Course Introduction

Geometric Computer Vision

GCV v2021.1

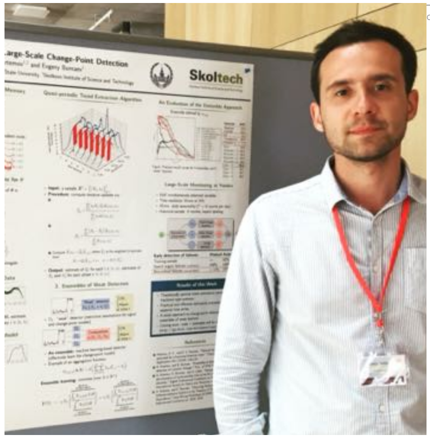
Alexey Artemov, Spring 2021

Your staff

Who am I?

Alexey Artemov, Ph.D.

- 2006–2012 Lomonosov MSU, *Physics*
- 2010–2012 Yandex Data School, *Data Science*
- 2011–2017 Yandex, Yandex Data Factory, Yandex Self-Driving Team, *Computer vision*
- 2012–2017 IITP RAS, Ph.D., *Statistics/ Data Science/Software*
- 2017–now Skoltech, *Computer vision*
- **Core:** software, statistics and data science, computer vision



Your TAs

Alexander Safin,
Ph.D. student, CDISE Skoltech

Sofia Potapova,
Computer vision developer
(ex-Yandex)

You

Outline: Course Introduction

§1. Getting to know each other & the GCV course [5 min]

1.1. Your staff [done]

1.2. Course goals

§2. Geometry processing applications [10 min]

2.1. What is geometric computer vision and why learn it?

2.2. What is a useful result of geometry acquisition?

2.3. Example applications

Outline: Course Introduction

§3. Course topics [10 min]

3.1. Topics covered by this course

3.2. Course flow and topic dependencies

§4. Organization, Q&A [10 min]

4.1. Learning scheme & assessment

4.2. Prerequisites, reaching out, contacts

§1. Getting to know each other & the GCV course

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Course goals

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§1. Getting to know each other & the GCV course

1.2. Course goals

- Provide an introduction into the **data representations, methods and models** in 3D/geometric computer vision
- Unlike traditional geometry modelling courses: **study where deep learning is useful and may bring advantages** in the geometry acquisition pipelines
- Hands-on experience with common **tools** for processing 3D data
- Obtain the **skills** needed to continue to engage in 3D/geometric vision

What you **will not** learn:

- Deep learning per se (only a subset of operations will be used, most are custom...)
- Techniques to obtain 3D data (will do a review but mostly assume these are given...)

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§2. Geometry processing applications

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What is geometric computer vision and why learn it?

§2. Geometry processing applications

2.1. What is geometric computer vision and why learn it?

Two main aspects:

- **Construct** 3D geometry representations suitable for various tasks from raw data (range images, volumetric CT and MRI, LIDAR)
  - Usually involves multiple steps going from low to high level
  - As an intermediate tool, requires analysis, e.g. segmentation
  - E.g.: Points -> meshes -> parametrized patch layout
- **Manipulate and analyze** geometry:
  - Deformations, boolean operations, comparisons, physically-based deformations (related to CAE)

What is a useful result of geometry acquisition?

§2. Geometry processing applications

2.2. What is a useful result of geometry acquisition?

- We briefly review several common applications
  - The goal is to understand better what is a useful result
  - For example: for geometry reconstruction how do we define acceptable quality?
  - E.g. accuracy of reconstruction:
    - 5-10 cm may be ok for cities (but barely)
    - 5 mm may be for furniture
    - << 1mm is needed for detailed objects, medical
  - Noise handling:
    - Outliers almost never ok
    - For medical, visual noise may not matter, need accuracy
    - For games/special effects/VR, better to remove some signal, vs. keep noise

Applications

2.2. What is a useful result of geometry acquisition?

Special effects

Slide Credit: Denis Zorin

Applications

2.2. What is a useful result of geometry acquisition?

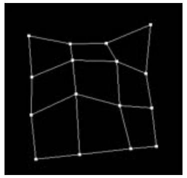
https://www.youtube.com/watch?v=zwU7io8Q7xo (see next slide, 3 min video)

- Highest-quality manually created geometry + physical simulation
- Different emphasis from CAD/CAE used in engineering: robustness + handling complexity, vs physical accuracy
- Driving a lot of research over years:
  - Animation+games industry (not serious): $250 bln
  - CAD/CAE industry (serious): ~$20 bln

Computer-Aided Geometric Design

2.2. What is a useful result of geometry acquisition?

- Traditional pipeline for modeling shapes from scratch



User defines a layout of surface patches and control points

Computer-Aided Geometric Design

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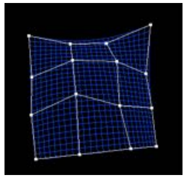

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Computer-Aided Geometric Design

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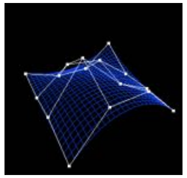

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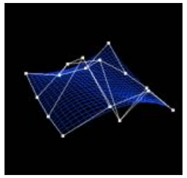

Editing is performed by moving control points and/or prescribing tangents

Computer-Aided Geometric Design

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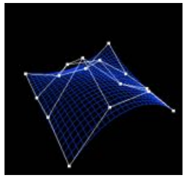

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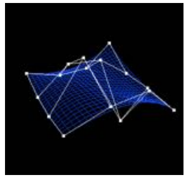

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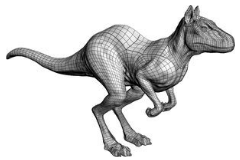
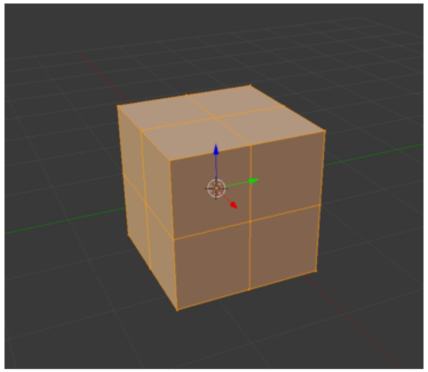


Patch-based construction of a surface

Blender Demo

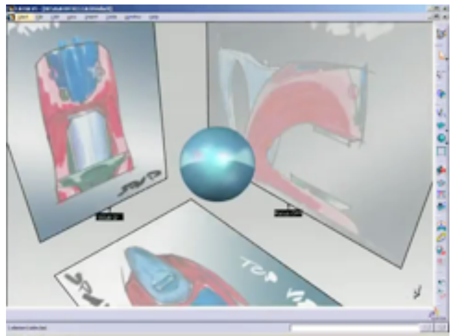
2.2. What is a useful result of geometry acquisition?



Computer-Aided Geometric Design

2.2. What is a useful result of geometry acquisition?

- High-quality surfaces
- Constrained modeling
- Requires a specific idea of the object first
  - Not easy to experiment and explore alternatives
- Requires training, skill and tedious work

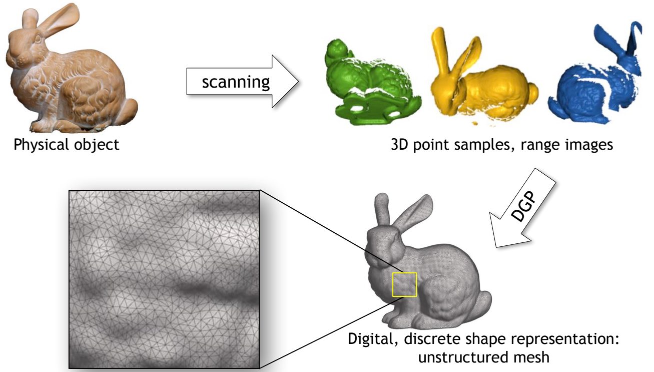


CATIA, Dassault Systemes

http://youtu.be/gTC5zMktMr0

Modern Geometry Acquisition Pipeline

2.2. What is a useful result of geometry acquisition?

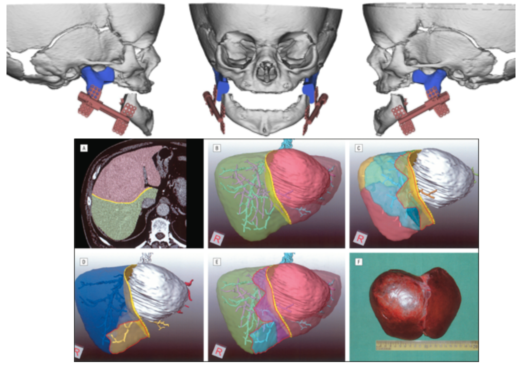


The Stanford Bunny, Stanford 3D Scanning Repository

Applications

2.2. What is a useful result of geometry acquisition?

Medical: e.g. virtual surgery planning



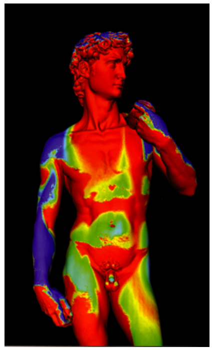
Digital Michelangelo Project

Cultural heritage preservation

1G sample points → 8M triangles   4G sample points → 8M triangles

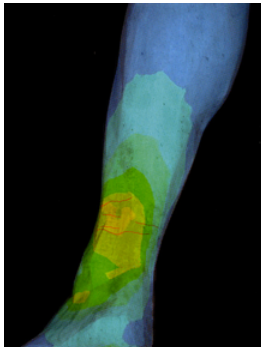
Digital Michelangelo Project

Cultural heritage preservation



Deposition of rainwater, dust, and other contaminants

Hypothetical placement of 16th century gilding



Tensile stresses in the left leg with the statue tilted 3 degrees forward, as it was in 1871.

§3. Course topics

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Topics covered by this course

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§3. Course topics

3.1. Topics covered by this course

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- Course structure for v2021.1: structured around data modalities/representations occurring in 3D
  - **Module 1: Geometry acquisition pipeline (today!)**
  - Module 2: Hardware systems for 3D data acquisition
  - Module 3: Dense range-images (+cameras and transformations)
  - Module 4: Point sets (+invariances in learning)
  - Module 5: Volumetric depth
  - Module 6: Implicit functions
  - Module 7: Surface-based representations
  - Module 8: CAD/Vectorized modalities (+shape programs)

Learning with...

§3. Course topics

3.1. Topics covered by this course

Skoltech
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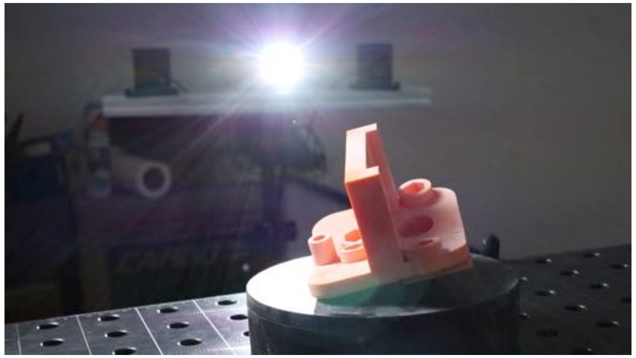
- Course structure for v2021.1: structured around data modalities/representations occurring in 3D
  - This year: few math-intensive methods, few
  - This year: focus on getting familiar with basic methods, models, and tools
  - Course updates: adding algorithmic / mathematical depth and detail

M1. Geometry Acquisition Pipeline

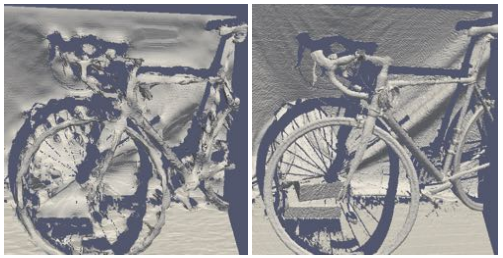
Scanning: results in range images ⇨ **Registration:** bring all range images to one coordinate system ⇨ **Stitching/reconstruction:** Integration of scans into a single mesh ⇨ **Postprocess:**
- Topological and geometric filtering
- Remeshing
- Compression

Slide Credit: Denis Zorin, Daniele Panozzo

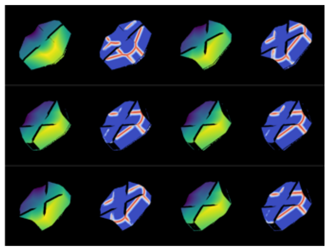
M2. Hardware systems for 3D data acquisition



M3. Dense range-images



Range-image super-resolution



Geometric feature line extraction

M4. Point sets

Point cloud generation

Recognition

Generation

Invariances

Equivariances

M5. Volumetric depth

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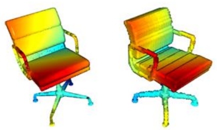

Sparse 3D CNNs

Depth fusion

M6. Implicit functions

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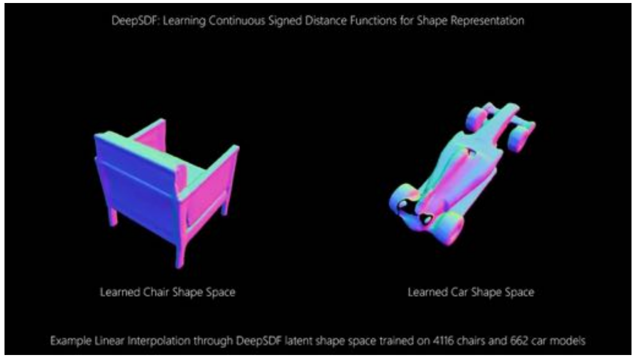

M7. Surface-based representations

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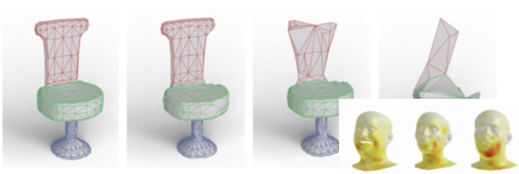
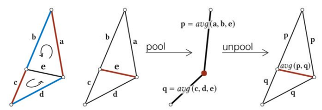
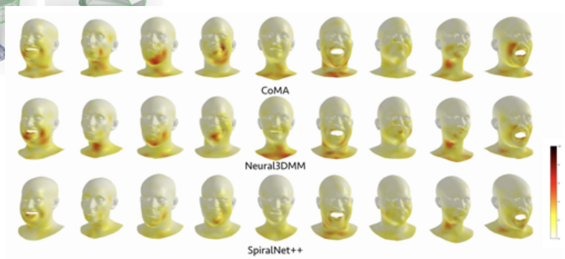


Convolutions on 3D meshes





M8. CAD/Vectorized modalities

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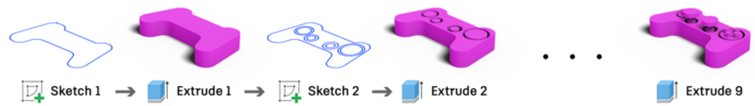


Constructive solid geometry trees

Boundary representations

Slide Credit: Denis Zorin, Daniele Panozzo

Course flow and topic dependencies

§3. Course topics

3.2. Course flow and topic dependencies

Structure of typical module:

- Monday: Pre-recorded lecture [45 – 60 min]
- Wednesday: Read supplementary [30 – 60 min]
- Wednesday: Offline quiz [should take 15 min, 48 hours] → submit for assessment
- Friday: Live practical [45 – 60 min]
- Friday: Live/offline Lab exercise [45 – 60 min] → submit for assessment
- Home assignment: offline [120 min] → submit for assessment

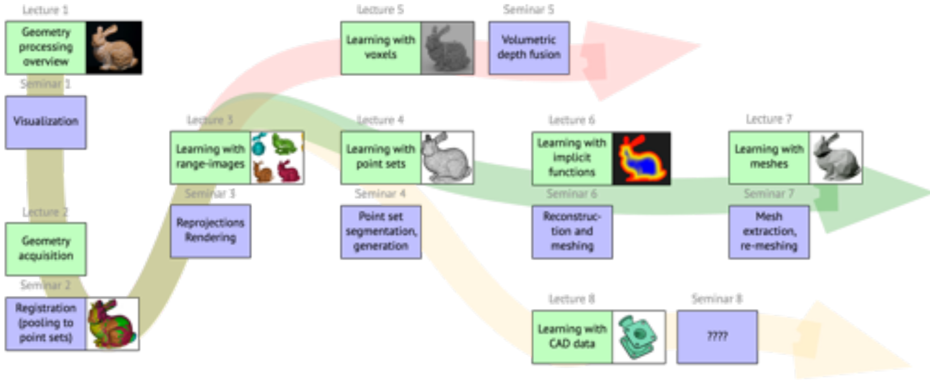
§3. Course topics

3.2. Course flow and topic dependencies

	Term 3 Week 1	Term 3 Week 2	Term 3 Week 3	Term 3 Week 4	Term 3 Week 5	Term 3 Week 6	Term 3 Week 7	Term 3 Week 8
Monday Lecture	Geometry processing overview	Geometry acquisition	Range-images	Point sets	Voxels	Implicit functions	Meshes	CAD data
Wednesday t Quiz								
Friday Practical	Visualizatio n	Registration (pooling to point sets)	Reprojectio ns Rendering	Point set segmentati on,	Volumetric depth fusion	Reconstruc-tion and meshing	Mesh extraction, re-meshing	
Friday Labwork								

§3. Course topics

3.2. Course flow and topic dependencies



§4. Organization

Prerequisites, reaching out, contacts

§4. Organization

4.1. Prerequisites

- Machine learning (including deep learning):
  - We will not cover the basic concepts that you need. If you are feeling insecure with **basic optimization, derivatives, gradients, or convolutions**, this course will be difficult to follow.
- Programming in Python (including basic operations with linear algebra packages such as NumPy and NN packages such as PyTorch), Linux, Dockers and Git:
  - We will not cover **basics of Linux, Dockers or Git, or give any reference on Python language**. If your are not familiar with Python programming or any of these tools, we suggest you first take the basic course

§4. Organization

4.1. Timetable

- Monday 12:30—15:30: pre-recorded lectures [Alexey]
- Friday 9:00—12:00: practicals, labwork [Alexander, Sofia]

§4. Organization

4.1. Reaching out & contacts

- Chat URL: https://t.me/joinchat/Iu0XzIjEIU_zPzri
- E-mails: a.artemov@skoltech.ru, a.safin@skoltech.ru

Learning scheme & assessment

§4. Organisation

4.2. Learning scheme & assessment

- The goal of this course is to introduce you to the baseline techniques and improve knowledge, not evaluate you
- But Education asks us to still somehow do this…

Final grade =	25% ×	Computer labs	8 Labs
	54% ×	Homeworks	2 HWs
	21% ×	Test/quiz	8 Quizzes

Textbooks

1. Botsch, M., Kobbelt, L., Pauly, M., Alliez, P., & Lévy, B. (2010). *Polygon mesh processing*. CRC press.
2. Zhang, S. ed., 2013. Handbook of 3D machine vision: *Optical metrology and imaging*. CRC press.
3. Ma, Y., Soatto, S., Kosecka, J. and Sastry, S.S., 2012. *An invitation to 3-d vision: from images to geometric models* (Vol. 26). Springer Science & Business Media.
4. Hartley, R. and Zisserman, A., 2003. *Multiple view geometry in computer vision.*
5. Hoffman, C. M. *Geometric & Solid Modeling: An Introduction.*