IFT 6113 INTRODUCTION

http://tiny.cc/6113



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INSTRUCTOR

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FORMALITIES

Lectures: Tue 9.30-11.30 Thu 16.30-18.30

Web: http://tiny.cc/6113

Use Piazza!

http://piazza.com/umontreal.ca/fall2019/ift6113

TEXTBOOK (OPTIONAL)

Polygon Mesh Processing by Botsch et al. Free online at UdeM library

Polygon Mesh Processing



PREREQS

- For sure:
 - Calculus
 - Linear algebra
- Bonus (but not required):
 Differential Geometry
 - Partial Differential Equations

THIS IS NOT AN EASY COURSE

Heavy math Heavy programming

BUT INTERESTING

I will help and be generous with grading

GRADING

Assignments (33%) Paper Presentation (25%) Participation (2%) Final Project (40%)

100%

ASSIGNMENTS (33%)

- Mostly coding, but math also
- ~ 2 weeks long
- Recommended framework: libigl (C++)



http://libigl.github.io/libigl/

FACE TO FACE GRADING

- Understand each line of your code
- Plagiarism policy

PAPER PRESENTATION (25%)

- Choose a SIGGRAPH paper on a related topic
- Give a talk!
- Others: ask questions

 Choose a paper (and post about it in Piazza) by Oct 29th

PARTICIPATION (2%)

- Classroom
- Questions/discussion at paper and project presentations

FINAL PROJECT (40%)

- 1. Choose a recent SIGGRAPH paper
- 2. Propose an improvement/modification
- 3. Implement
- 4. Present!

Important dates: Project proposal: Oct 15th, by midnight Final Presentation: Dec 5th, in class **NO EXAMS**

WHAT YOU WILL LEARN

Fundamentals:

Mesh data structures Discrete Differential Geometry Discrete Laplacians Vector Fields

Applications: Shape Deformations Surface Reconstruction Mesh Parameterization Remeshing Animation/Sketch-based modeling/... Learning geometry

TODAY

- 1. Geometric modeling?
- 2. Shape analysis?
- 3. Studying shapes: what we need
- 4. Applications

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WHAT IS GEOMETRIC MODELING?









EVENT COVERAGE

AND THIS.



AND EVEN THIS.



- How to represent 3D shapes?
- Model them?
- Generate them?

How to scan a building? An animal? A molecule?

H to represent 3D shapes?
M del them?
H to scan a building?
H to scan a building?
How to deform a model?

H vto represent 3D shapes?

MODELING SESSION



Which parts of 3D shape are *interesting*?



How can we compare shapes?



Sketch-Based 3D Shape Retrieval: Mathias Eitz, Kristian Hildebrand, Tamy Boubekeur, and Marc Alexa, ACM SIGGRAPH 2010

- How can we compare shapes?
- How to map them onto each other?



Segment shapes?



https://arxiv.org/pdf/1705.11050.pdf

ROADMAP

- Data Structures $\int dx$
- Recap of differential geometry *∭ dxdydz*
- Mesh Simplification & Saliency $\iint dxdy$
- Vector Fields $\iint dxdydz$
- Mesh Parameterization $\iint dxdy$
- Shape Deformation $\iint dxdy$
- 2D modeling $\int dx$
- Remeshing $\iint dxdy$
- Learning $\int dx$



TODAY

- 1. Geometric modeling?
- 2. Shape analysis?
- 3. Studying shapes: what we need
- 4. Applications
What (pure) mathematicians think:



EUCLIDEAN GEOMETRY

- 10* diplicare ed q que diametro dirette sturre אס היו על הקנ המקיף נוה מה שרטנו לבארי כאשר 15 Anun der על אמן ואמוב ומהייטה בענולות שוות שתי זוינת שונת היועל p equalia המרכואוהיו על המקיף המשו כוני שתי עבוות אבל דהי שנוכ הנה הוויו ferane non dif שוות ושתי קשתות כל הו שוות עלהם שתי זויות בעל החל omniñ mmma. שוות ושתי קשתות כל הי שוות עלימם שתי גויות ומם על erq: punquio/ i rechtinent angulut mfernen auto inp avenm slutar.recht fe. Si in portone temtarailo maioze. המרכואוט המקיף הנה אום ביהם שמהם שונת אי אפשר memoref due כיאסוה שאם היה אפשר שמר שמהיה ווית בטו יותר q: unee buille me. q ummque הענה אוויה המז וטנמיד recto minaz. ע נקורתה מקו הה eque punquar fummineze: 03 reeto matoz. זוית החב כמו זוית. בעוב הנה השת פו i enculum linea reita co araluo y a contactu in entulum linea q כמוקטת הכאבל Inea reda dam ozogontrcomingar. a gradam fe קשת כן כבר היה כמו השת הז הנה השל train dreath no in circulum quectaritie cant dreathan yeek linea pror an train ducanny quofain qi angu lof facer, duof duob; angulis; ag in alterinant circult fup arcum do future pomondy fune equales. commum carcula הו כמו הב הוצולה ee neceffe e. 99 כמו הקשנה זה שקר אם בואין בשנ כלתי שוה לורת החואס 1 in und circu כן היא שום לה ושתי הוויות אשר מחיינה על מקשת באן, הרו קעי זוית בטג החו השוות העה אמכן שוותי וזה מה שרעינו, le pomone. fup aram sfiftant. angulof quof כן למודי המיתרים השווים אשר בעגווות משוותי בריעו unu danun errenhum : 1 tint's circu Dare reche .08. lum quadat Laterum deferi הטשוים הנה אומר ני linee. que שנהם יבדיון קשתות שני שונה אנלם קשת פנ ovamerro mi barut omf du nume maiai of angulof euf ex aduerfo col to carof. duob; . 6.0. כתוקשת הו יואנלסי alem rechan קשת נאג נקשת הרי lineam figu reda angulus והיושני המרכזי פעא mare n R. 28 equaler esse eft mo ונוצא עצ ועג וחה 01. ens. CARD CORSERVATION CONTROL CONTROL A CALLER CONTRACT CONTRACT LIBER IV. SEVCLID. ELEM. GEOM EVCLIDIS Je EVCLID. ELEM. OEOM. verð tangatt quad fuð tota fecante, kette, rius interpunktum & conuexam periphe. riam aflempta comprehenditur; rettangu lumærgualerri et, quad å tangente defat. Cincta effectas effec Cincus eft cuins po no eft. E Línea eft QVARTVM. 2.600 bitur, quadrato. DEFINITIONES. الالانامة د- الحرمزا 5 Canal Theoremage. Propo-زاوه - الراقل راوي - الماعه fitio 37. a plana é ab yna linea ad Cancel and the constraints of th fugfisics otera. عامر وسنسم بعديج - 1) سط Figura rectilinea in feribi dicitur, cumfingu-li elus figura; que inferi-Si extra circulum fumatur puntum ali-quod, ab coque puntto in circulum cadane duz reftz linez, quarum altera circulam the state fecet, altera in cum incidat, fit autem, quod bitur, angali, fingula late-ra cius, in qua inferibitur, feet, aitera in euto actoration, quod fub tota feetone, & exter-rius inter punctum , & conuexam peripheriam alfiumpta, comprehendi-turrectangulum, aquaferenă execiteo fibiluites fut conalea. "Et bie reali of. C. Diameter carcali e luica recta que o extremitatelo; finas circuiferêne applicana bindit. C. Semicirculuo ê figura plana pia cangunt. Similiter & figura circum figuram deferibi dicitur,quum fingula cius,quç circumferinte trahiens extremitatelq; mas circúterètie ono media bimdit. (L@emicirculus é figura p reuli a medietate circúferentie stema, (LAD) "Decile main province and a second control of the second le ci, quod ab incidente bitur, ladefcribitur quadrato;in-eidensipfa circulum tanget. tera fingulose-- See ria latera conalia. Blia trianguluo ono anguluo triu inequalium lateru. Roag i ius figu-متوارف وال FINIS ELEMENTI III. ra angulos tetiquadrilatera gerint, circum quam illa defcribitur. n'long': q eff figura rectangula : fed ec l belmuaym: que eff equilatera : fed re EVCLL Figura redilines in circulo inferibi dicitur, quum finguli cius figura, qua inferibitur, D f angu-

EUCLIDEAN GEOMETRY



EUCLIDEAN GEOMETRY



http://www.turbosquid.com/3d-models/medically-human-brain-3d-model/437885

DIFFERENTIAL GEOMETRY

Easy intro:



Harder intro (5 volumes):











Spivak: A Comprehensive Introduction to Differential Geometry

DIFFERENTIAL GEOMETRY



http://en.wikipedia.org/wiki/Differential_geometry

Study of smooth manifolds

MANIFOLD $\phi(U) \subseteq \Sigma \subseteq \mathbb{R}^n$ $\phi: U \to \mathbb{R}^n$ $U \subseteq \mathbb{R}^k$

http://upload.wikimedia.org/wikipedia/commons/b/bc/Double_torus_illustration.png









DIFFERENTIAL GEOMETRY TOOLBOX



 $K := \kappa_1 \kappa_2 = \det \mathbb{I}$

 $H := \frac{1}{2}(\kappa_1 + \kappa_2) = \frac{1}{2} \operatorname{tr} \mathbb{I}$

http://www.sciencedirect.com/science/article/pii/S0010448510001983

Curvature and shape properties

What graphics people think:



- Collection of flat triangles/quads
- Approximates a smooth surface



• Can such a mesh have curvature?





DISCRETE DIFFERENTIAL GEOMETRY

Structure preservation:

- Keeping properties from the continuous abstraction exactly true in a discretization.

EXAMPLE: TURNING NUMBERS



 $\kappa \, ds = 2\pi k$



Images from: Grinspun and Secord, "The Geometry of Plane Curves" (SIGGRAPH 2006)

D	DISCRETE DIFFERENTIAL GEOMETRY Eurographics Symposium on Geometry Processing (2007)	
1	Eurographics Symposium on Geometry Processing (2007) Alexander Belyaev, Michael Garland (Editors)	
	Discrete Laplace operators: No free lunch	

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the continuous setting. Building on the smooth setting, we present a set of natural properties for discrete Laplace operators for triangular surface meshes. We prove an important theoretical limitation: discrete Laplacians cannot satisfy all natural properties; retroactively, this explains the diversity of existing discrete Laplace operators.

not satisfy all natural properties; retroactively, this explains the diversity of existing discrete Laplace operators. Finally, we present a family of operators that includes and extends well-known and widely-used operators.

1. Introduction

Discrete Laplace operators on triangular surface meshes span the entire spectrum of geometry processing applications, including mesh filtering, parameterization, pose transfer, segmentation, reconstruction, re-meshing, compression, simulation, and interpolation via barycentric coordinates [Tau00, Zha04, FH05, Sor05].

In applications one often requires certain structural prop-

1.1. Properties of smooth Laplacians

Consider a smooth surface *S*, possibly with boundary, equipped with a Riemannian metric, *i.e.*, an intrinsic notion of distance. Let the intrinsic L^2 inner product of functions *u* and *v* on *S* be denoted by $(u, v)_{L^2} = \int_S uv \, dA$, and let $\Delta = -\text{div}$ grad denote the intrinsic smooth Laplace-Beltrami operator [Ros97]. We list salient properties of this operator:

(NULL) $\Delta u = 0$ whenever u is constant.

THEORY: GRAD



THEORY: LAPLACIAN Δ



Vallet and Lévy. Spectral Geometry Processing with Manifold Harmonics. EG 2008

THEORY: VECTOR FIELDS AND FLOWS





Vaxman et al. Directional field synthesis, design, and processing. EG STAR 2016.

NUMERICS



"Boundary First Flattening" by Rohan Sawhney and Keenan Crane

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APPLICATION: 3D RECONSTRUCTION



Depth maps $\xrightarrow{?}$ points $\xrightarrow{?}$ triangle mesh

APPLICATIONS: MESH DEFORMATION



How to propagate deformations to **unconstrained parts of shape**?

APPLICATIONS: HEAT AND GEODESICS



How to compute distances between points on a surface?

APPLICATIONS: RETRIEVAL



How to **compare** shapes of **different modalities**?

APPLICATIONS: REMESHING



Pierre Alliez, David Cohen-Steiner, Olivier Devillers, Bruno Lévy, and Mathieu Desbrun. 2003. Anisotropic polygonal remeshing. ACM Trans. Graph. 22, 3 (July 2003)

How to **convert** any mesh into a **nice** one?

APPLICATIONS: QUADMESHING



How to make a **mesh** out of **quads**?

APPLICATIONS: MESH SIMPLIFICATION



Joel Daniels, Cláudio T. Silva, Jason Shepherd, and Elaine Cohen. 2008. Quadrilateral mesh simplification. ACM Trans. Graph. 27, 5, Article 148 (December 2008)

How to **compress** geometry?

APPLICATIONS: CLOTH MODELING



APPLICATIONS: SKETCH-BASED MODELING

...perceptual validation

#1 Humans are consistent in perceiving regularity cues in a design sketch.





APPLICATIONS: LEARNING



APPLICATIONS: LEARNING



"MeshCNN: A Network with an Edge" by Rana Hanocka, Amir Hertz, Noa Fish, Raja Giryes, Shachar Fleishman, Daniel Cohen-Or, SIGGRAPH 2019

How to bring **learning** approaches from images to **3D geometry**?
APPLICATIONS: LEARNING



ZHIJIE WU, Shenzhen University XIANG WANG, Shenzhen University DI LIN, Shenzhen University DANI LISCHINSKI, The Hebrew University of Jerusalem DANIEL COHEN-GR, Shenzhen University HUI HUANG', Shenzhen University

How to bring **learning** approaches from images to **3D geometry**?

</INTRO>

http://www-labs.iro.umontreal.ca/~bmpix/teaching/6113/2019/ Piazza! Office hour: Fri, 1-2 pm, AA 6191



WARM-UP PROBLEMS





WARM-UP PROBLEMS



WARM-UP PROBLEMS



LIBIGL & EIGEN

- Eigen: a linear algebra library
- libigl: geometry processing library