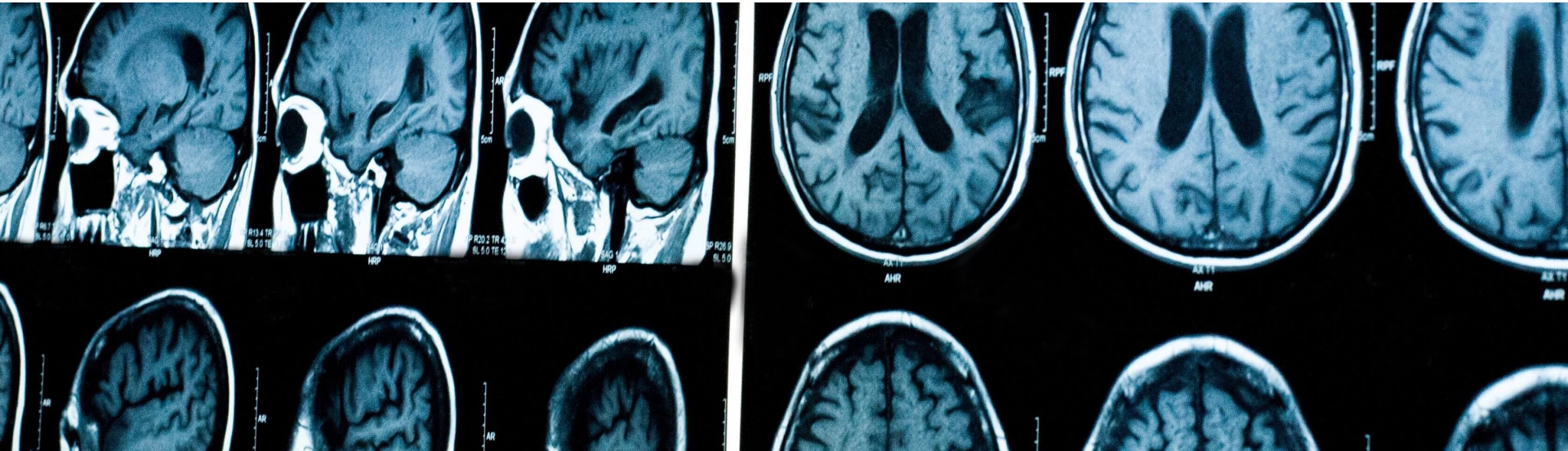
BioShape Lab

Welcome to ECE 594n

Geometric Machine Learning for Biomedical Imaging & Shape Analysis

Nina Miolane, Assistant Professor @ BioShape Lab



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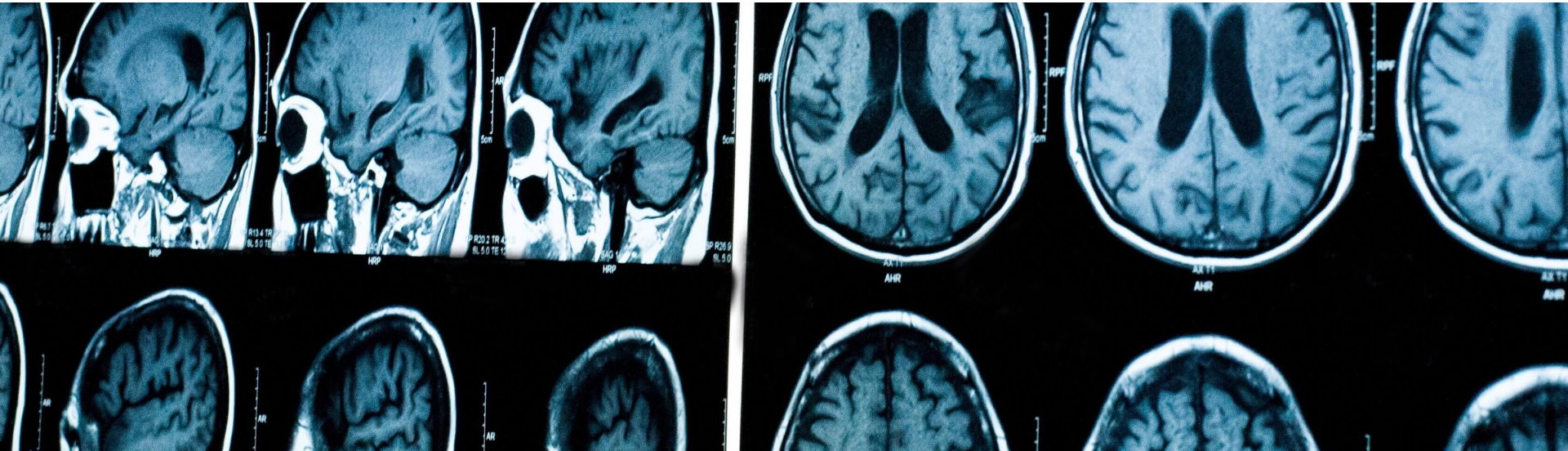


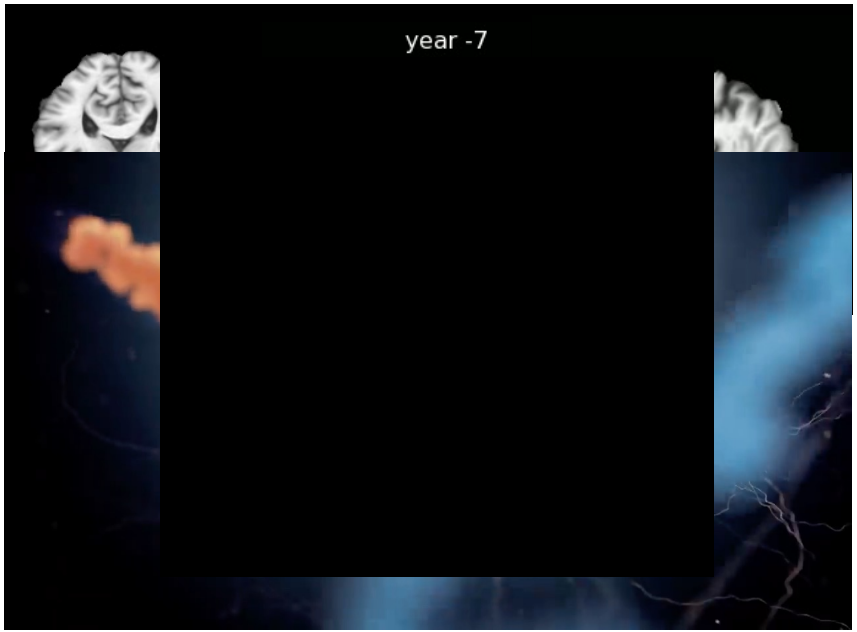
The Many Shapes of Alzheimer's Disease

The Many Shapes of Alzheimer's Disease

Macroscopic

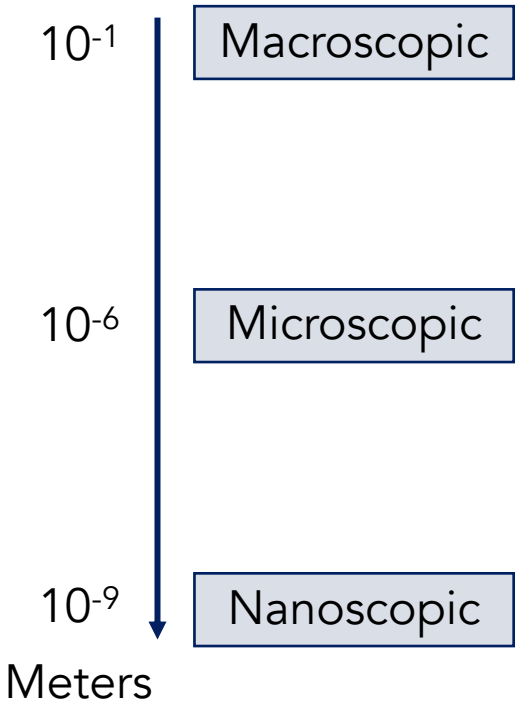
Microscopic

Nanoscopic

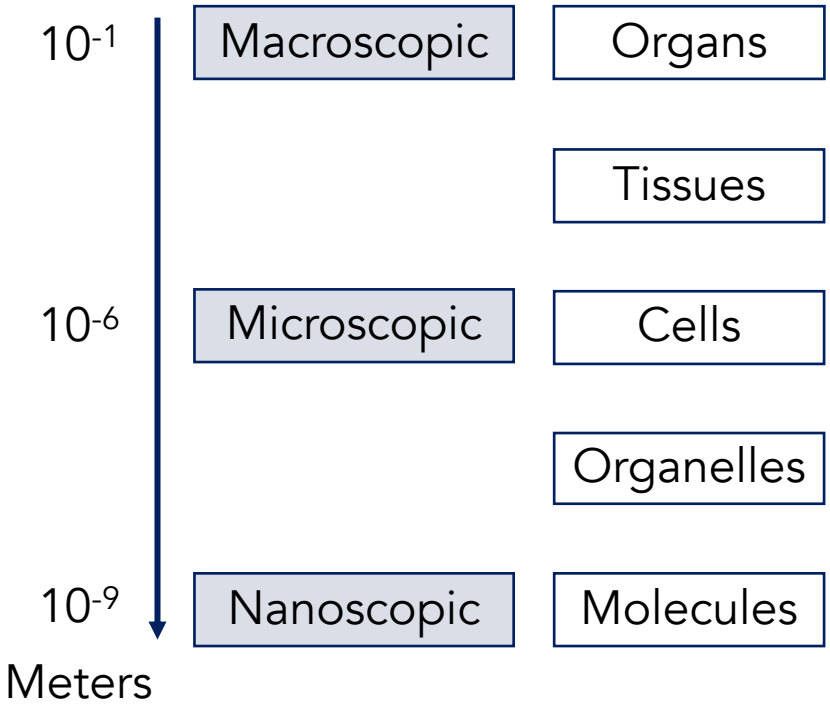


Simulation credits: Lorenzi, Ayache, Frisoni, Pennec (Inria). Video credits: US National Institute on Aging (NIH).

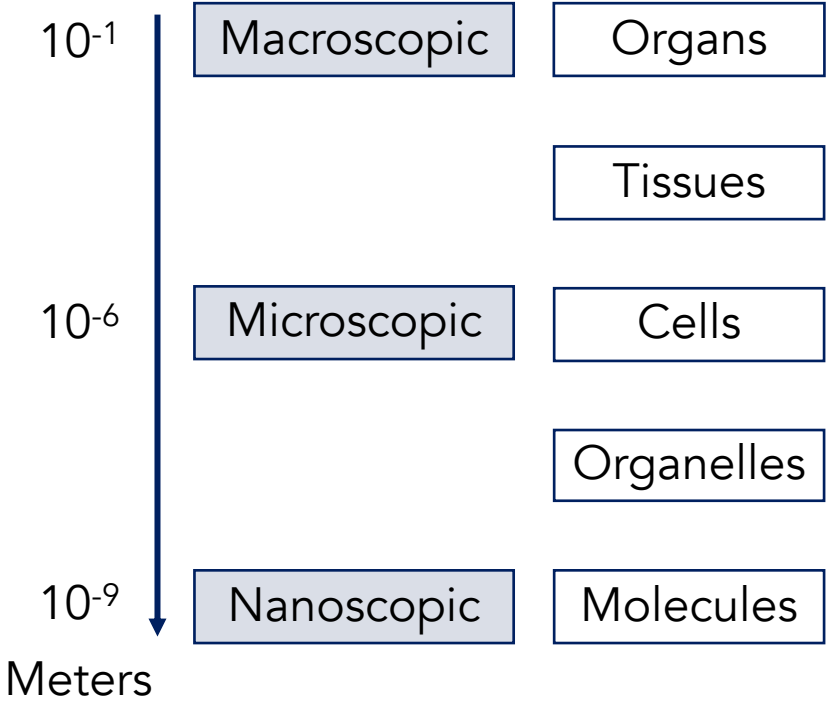
Biological Shapes

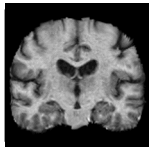


Biological Shapes



Biological Shapes

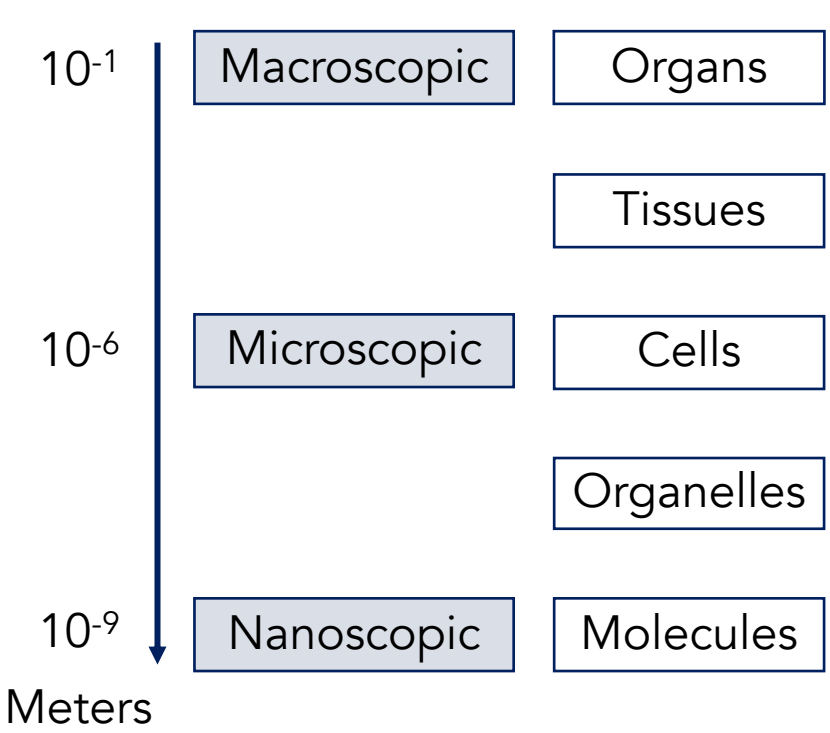


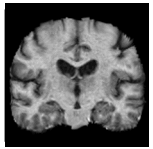


Brain

Magnetic resonance imaging
(Nobel 2003)

Biological Shapes





Brain

Magnetic resonance imaging (Nobel 2003)

X-ray computed tomography
Positron emission tomography
Photoacoustic microscopy
Two-photon microscopy
Optical coherence tomography
Confocal microscopy
Etc.

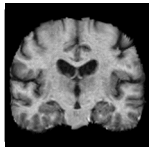
Biological Shapes

10^{-1} Macroscopic — Organs, Tissues

10^{-6} Microscopic — Cells, Organelles

10^{-9} Nanoscopic — Molecules

Meters



Brain

Magnetic resonance imaging (Nobel 2003)

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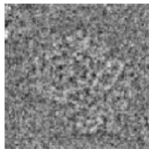


Protein

Cryo-electron microscopy (Nobel 2017)

From BioShapes to Biological Insights

From BioShapes to Biological Insights

Biophysics

Healthy/pathological state
Function

→ BioShapes

From BioShapes to Biological Insights

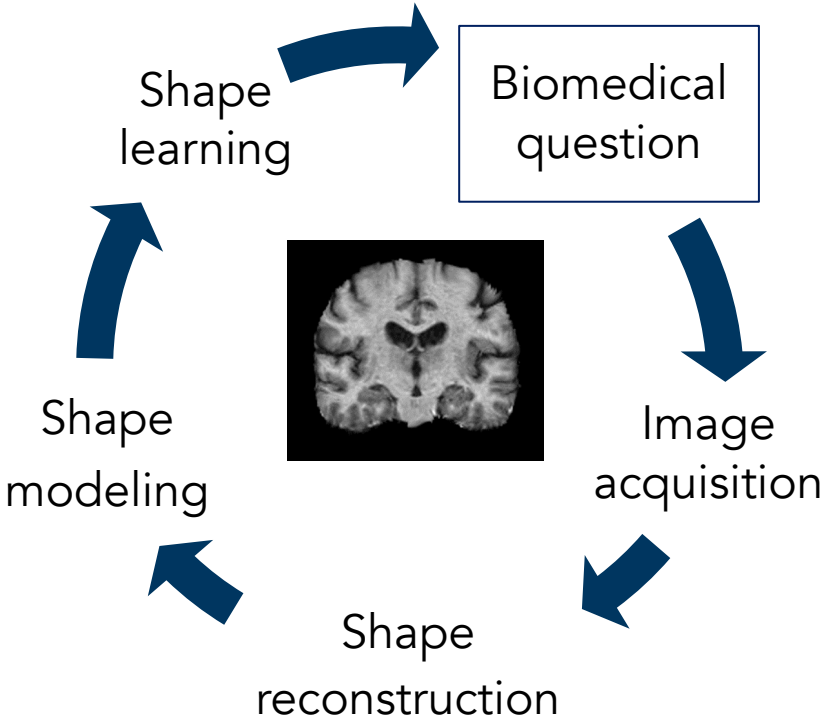
Biophysics

Healthy/pathological state
Function
→ BioShapes

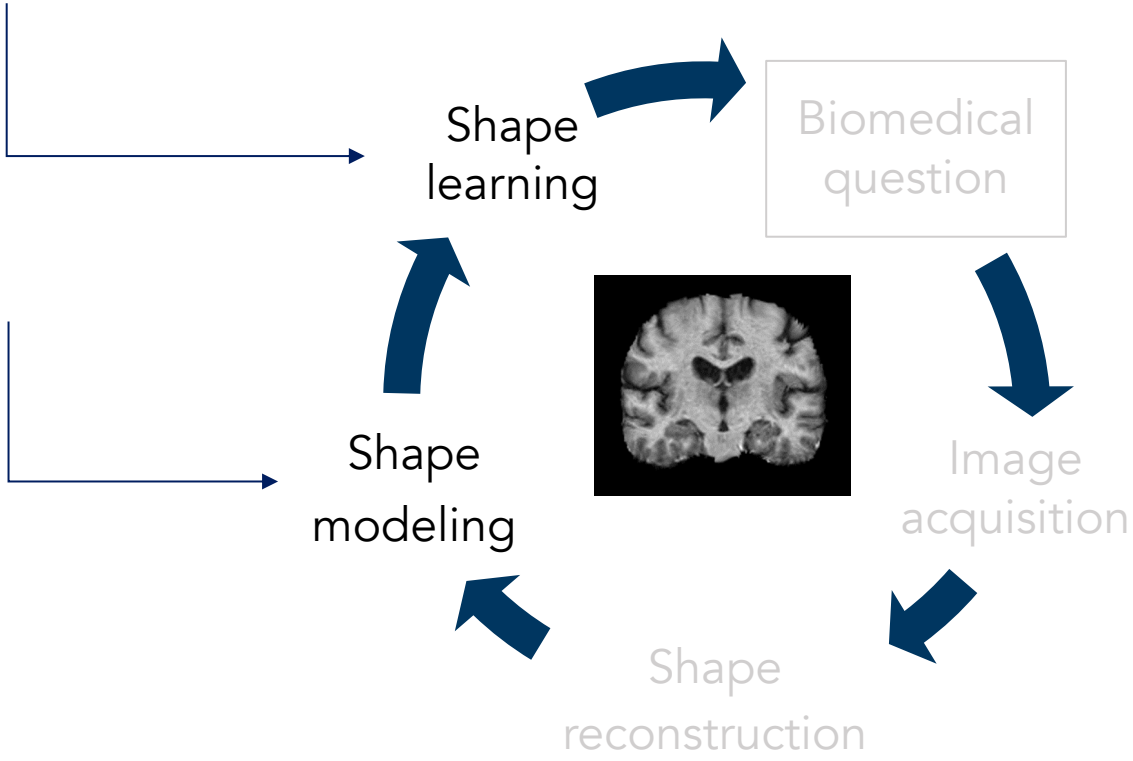
Biomedical insights ← BioShapes

Geometric
Machine Learning

Geometric Machine Learning for Biomedical Imaging & Shape Analysis

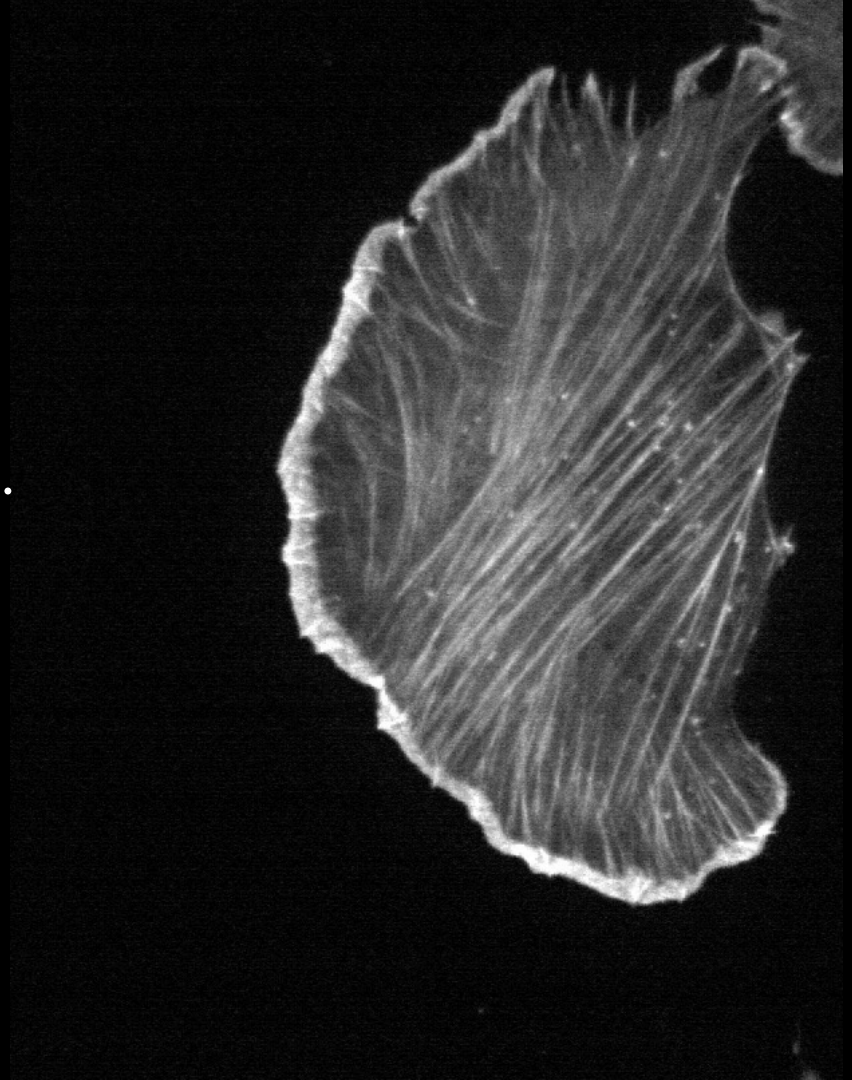


Geometric Machine Learning for Biomedical Imaging & Shape Analysis



- Mathematical…
- Computational…
- Statistical…

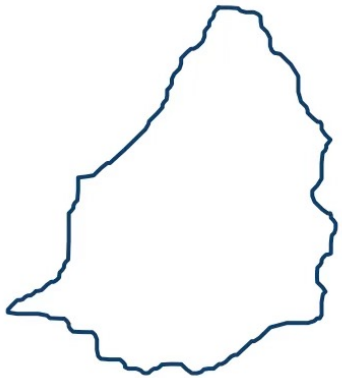
…shape models



Math of Shapes & Shape Transformations

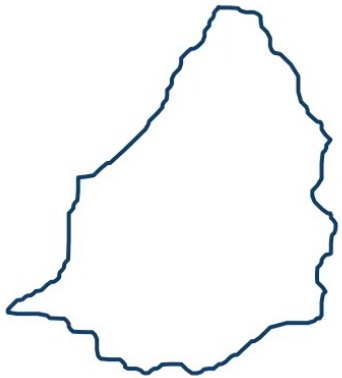
Math of Shapes & Shape Transformations

Translation



Math of Shapes & Shape Transformations

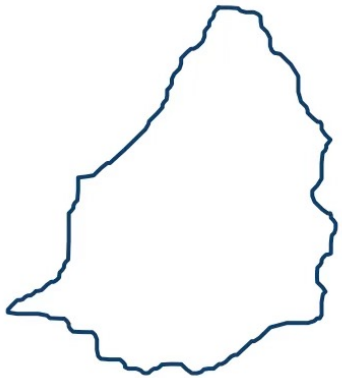
Translation



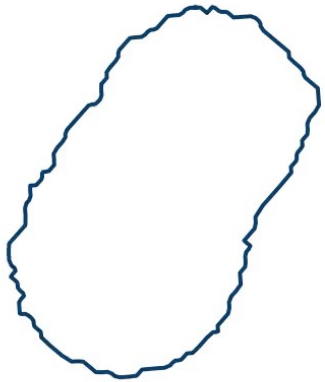
Shapes ↔️ Equivalence classes
= Elements of “Quotient space” Q

Math of Shapes & Shape Transformations

Translation



Smooth deformation



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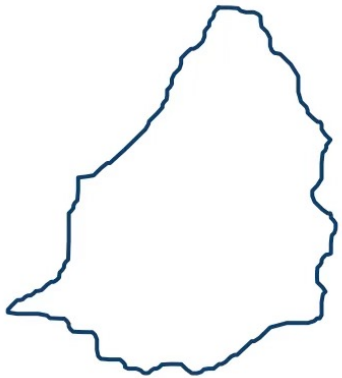
Math of Shapes & Shape Transformations

Translation



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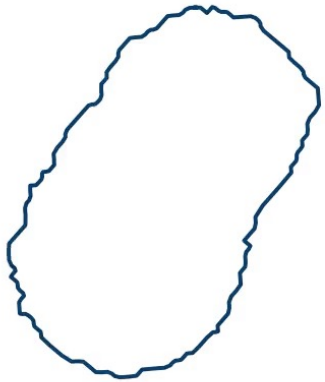
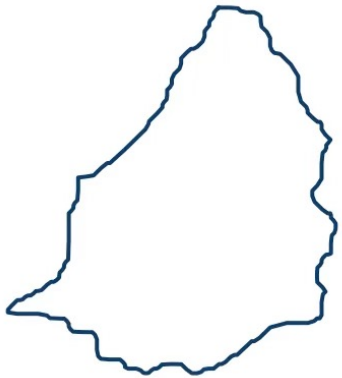


Shapes ↔️ Deformations
= Elements of "Lie group" G

Math of Shapes & Shape Transformations

Translation



Shapes ↔️ Equivalence classes
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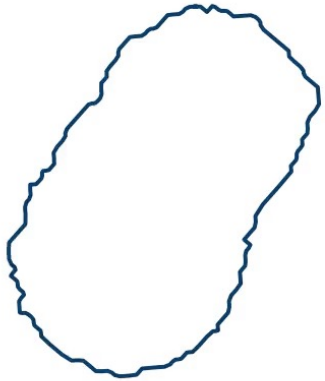
Smooth deformation



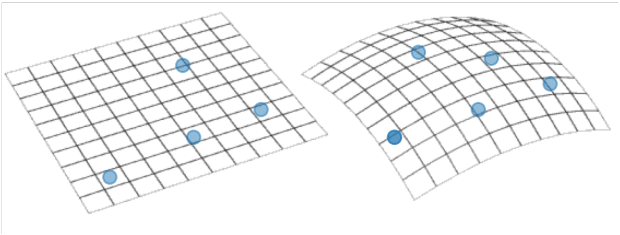
Shapes ↔️ Deformations
= Elements of "Lie group" G

= "Manifolds"

Computations on Manifolds

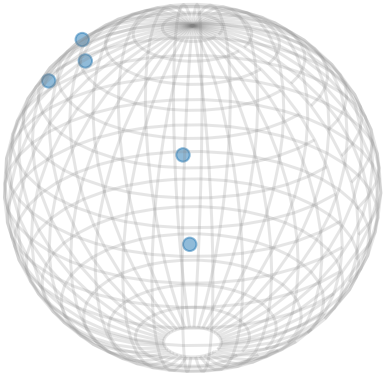
Computations on Manifolds

- Computing with data on curved spaces



Data on a
vector space

Data on a
manifold



Example:
Data on the sphere

Statistics and Machine Learning on Manifolds

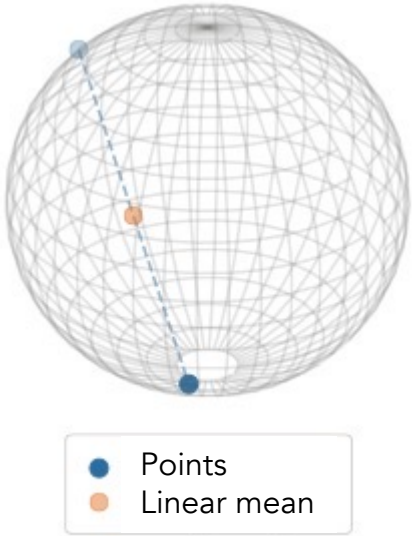
Statistics and Machine Learning on Manifolds

- Traditional statistics and machine learning (ML) fail

```
from geomstats.geometry.hypersphere \
    import Hypersphere

sphere = Hypersphere(dim=2)
points = sphere.random_uniform(
    n_samples=2)

linear_mean = gs.sum(
    points, axis=0) / n_samples
```



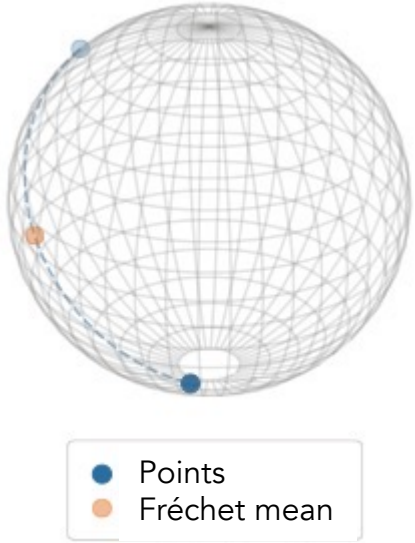
Statistics and Machine Learning on Manifolds

- Need geometric statistics and machine learning (ML)

```
from geomstats.learning.frechet_mean import \
    FrechetMean

estimator = FrechetMean(metric=sphere.metric)
estimator.fit(points)

frechet_mean = estimator.estimate_
```



Outline of ECE 594 N

Outline of ECE 594 N

1. (Geometry): Differential Geometry for Engineers
2. (Shapes): Computational Representations of Shapes
3. (Machine Learning): Geometric Machine Learning

With applications from cutting-edge research in biomedicine.

Software: Geomstats

Software: Geomstats

- Computations, statistics and machine learning on manifolds

1. Instantiate manifold of interest

```
sphere = Hypersphere(dim=2)
```

2. Apply machine learning method

```
estimator = FrechetMean(metric=sphere.metric)
estimator.fit(points)
```

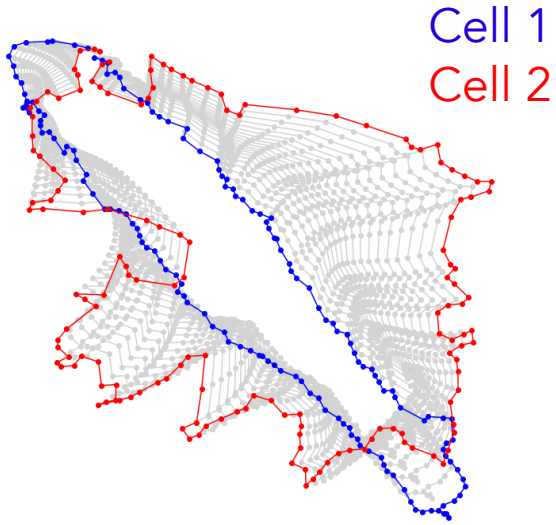
Run Operations on 20+ Manifolds

Run Operations on 20+ Manifolds

```
from geomstats.geometry.discrete_curves \
    import R2, DiscreteCurves

curves = DiscreteCurves(R2)
metric = curves.square_root_velocity_metric

geodesic = metric.geodesic(
    initial_curve=cells_shape[i],
    end_curve=cells_shape[j])
```

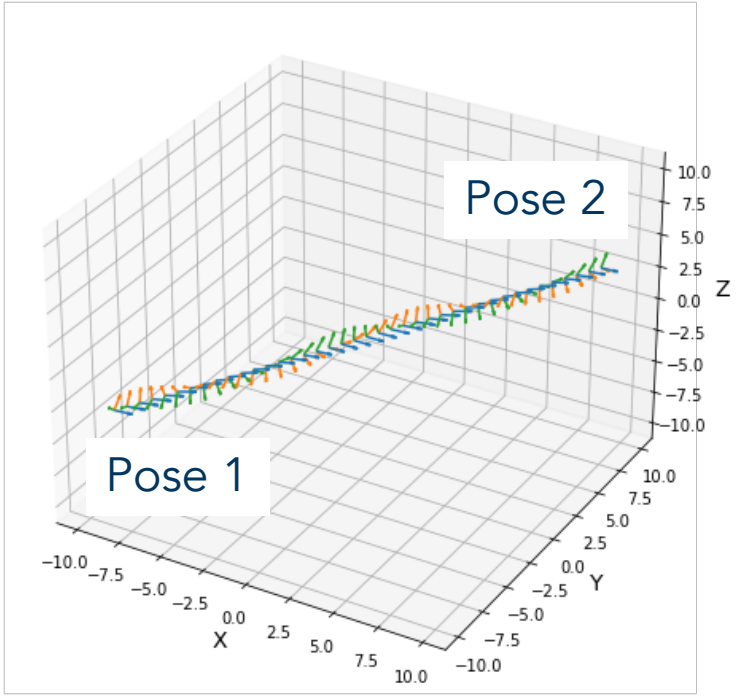


Run Operations on 20+ Manifolds

```
from geomstats.geometry.special_euclidean \
    import SpecialEuclidean

se3 = SpecialEuclidean(n=3, point_type='vector')
metric = se3.left_canonical_metric

initial_point = se3.identity
initial_tangent_vec = gs.array(
    [1.8, 0.2, 0.3, 3., 3., 1.])
geodesic = metric.geodesic(
    initial_point=initial_point,
    initial_tangent_vec=initial_tangent_vec)
```



…Statistics and Machine Learning

Geometric…

	Statistics	Machine Learning	…
Riemannian		(2019)	
Affine			
Stratified spaces	(2017-18)	(2020)	
Lie groups	(2015)		
Quotient spaces	(2017-21)		
Subriemannian	(2015)		
…			

Miolane, Pennec: *Computing bi-invariant pseudo-metrics on Lie groups for consistent statistics* (2015).
Miolane, Pennec: *A survey of mathematical structures for extending 2D neurogeometry to 3D image processing* (2015).
Miolane, Holmes, Pennec: *Template shape estimation: correcting an asymptotic bias* (2017).
Miolane, Holmes, Pennec: *Topologically constrained template* (2018).
Miolane, Holmes : *Learning submanifolds with Riemannian variational autoencoders.* (2019).
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…Statistics and Machine Learning

Geometric…

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Questions?