mostly use C/C++/Matlab
- Welcome (not mandatory): linear algebra, calculus, numerical methods, optimization

Grading and exams

Modality: Mid-term written exam + final project with oral examination.

- In-depth survey (possibly with code)
- Software project plus report

Topics and project descriptions will come later.
Original ideas are encouraged.

Lecture exercises are part of the oral exam.

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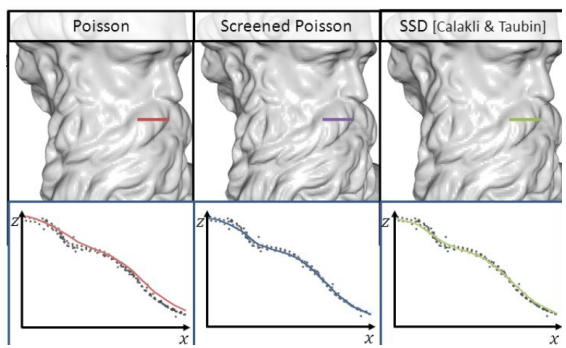
Project examples:

- Survey: Review of shape reconstruction techniques



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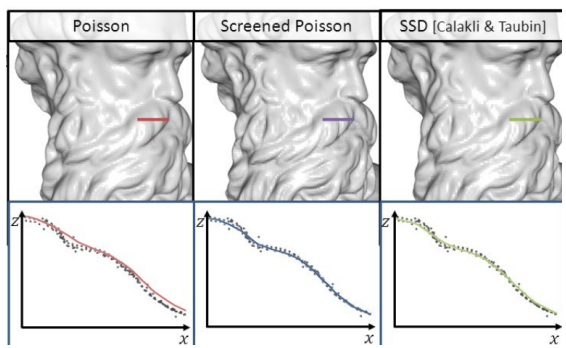
Project examples:

- Survey: Review of shape reconstruction techniques
- Project: Implement one such technique and discuss results



Overall objective

What will you get out of this course?

- You will understand next-generation technology dealing with 3D data
- You will understand scientific articles in the 3D area

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- You will understand scientific articles in the 3D area
- You will obtain unique skills

Minority Report (20th Century Fox/Dreamworks) 2002

Microsoft Kinect 2010

>$10K

2005

$100

2010

$20

2014

Deluge of geometric data

KINECT for XBOX 360 SoftKinetic The Interface is You

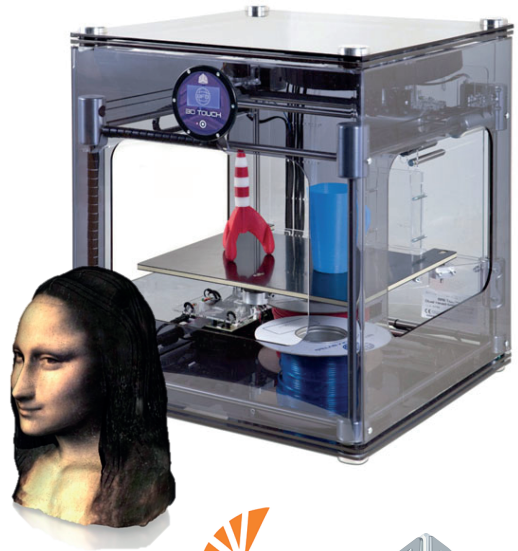
intel REALSENSE

3D sensors

Google 3D warehouse

shapeways

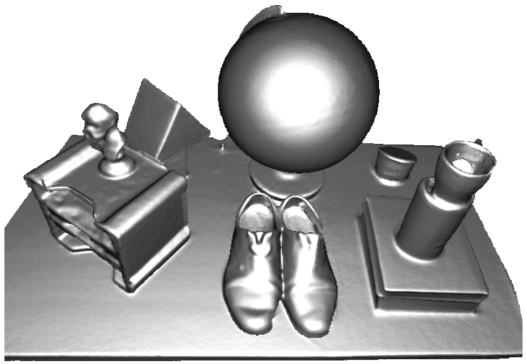
Repositories



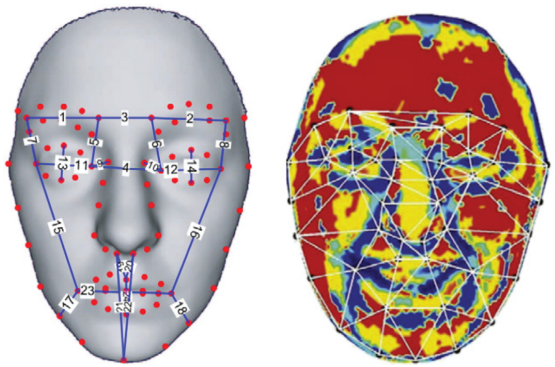
Stratasys 3DSYSTEMS

3D printers

Applications



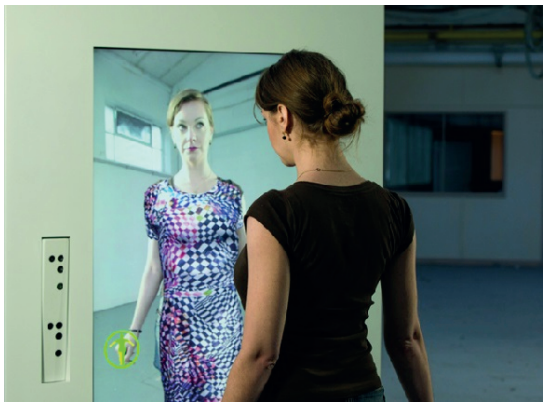
Reconstruction



Recognition

Retrieval

Avatars



Virtual dressing

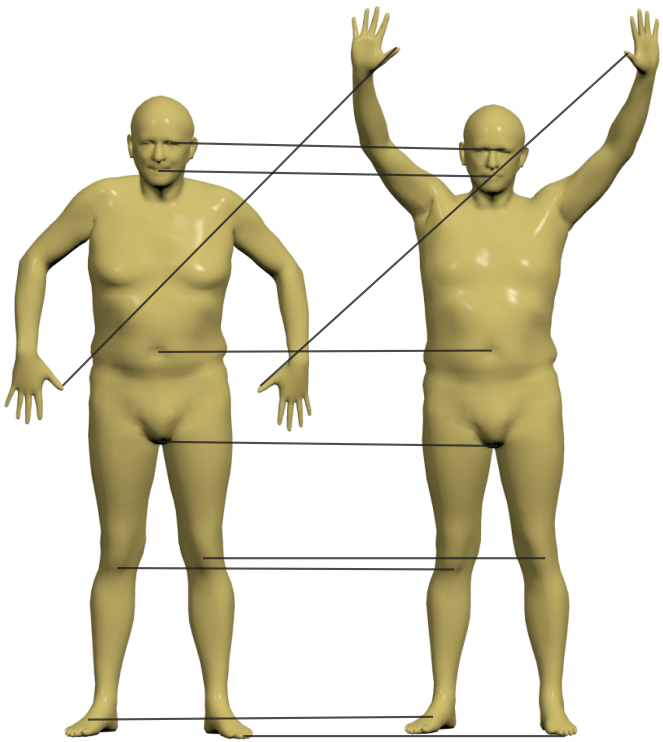
Gesture control

Images: Davison et al. 2011; Zaiferiou et al. 2012; Kim et al. 2013; Faceshift; Fashion3D; Minority report

Microsoft

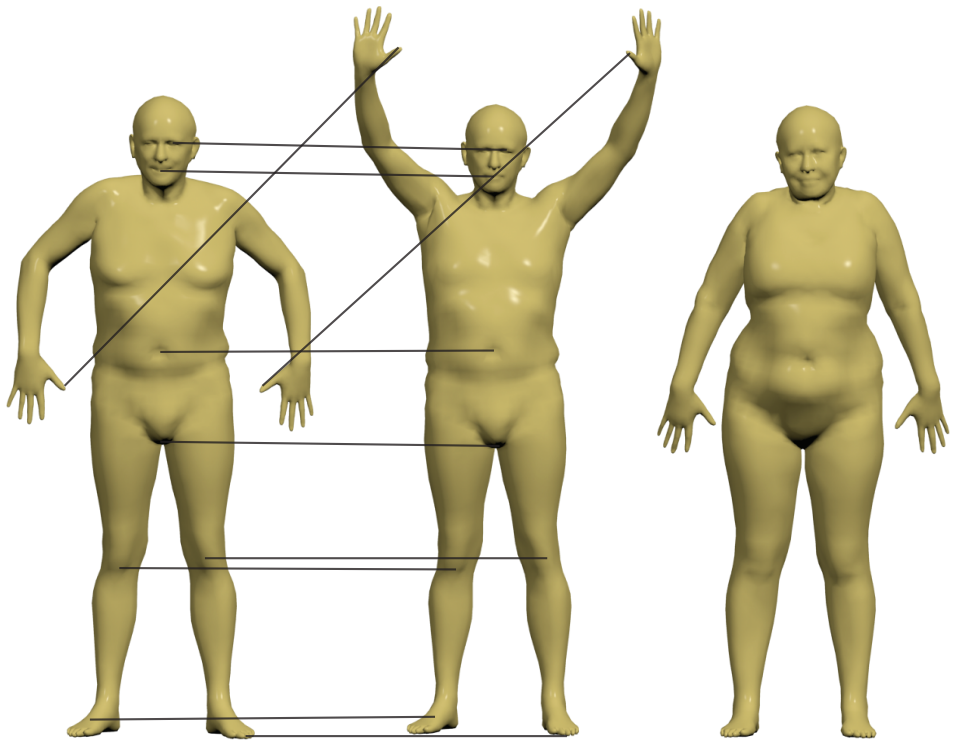
Faceshift (acquired by Apple in 2015)

Basic problems: shape similarity and correspondence



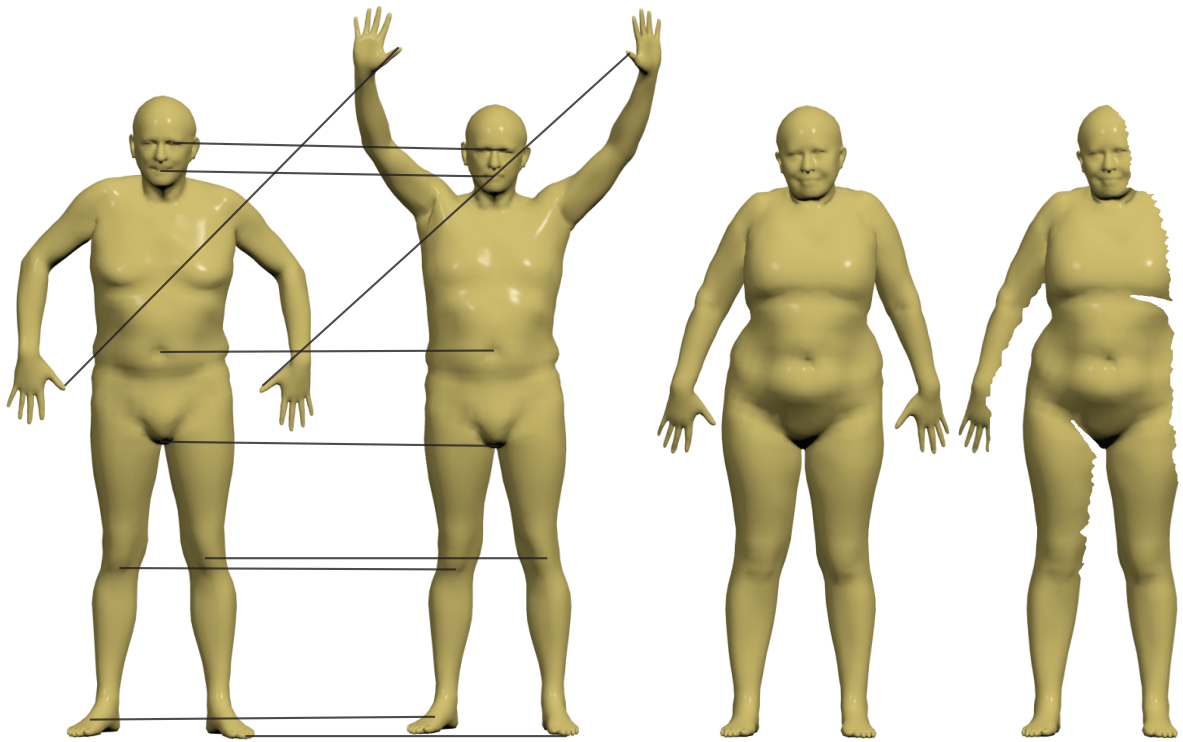
Isometric

Basic problems: shape similarity and correspondence



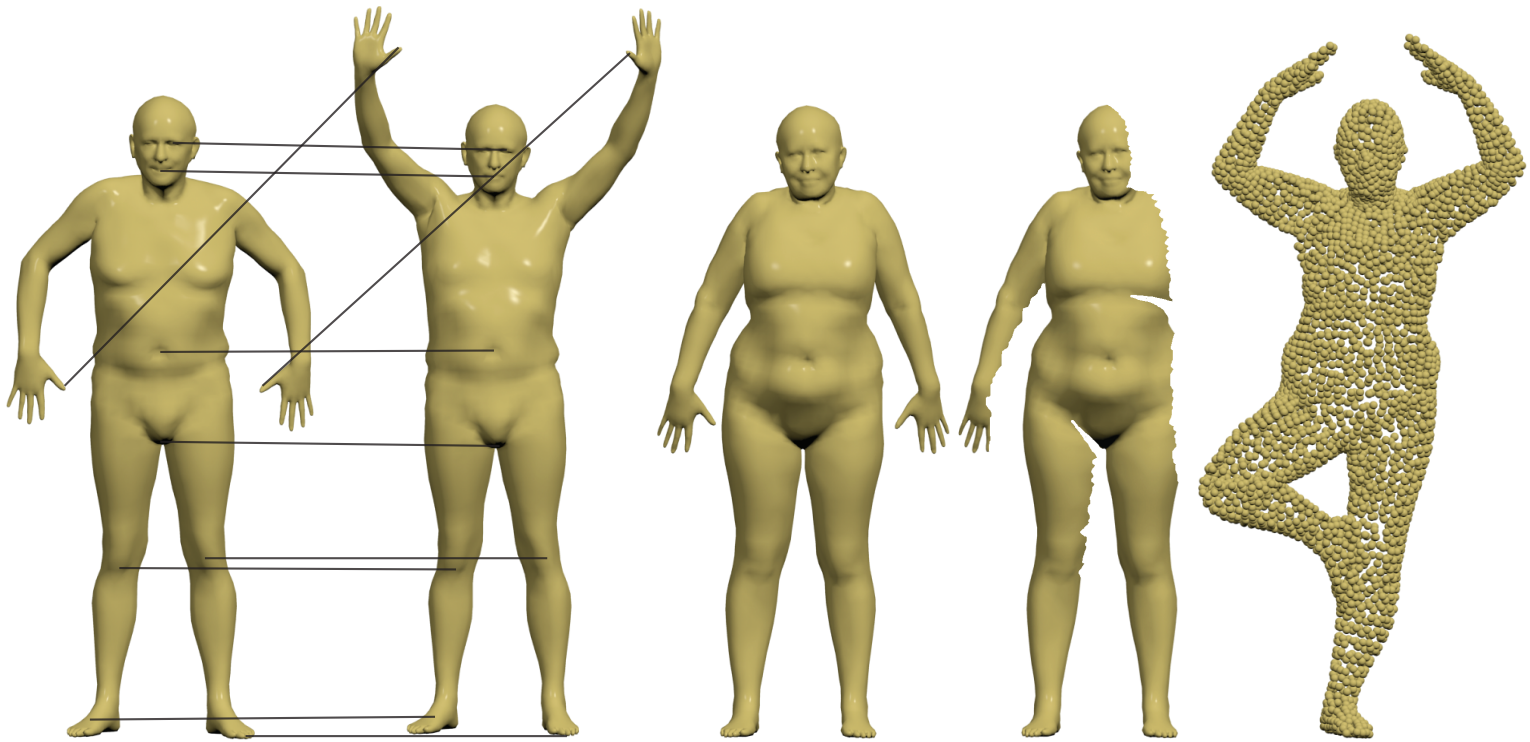
Isometric Non-isometric

Basic problems: shape similarity and correspondence



Isometric Non-isometric Partial

Basic problems: shape similarity and correspondence



Mathematical tools

- Linear algebra
- Metric spaces
- Differential geometry
- Partial differential equations
- Optimization

But...

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- Linear algebra
- Metric spaces
- Differential geometry
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But...

90% of the time we will be able to visualize what we are doing!

Example

"Vector-valued function on a 2-Riemannian manifold"

Example

"Vector-valued function on a 2-Riemannian manifold"
= A color for each point of a 3D shape

What is a shape?

"There can be no such thing as a mathematical theory of shape. The very notion of shape belongs to the natural sciences."[1]

[1] J. Koenderink, "Solid Shape". MIT Press 1990

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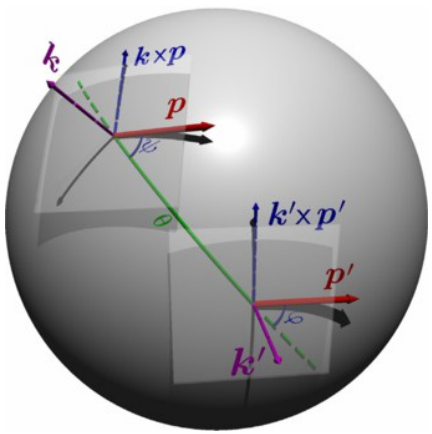
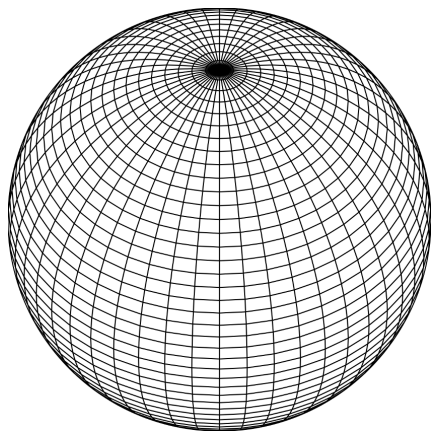
"There can be no such thing as a mathematical theory of shape. The very notion of shape belongs to the natural sciences."[1]

For us, shapes are mathematical objects (specifically, manifolds) with a precise and rigorous definition. We will model them mathematically in the continuous setting ("pen and paper") and bring them to the digital world by translating to the discrete setting.





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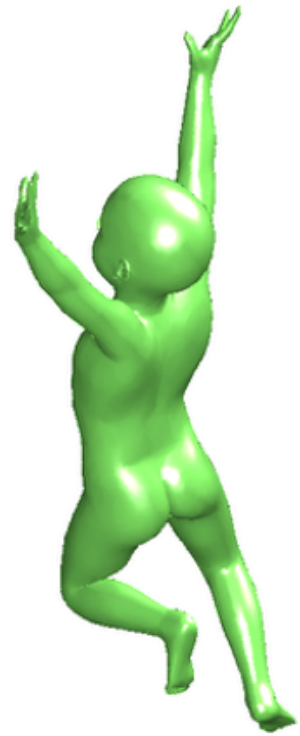
Shapes vs Images: Domain

Euclidean (flat)

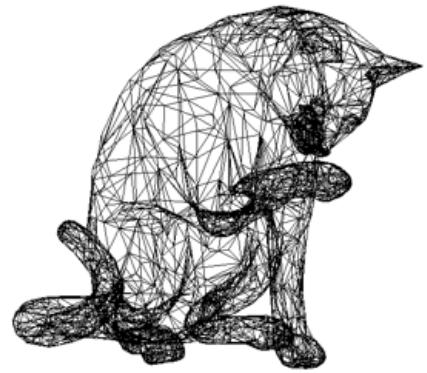


non-Euclidean (curved)

Shapes vs Images: Representation

Array of pixels (uniform grid)

Splines

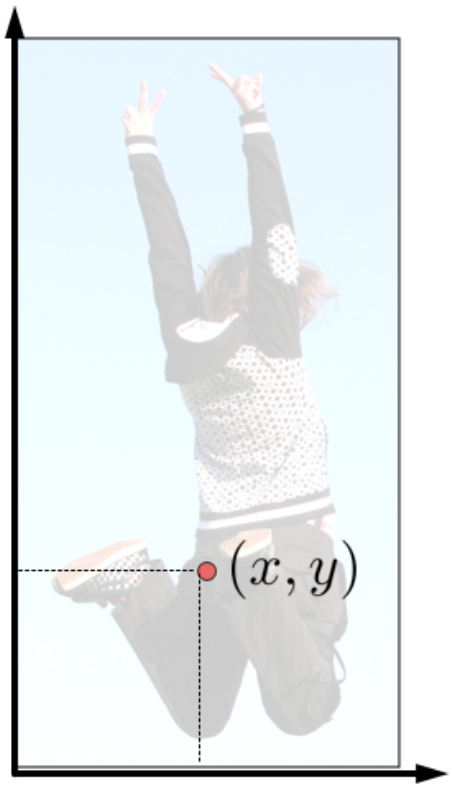


Graph

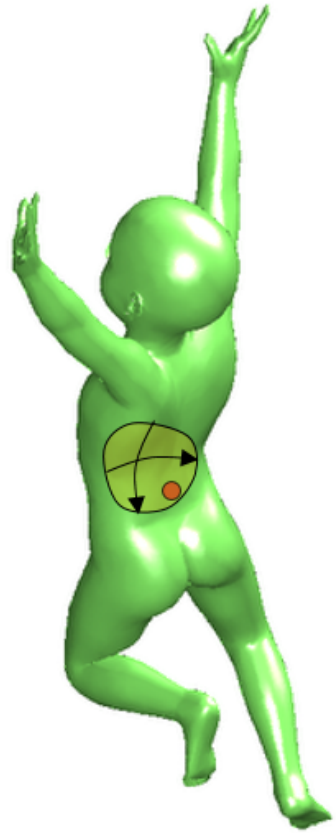
Point cloud

Triangle mesh

Shapes vs Images: Parametrization

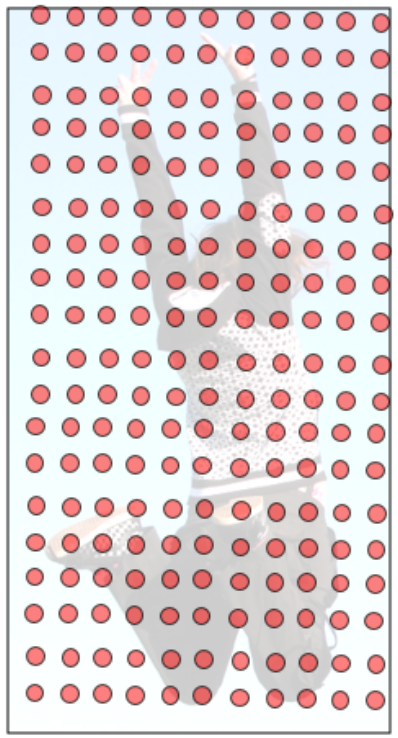


Global

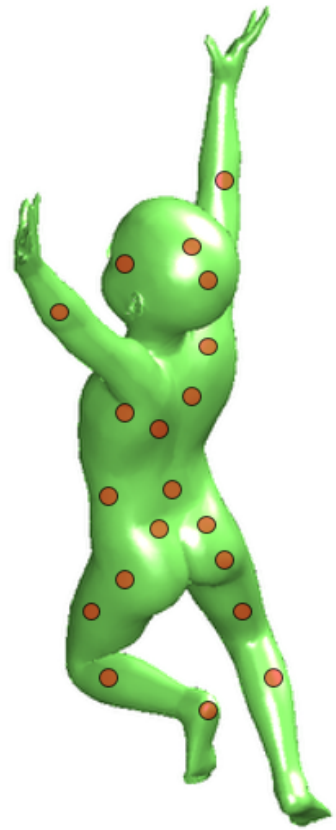


Local

Shapes vs Images: Sampling



Uniform

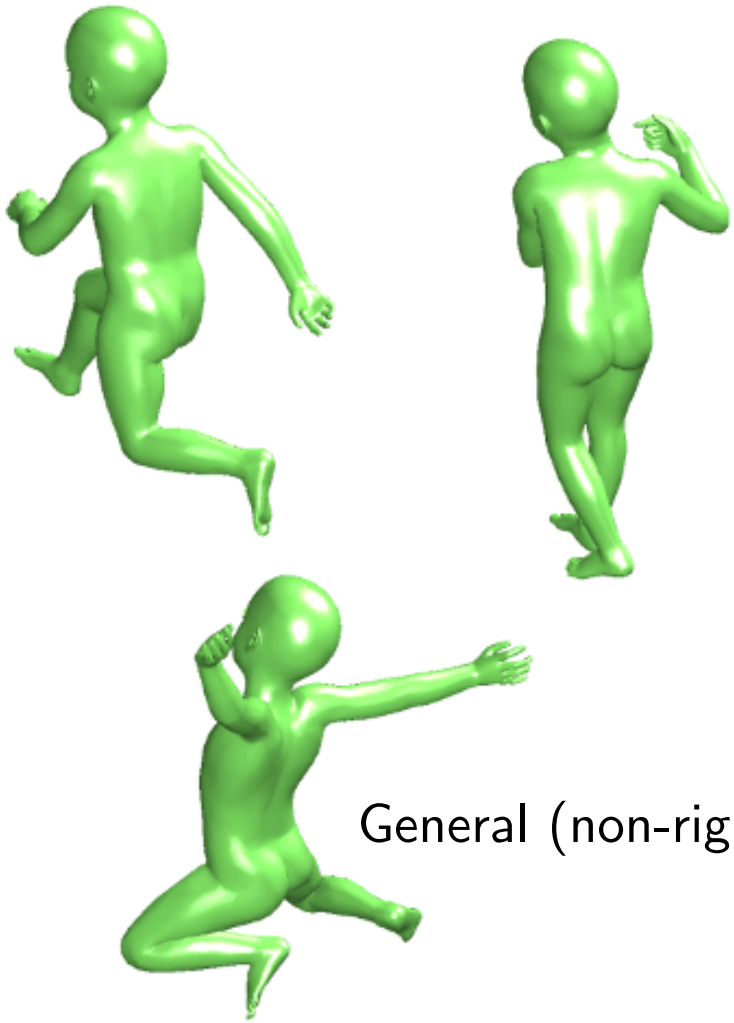


"Uniform" is not well defined

Shapes vs Images: Transformations

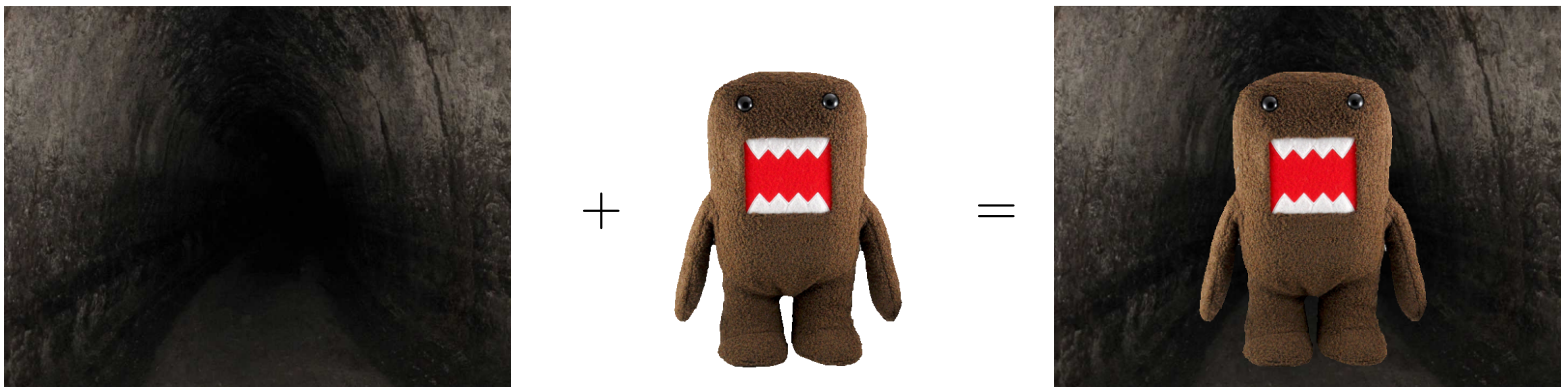
Perspective

Affine



General (non-rigid)

Shapes vs Images: Calculus



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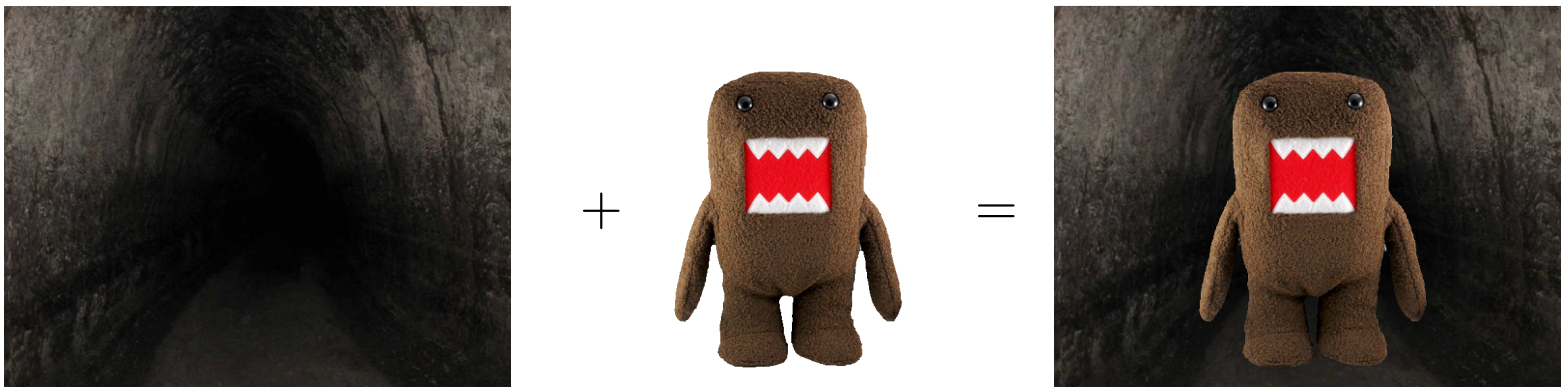

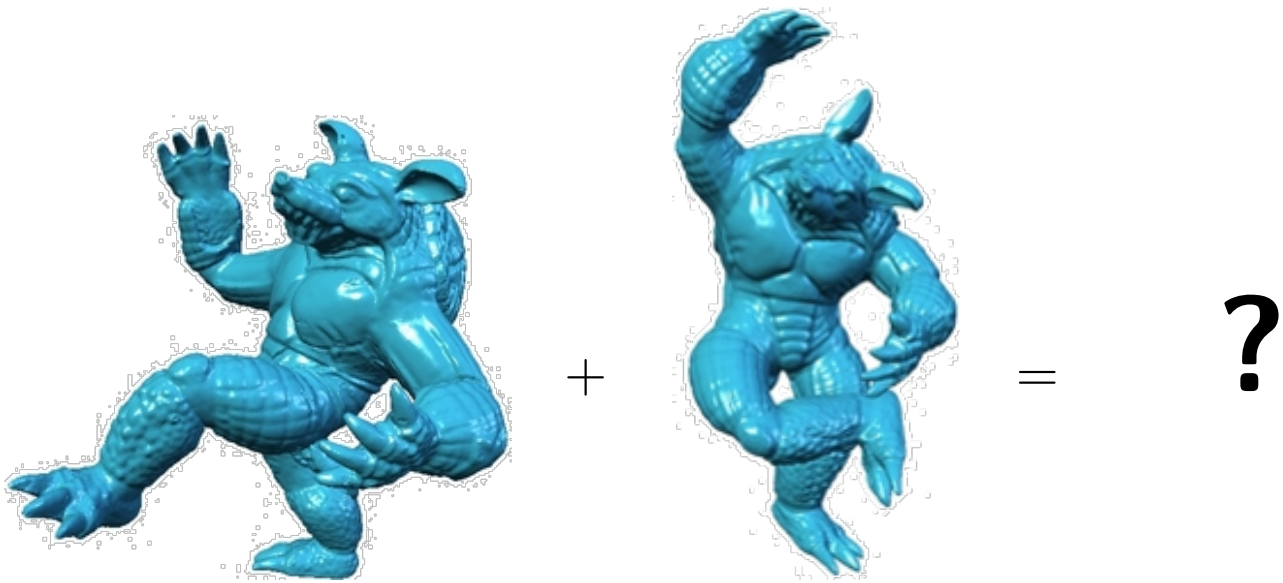

Shape representation

We will use mainly two representations for shapes:

- Triangle mesh
- Point cloud

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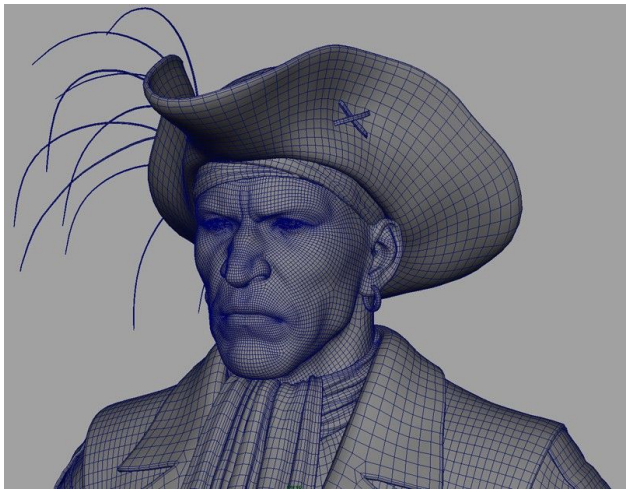
Other shape representations exist:

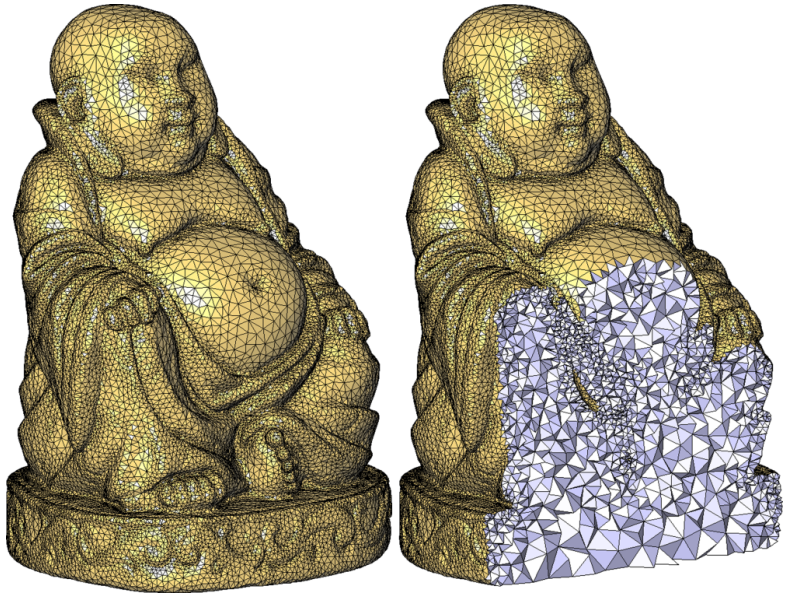
- Polygonal meshes (polygons are not restricted to triangles)
- Parametric surfaces
- Tet-meshes (volumetric)
- Voxel grids (volumetric)
- ...

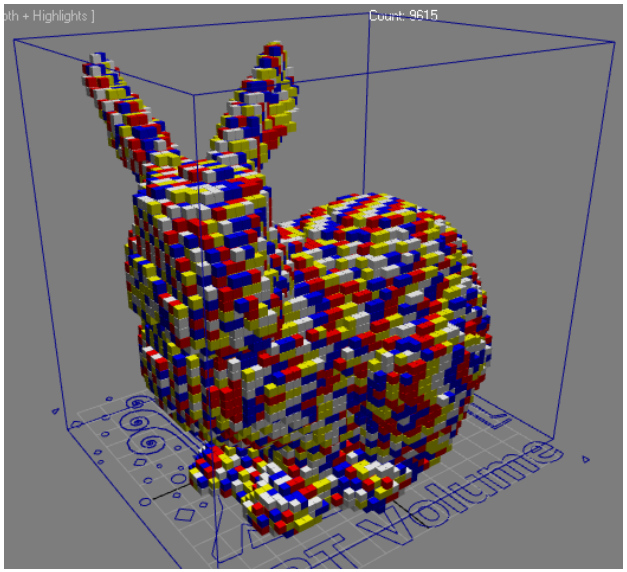
The volumetric representations model the interior of the object, whereas the shape surface is the corresponding boundary.

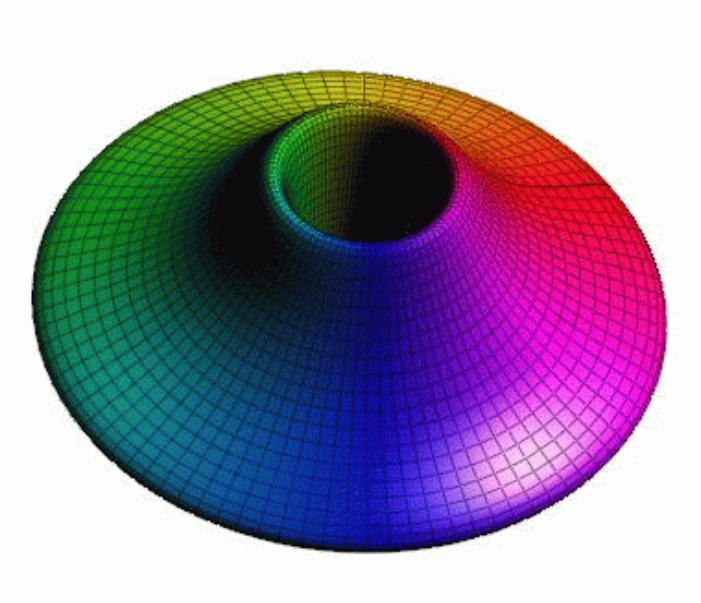
However, these alternative representations will not be considered in the remainder of this course.

Example: Other representations









Shape representation: Key ingredients

- We want to represent surfaces
- Each point can have attributes attached to it (e.g., RGB color)

Note: These notions will be covered more rigorously in the next lectures.

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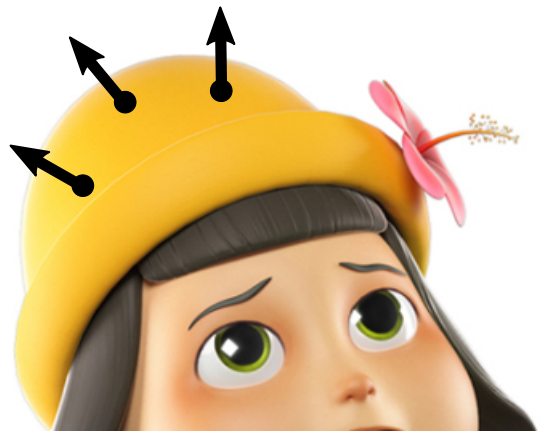
- Each point can have attributes attached to it (e.g., RGB color)
- Surfaces have an orientation defined by normal vectors



Visualization of 3 normal vectors

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Shape representation: Triangle mesh

A triangle mesh is a collection of connected triangles.

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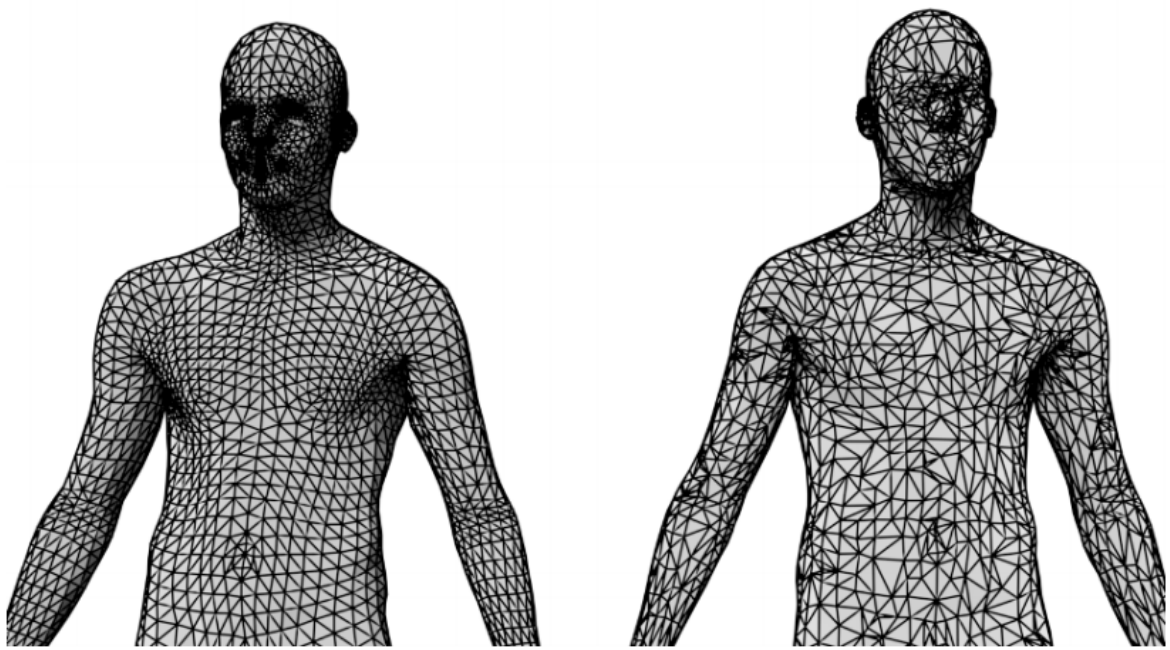
A triangle mesh is a collection of connected triangles.

The incidence relations of triangles defines the mesh connectivity (also referred to as mesh topology).

In this example, the same underlying surface is discretized with meshes having different connectivity:

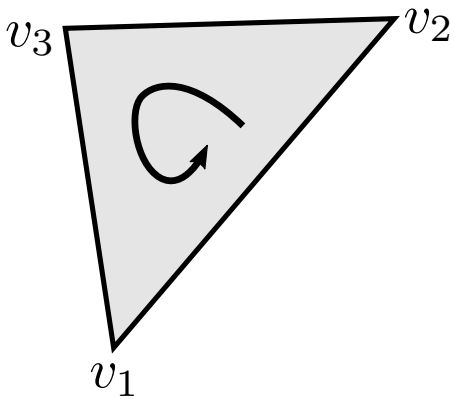


Shape representation: Triangle mesh

A triangle mesh is a collection of connected triangles.

We will only consider oriented manifold meshes.

- Each triangle has an orientation



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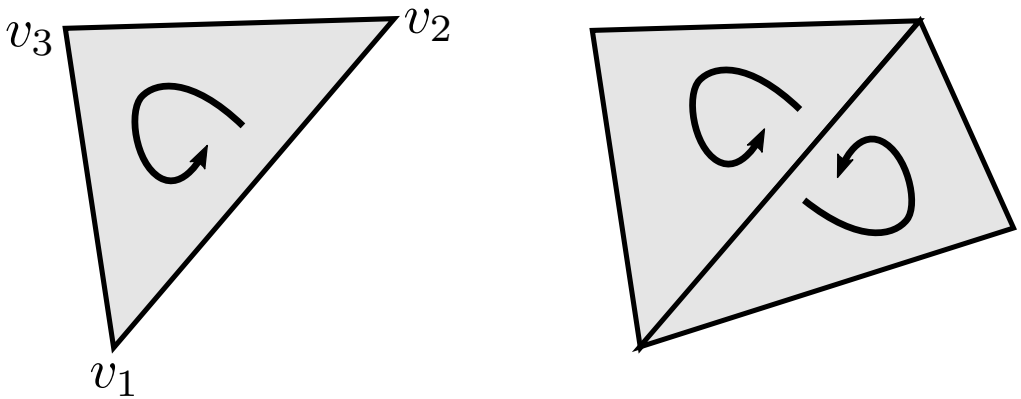
- All triangles should be consistently oriented (e.g. counter-clockwise)



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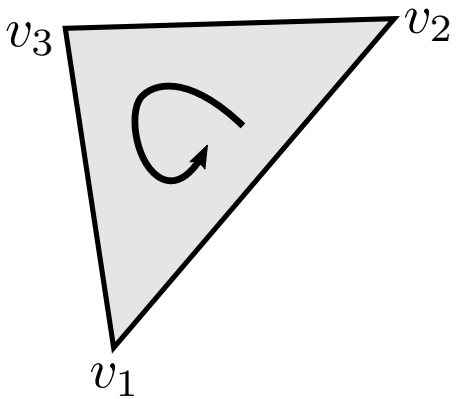
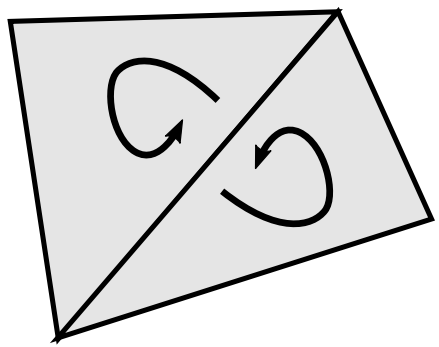
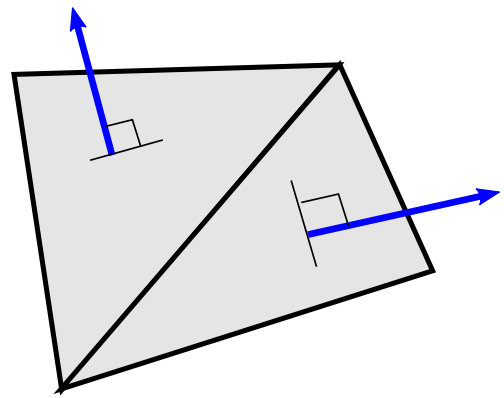
- All triangles should be consistently oriented (e.g. counter-clockwise)
- Each triangle has a normal (i.e. orthogonal) vector consistent with the triangle orientation







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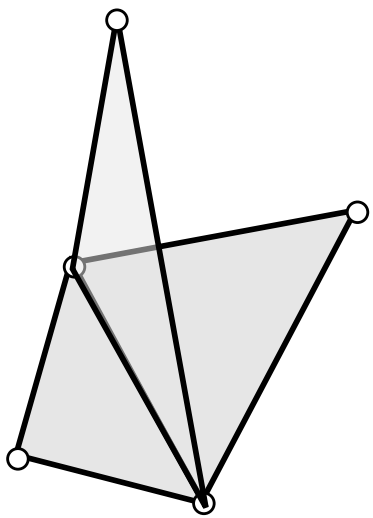
- All edges have at most two incident triangles



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$\Rightarrow$ non-manifold

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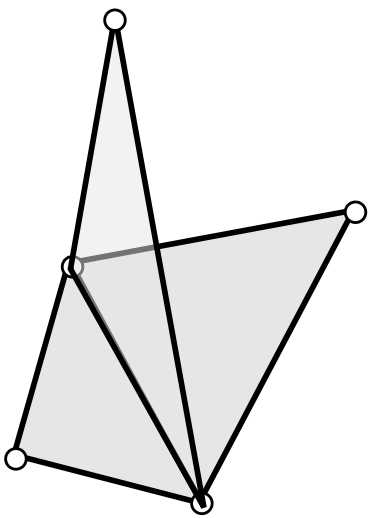

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Shape representation: Triangle mesh

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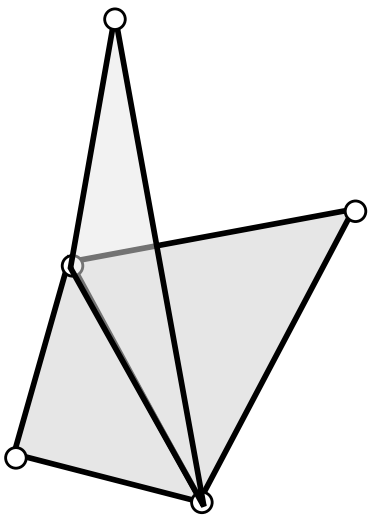
- All edges have at most two incident triangles
- Edges with only one incident triangle form the mesh boundary
- The faces incident to a vertex form a closed or an open fan



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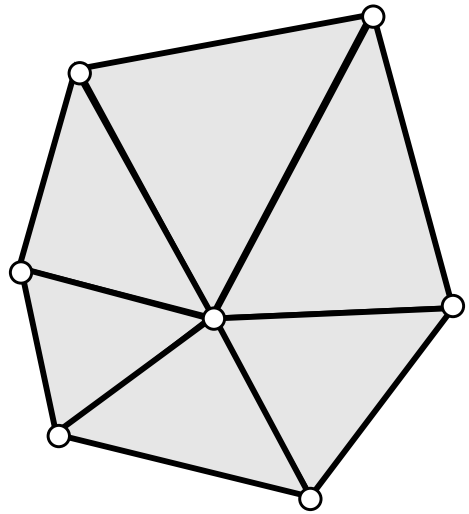
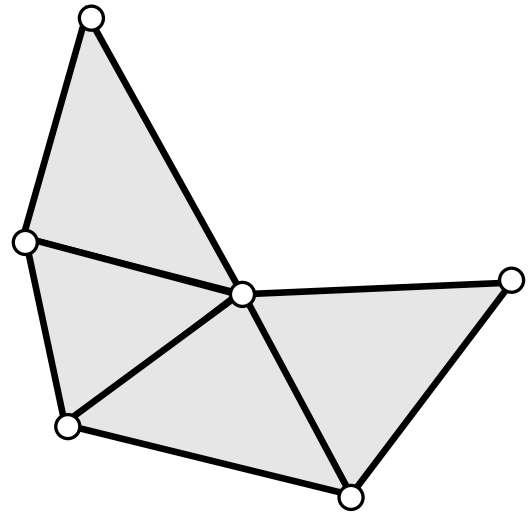
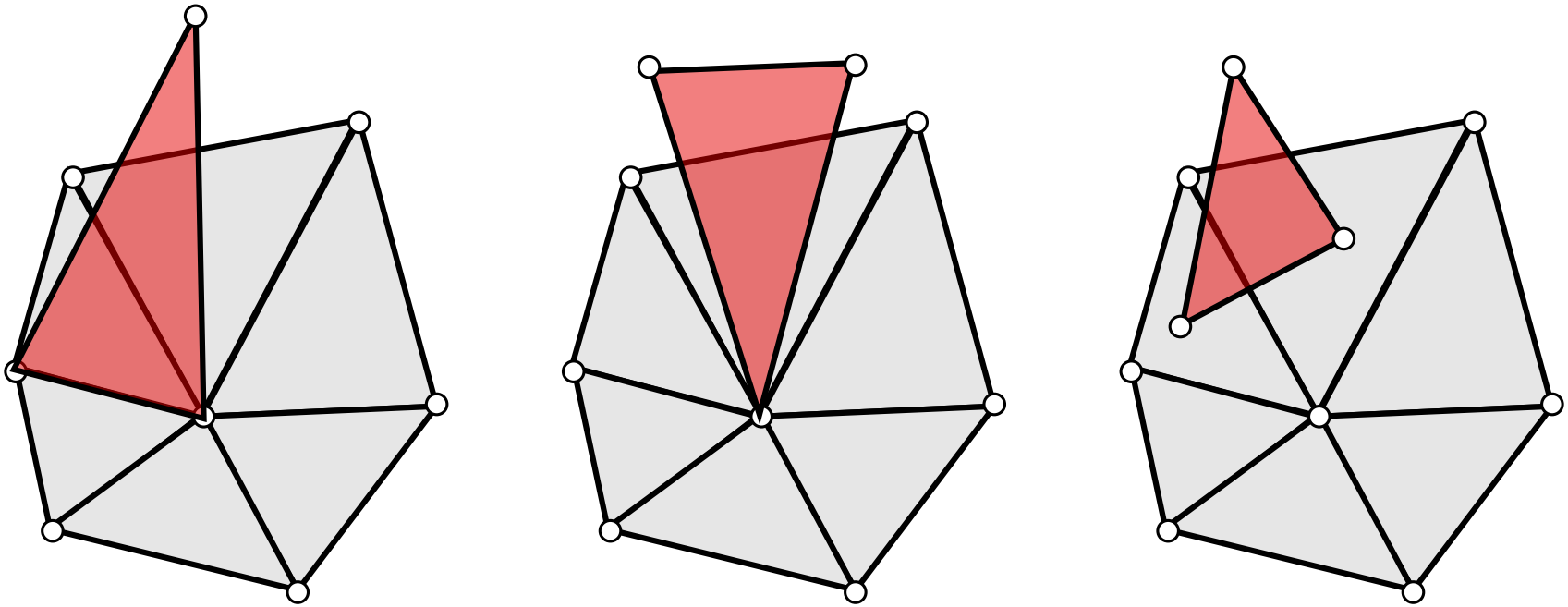


closed fan



open fan

Example: Non-manifold meshes



Shape representation: Point cloud

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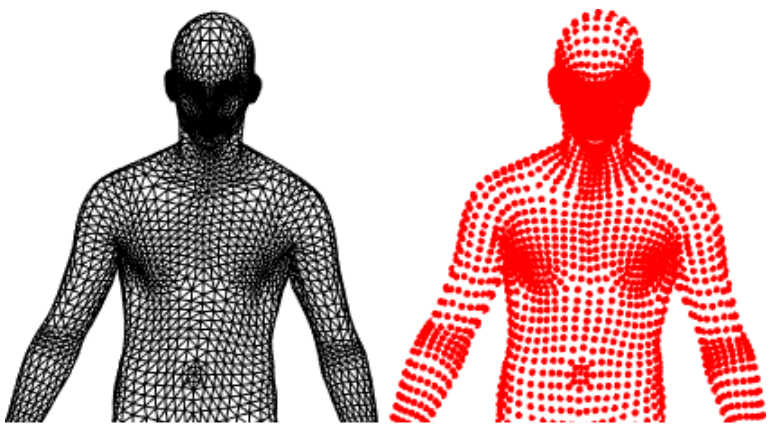
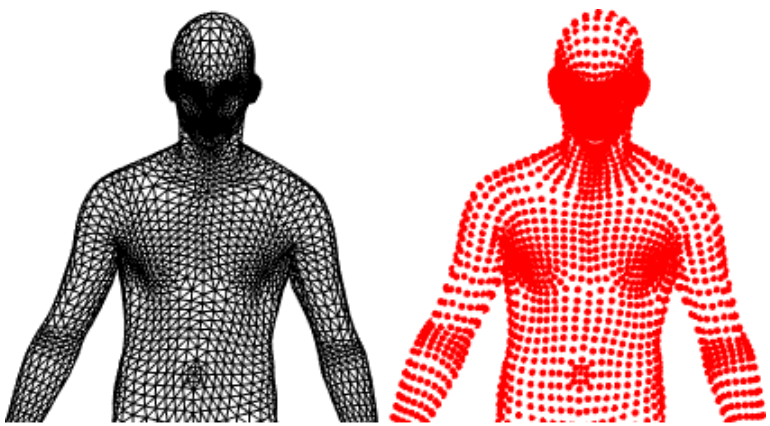


Synthetic point cloud
(obtained by removing mesh connectivity)

Shape representation: Point cloud

A point cloud is a collection of points in 3D space.

- An oriented point cloud also has a normal vector for each point
- Point clouds are interpreted as point-wise samplings of an underlying unknown continuous surface...
- ...in practice, they come from depth sensors and can be very noisy!



Synthetic point cloud
(obtained by removing mesh connectivity)

Real-world Kinect scan

Exercise: Triangle mesh data structure

Create a data structure to represent a generic triangle mesh. The data structure must contain the following information:

- A collection of (x, y, z) coordinates for all the triangle vertices;
  Example: A matrix of size $n \times 3$, where n is the total number of vertices
- A collection of triangles (v_1, v_2, v_3); each v_1, v_2, v_3 is an index to the set of vertices;
  Example: A matrix of size $m \times 3$, where m is the total number of triangles

Additionally, write the following functions:

- read_off(): reads from disk a triangle mesh in .off format
- write_off(): writes to disk a given triangle mesh in .off format
- calc_tri_areas(): computes the area for each triangle in the mesh
- calc_boundary_edges(): identifies the boundary edges (if any) of the mesh

Test your code by loading and visualizing cat0.off (download from the course website)

Exercise: Point cloud data structure

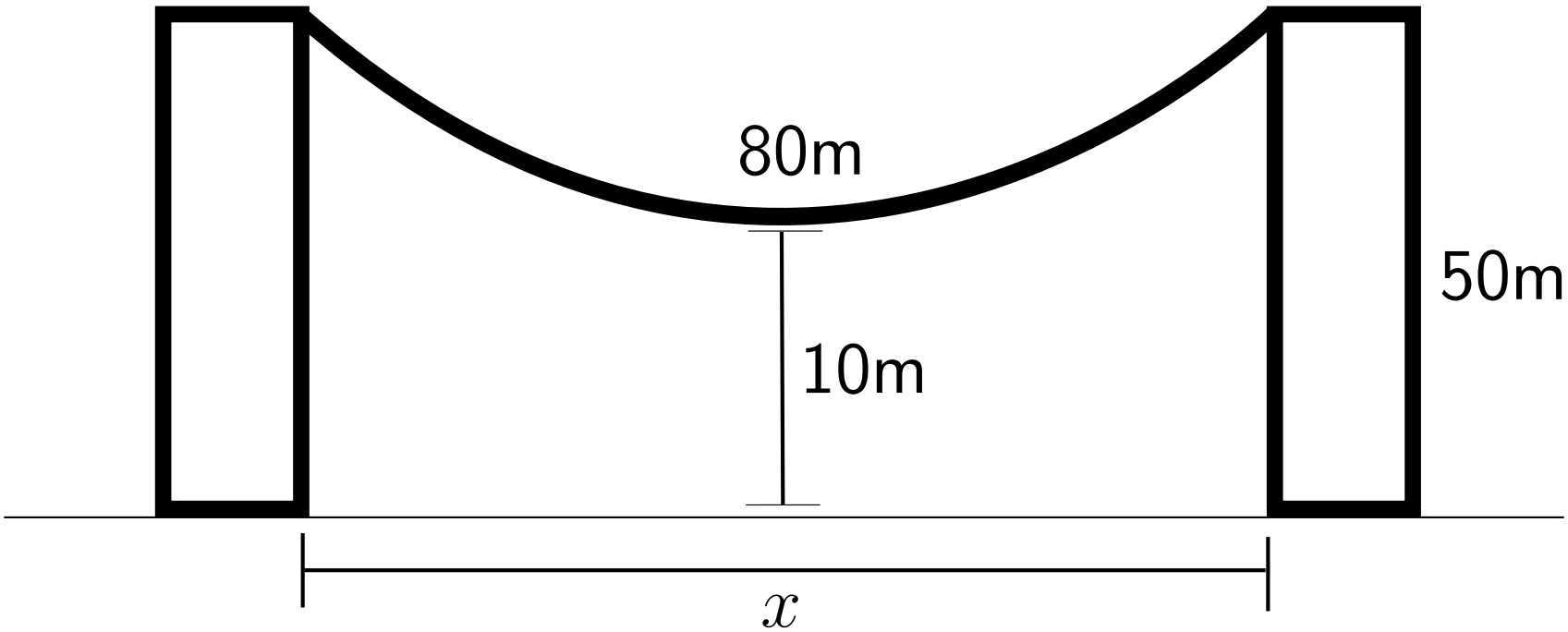
Create a data structure to represent a generic point cloud. The data structure must contain the following information:

- A collection of (x, y, z) coordinates for all the point vertices;
  Example: A matrix of size $n \times 3$, where n is the total number of vertices

Test your code by encoding the mesh from the previous example simply as a point cloud, and by visualizing it

Teaser exercise: Metric spaces

Consider the following design for a bridge:



What is x?